SEFI ANNUAL CONFERENCE
2–5 SEPTEMBER 2024
LAUSANNE

52ND ANNUAL CONFERENCE OF THE EUROPEAN SOCIETY FOR ENGINEERING EDUCATION 2024

PROCEEDINGS

Educating Responsible Engineers

Book of Proceedings for the 52nd Annual Conference of the European Society for Engineering Education

Ecole Polytechnique Fédérale de Lausanne (EPFL) 2-5 September, 2024

“Educating Responsible Engineers”

Co Organised by Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland and the European Society for Engineering Education (SEFI)

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Summary Table of Contents

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Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

European Society for Engineering Education (SEFI)

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Dassault Systèmes

Switch

MathWorks & Bentley

EPFL's Vice-presidency for Responsible Transformation

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3T PLAY

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SEFI

SEFI is the largest network of higher engineering education institutions (HEIs) and engineering stakeholders in Europe. As an international NGO created in 1973. SEFI contributes to the development and improvement of Higher Engineering Education (HEE) in Europe, promotes information about HEE and improves communication between teachers, researchers and students, reinforces the university-business cooperation and encourages the European dimension in higher engineering education. SEFI is an international Forum composed of HEIs, academic staff and teachers, students, related associations and companies in 41 countries.

Our activities:

Annual Conferences, Ad hoc seminars/workshops organised by our working groups, councils and ad hoc committees, organisation of the European Conventions for Engineering Deans, Scientific publications (including the European Journal of Engineering Education), European cooperation projects, position papers, cooperation with other major European associations and international bodies such as the European Commission, the UNESCO, the Council of Europe or the OECD. SEFI also participated in the creation of several organisations such as ENAEE, IFEES, IACEE and IIDEA.

SEFI is based in Brussels.
For further information please visit www.sefi.be or contact office@sefi.be.

Wecolme from SEFI

Dear Participants of the 52nd SEFI Annual Conference,

In the name of the European Society for Engineering Education, I warmly welcome you to Lausanne to the 2024 SEFI annual grand meeting devoted to the education of responsible engineers.

The global landscape is stirred up and this involves all aspects of our life. The new challenges induce major evolutionary changes for both human (slow) and machine (really fast) and require the transformation of teaching, especially within engineering, the technological driving force with an important role in aligning these evolutionary paths.

We, engineering educators, have major tasks and principal responsibility in the transition towards new discoveries and at times unprecedented territories within education.

How can we efficiently and benevolently apply generative artificial intelligence, large language models and machine learning into education and research?

How can we update and upgrade our pedagogical approach towards transversal skills on sustainability, diversity, ethics and core technical skills?

Is the gradual development of teaching the right way forward, or should we venture into fundamental transformations?

Anyhow, we may need to speed up, as technological development will not slow down.

The educational methods and tools that we develop define not only our present and future but also the attitude and motivation of our graduates and university colleagues.

Therefore, it is vital that platforms such as the SEFI annual conference provide an open space to discuss and conclude on the shared understanding of our duties and responsibilities in engineering and its education.
With its workshops, research and practice presentations, symposia, keynotes and panel discussions the 2024 SEFI conference at EPFL will provide us with the opportunity to analyze current challenges, allows us to personally meet our peers and foster impactful dialogues to jointly generate the future of engineering education.

Let us use these days together to foster fruitful discussions and find common solutions!

Balázs Vince Nagy, SEFI President

Welcome from EPFL

To professors, lecturers, students, researchers, and engineering education leaders from across Europe and the world: we are delighted to welcome you to EPFL, Switzerland for the 52nd SEFI Annual Conference.

EPFL is pleased to host this SEFI conference with the theme 'Educating Responsible Engineers'. 'Responsibility' has been a key theme for EPFL in recent years as we have sought to ensure that, in our research, our teaching, and in our operations, we embody a sense of responsibility.

As the person who bore overall responsibility for our education programmes over recent years, that has meant that I have worked with my colleagues to ensure that respect and sustainability are at the heart of our education offer. This has seen the restructuring of our first year programme with the introduction of a new mandatory course in sustainability science for all our students. Later years of our programmes have also been restructured to ensure that at both Bachelor's and Master's level, students will learn the sustainability practices and knowledge that will enable them to research, innovate, design and implement engineering solutions that are ethical and environmentally responsible.

As an education researcher as well as a computer scientist, I recognise that such transformations need to be supported by educational research. EPFL has long been a national and international leader in research on Digital Education with a particular focus on computer human interaction in learning, on learning with robots, and on machine learning in education. Our commitment to world-class research in this area led to the establishment of the Joint EPFL-ETHZ Doctoral Programme in the Learning Sciences (JDPLS), and to us bringing the relevant labs together in our Center for Learning Sciences (LEARN). Through this Center we work to bring together cutting edge technological education research with professors, school teachers, and pedagogical development teams to drive the development of evidence-informed educational practices, and practically useful educational research. We see these same synergies of research-informed engineering education innovation in the SEFI community, and that is why we are delighted to host the SEFI 2024 conference in Lausanne.

We hope you get a lot from your stay at our campus. We are rather proud of our location and we hope you find time to enjoy the lake shore, the mountains and the charming city of Lausanne. We hope too that we will learn a few things from you, and that you will learn something from us, and from each other.

I look forward to the opportunity to discuss with you over the course of the conference.

Welcome to #SEFI2024 at EPFL!

Pierre Dillenbourg,
Vice President Academic Affairs *ad interim*, EPFL

Conference Theme

Building a socially and environmentally sustainable society is intrinsically linked to the work of engineers and scientists. As UNESCO has noted, each and every one of the Sustainable Development Goals (SDGs) requires solutions which are rooted in science, technology and engineering. But there is a concern too that engineering is not only part of the solution but also part of the problem: for many engineers, their work is contributing to carbon emissions, unsustainable resource use, biodiversity and habitat loss, and pollution. There are equally concerns about engineers' responsibilities in warfare and violence across the globe, and in new, technologically-enabled vectors for discrimination, impoverishment and inequalities. A focus on responsibility has also seen a parallel growth in questions about how thinking and feeling interact in engineering: about excitement, anxiety, burnout, compassion, guilt, shame and hope.

Addressing these questions in engineering education is not straightforward: innovative engineering solutions to social and environmental challenges will require the highest levels of technical competence and scientific knowledge. But the centrality of technical knowledge to engineering education can create in students the impression that responsibility is a marginal concern for them. Building a sustainable society means educating scientists and engineers that can apply the best scientific knowledge with ingenuity, with ethical competence and with respect for colleagues, for those in wider society and for the natural environment, and therefore need social and human sciences as part of their education. How can we ensure the highest quality of technical competence while at the same time ensuring that social and environmental responsibility is core to the identity of engineering graduates? This was the focus of the European Society for Engineering Education (SEFI) 2024 conference, which took place at EPFL, Lausanne, Switzerland on 2 – 5 September, 2024.

The conference particularly welcomed contributions aligned with one of the following conference tracks.

- Teaching the knowledge, skills and attitudes of sustainable engineering
- Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing
- Teaching technical knowledge in and across engineering disciplines
- Teaching foundational disciplines of Mathematics and Physics in engineering education
- Teaching social and human sciences to engineering and science students
- Digital tools and AI in engineering education
- Open and online education for engineers
- Diversity, equity and inclusion in our universities and in our teaching
- Continuing education and life-long learning in engineering
- The attractiveness of engineering education
- Engineering skills, professional skills, and transversal skills
- Engineering ethics education
- Curriculum development and emerging curriculum models in engineering
- Outreach and openness: industry and civil-society in engineering education
- Building the capacity and strengthening the educational competences of engineering educators

Keynotes

First keynote:
Johanna Lönngren: Emotions in Engineering Education: The emergence of a new field of research

Biography:
As an associate professor in Science and Engineering Education at Umeå University, starting 2020, Johanna Lönngren brought together, coordinated and led a team of researchers from across the globe to scope out the field of emotions in engineering education research, and to show how emotion could be better understood, theorised and researched in the field.
The result is a new community of engaged scholars who together developed – and continue to develop – a series of publications, seminars and events that are profoundly changing the conversation on engineering education, scoping out new ways of doing and being in engineering education research and practice.

Second keynote:
Margarita Boenig-Liptsin: Computing Education, Cultures of Responsibility

Biography:
Assistant Professor of Ethics, Technology and Society at ETH Zurich, Margarita Boenig-Liptsin completed a Ph.D. in History of Science at Harvard University with a concurrent degree in Philosophy from the Sorbonne.
"Data-driven technologies challenge the fundamental assumptions upon which our societies are built," she explains.
"In this time of rapid social and technological change, concepts like agency,' 'justice,' and 'representation' are reconstituted, with real consequences for how people live".

Third keynote:
Donna Riley: Engaging Moral Imagination in Engineering Ethics Education

Biography:
Donna Riley is Dean of Engineering at the University of New Mexico.
She is vice president of scholarship for the American Society for Engineering Education (ASEE) since 2023 and was program director for engineering education at the NSF (2013-15).
Donna’s work focuses on ethics and social analysis in training engineers.
She is the author of Engineering and Social Justice (2008), she is the recipient of the 2012 Sterling Olmsted Award from ASEE, and the 2010 Educator of the Year award from Out to Innovate.

Papers Table of Content

SEFI
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Papers Table of Contents

Research Papers

Practice Papers

Workshop Papers

Doctoral Symposium

SEFI
ANNUAL CONFERENCE
2–5 SEPTEMBER 2024
EPFL LAUSANNE

Doctoral Symposium Report

A GROWING AND MATURING FIELD: REFLECTIONS FROM THE DOCTORAL SYMPOSIUM IN ENGINEERING EDUCATION RESEARCH AT SEFI 2024

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Conference Key Areas: *Fostering Engineering Education Research*
Keywords: *Engineering Education Research, doctoral education, networking*

ABSTRACT

The 8th SEFI Doctoral Symposium in Engineering Education Research, held at the campus of EPFL on Sunday, September 1st, preceded the SEFI 2024 Annual Conference. In all, 31 Ph.D. researchers attended. They came to share and further probe their Ph.D. research topics and study plans and to strengthen and extend their professional networks. During this full and intense day, 22 established scholars provided the Ph.D. researchers with personal feedback and ideas regarding their research. Highlights, according to the Ph.D. student participants, were the welcome and sense of support and belonging they experienced from the engineering education research community, including both the advising senior researchers and the other Ph.D. students. Although SEFI is a European organization, the Ph.D. researchers and senior advisers travelled from Africa, Australia, and North America, as well as from all over Europe, to Switzerland for this event.

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1 INTRODUCTION

1.1 The Role of the Doctoral Symposium in Engineering Education Research

Engineering education research (EER) is an emerging and expanding field, and it is now possible to pursue doctoral education in many institutions in Europe and other parts of the world. As in any research field, PhD students can benefit greatly from getting to know the leading scholars. This is, however, particularly true in EER since many Ph.D. supervisors are educational champions with a background in engineering subjects but have not been formally trained in educational research. It is common for a Ph.D. student to be the only one working on EER in their department, faculty, or university. In such cases, it is particularly important to develop a supportive network beyond the immediate environment (Edström et al., 2018). Within this context and in conjunction with its annual conference, SEFI organises an annual Doctoral Symposium (DS). Before this year, the DS has been held in Tampere the day before SEFI 2016, in Copenhagen in 2018, in Budapest in 2019, online in 2020 from Twente, online from Berlin in 2021, in Barcelona in 2022, and in Dublin in 2023. This paper aims to document and share insights from the 8th SEFI Doctoral Symposium in Lausanne in 2024. The paper explains the design of the program and discusses the recruitment of participants – doctoral students as well as experienced researchers, here called juniors and seniors respectively. Then, some of the rich materials created and captured during the event is presented, including introductions, literature, tips and advice from seniors and reflections from all participants. Finally, the authors provide reflections on the 2024 event.

1.2 The SEFI Doctoral Symposium 2024

As with previous SEFI conferences, this year's DS was held as a full-day event on the Sunday preceding the annual conference. The DS is fully interactive and uses a variety of formats to create an enriching experience:

- Short (half-minute) pitches by the seniors so the early career researchers can familiarise themselves with well-established researchers
- Discussions in small groups focusing on each student's Ph.D. project (up to 30 minutes per student)
- Speed-dating activities to grow each participant's network
- Presenting (one-minute) take-home messages to help ensure valuable lessons are crystalised and shared

1.3 Doctoral Student Participants

As in previous years, Ph.D. students were invited to apply via an extended abstract that included:

- *A general introduction* (about their background and interest in EER)
- *An outline of their research* (an elevator pitch, along with identification of their research interest, thesis title, supervisors, and current work)
- *Reflections* (their current questions, challenges, dilemmas, wishes, and ambitions)
- *Preferences for networking* (both at SEFI2024 and after the conference)

The organising team, who has worked together on this and similar events over the years, was delighted by the high number of applicants applying to attend in 2024. The quality of applications was high this year, and 32 proposals were accepted. Ultimately, 31 Ph.D. students attended for the full day, identifying their academic affiliations within 13 countries on four continents: Australia (1), Belgium (2), Denmark

(1), Finland (5), France (1), Germany (3), Ireland (2), Lithuania (1), the Netherlands (6), South Africa (3), Sweden (2), the UK (1), and the USA (3).

1.4 Senior Participants

To provide the doctoral students with feedback, coaching, and guidance, the organising team recruited a diverse group of well-established researchers in the field. To optimally support the Ph.D. students during the day's focused sessions, the organisers aimed for a ratio of three to four juniors to every two senior coaches. This ratio has proven to help ensure diverse, lively, and targeted feedback for juniors. The willingness and eagerness of the seniors to participate in this event in the past few years has been remarkable. Seniors volunteered their time to travel to SEFI a day early and dedicate an entire Sunday to the event, yet their enthusiasm was palpable before and during the event, and nearly every invitation issued was accepted. This year 22 established scholars came to serve as senior advisors, including the organising team (the four authors of this paper). The senior participants and organisers travelled to the DS from Australia, Belgium, Denmark, Germany, the Netherlands, Portugal, South Africa, Sweden, Switzerland, the UK, and the USA.

1.5 Group Formation

The core of the symposium consisted of group activities in which doctoral students and seniors worked together. This year, nine groups were formed, each containing three or four doctoral students and two senior participants. The groups were composed considering a balance between diversity and similarity regarding years of experience, research interests (in terms of topics and methods), university, and country. The group formation was sent out to all participants in advance, with a compilation of all extended abstracts. The instruction was to prepare by reading the abstracts of the doctoral students, particularly ones in their assigned group. The groups were formed a week in advance to allow for last-minute adjustments.

1.6 Event Outline

The program facilitated deep and meaningful discussion among doctoral students and experienced researchers. Group activities were the focus, and these were interspersed with plenary sessions:

09:00-09:30	Arrival, coffee, and tea
09:30-10:00	Introductions and Instructions
10:00-12:00	Group Session
12:00-13:00	Lunch
13:00-14:30	Speed Dating
14:30-14:45	Reflection
14:45-15:15	Refreshments
15:15-16:30	Plenary Report (Take-Home Messages up to minute per person)
16:30-17:00	Final Reflections

2 CAPTURING THE DISCUSSIONS

2.1 Getting to Know the Experienced Researchers

Before the Doctoral Symposium, the senior participants were asked to submit reading tips for the doctoral students. The first question to the seniors was: *If a doctoral student wanted to read something by you, what would you recommend and why?* In response, the seniors mentioned the following selection of their own work (in alphabetical order):

Jonte Bernhard

Issues related to quality in engineering education research (EER):

- Bernhard, J., & Baillie, C. (2016). Standards for quality of research in engineering education. *International Journal of Engineering Education, 32*(6), 2378-2394.

The relationship between "pure" engineering research and EER:

- Bernhard, J. (2015). Engineering education research as engineering research. In S. Hyldgaard Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, & B. Newberry (Eds.), *International perspectives on engineering education: Engineering education and practice in context, volume 1* (pp. 393-414). Springer.

How engineering thinking can improve the methods of EER:

- Carstensen, A.-K., & Bernhard, J. (2019). Design science research – a powerful tool for improving methods in engineering education research. *European Journal of Engineering Education, 44*(1-2), 85-102.

Tom Børsen

If you are interested in curriculum development and interdisciplinary:

- Karadechev, P., Petersen, L. S., & Børsen, T. (2021). *Interdisciplinary competencies in the study program of Techno-Anthropology*. Aalborg University Press.

If you are interested engineering ethics education:

- Børsen, T. Serreau, Y., Reifshneider, K., Baier, A., Pinkelman, R., Smetanina, T., & Zandvoort, H. (2021). Initiatives, experiences and best practices for teaching social and
  ecological responsibility in ethics education for science and engineering students. *European Journal of Engineering Education, 46*(2), 186-209.

Jenni Case

This recent piece tries to frame some important questions on what we are doing / what we think we are doing / what we might be doing:

- Case, J., & Blackie, M. (2022). Engineering Education Research for educational change: the possibilities of critical realism for conceptualising causal mechanisms in education. *Southern Journal of Engineering Education, 1*, 61-74.

Shannon Chance

A collaborative research project that won an award at SEFI:

- Direito, I., Chance, S., Clemmensen, L., Craps, S., Economides, S., Isaac, S., Jolly, A-M., Truscott, F., & Wint, N. (2021). *Diversity, equity, and inclusion in engineering education: an exploration of European higher education institutions' strategic frameworks, resources, and initiatives*. The 49th Annual Conference of the European Society for Engineering Education (SEFI 2021), 13-16 September, Berlin, Germany.

A paper comparing two methodologies and providing examples:

- Chance, S., Duffy, G., & Bowe, B. (2020). Comparing grounded theory and phenomenology as methods to understand lived experience of engineering educators implementing problem-based learning. *European Journal of Engineering Education, 45*(3), 405-442.

Tinne De Laet

This paper is recent work of my student, who was part of the doctoral symposium in 2020 and has now finished her Ph.D. degree. The paper nicely reflects the multi-disciplinary work I enjoy, in this case also together with my colleague Mieke De Cock from physics education research:

- Sijmkens, E., De Cock, M., & De Laet, T. (2023). Scaffolding students' use of metacognitive activities using discipline-and topic-specific reflective prompts. *Metacognition and Learning, 18*(3), 811-843.

Xiangyun Du

- Chen, J., Du, X., Jiang, D., Guerra, A., & Nørgaard, B. (2024). A review study with a systematic approach: pedagogical development for educators in higher engineering education. *European Journal of Engineering Education*, *49*(2), 299-329.

Kristina Edström

Just because this paper was such a joy to write:

- Edström, K. (2018). Academic and professional values in engineering education: Engaging with history to explore a persistent tension. *Engineering Studies*, *10*(1), 38-65.

Aditya Johri

- Johri, A., & Olds, B. M. (2011). Situated engineering learning: Bridging engineering education research and the learning sciences. *Journal of Engineering Education, 100*(1), 151-185.

Here are revised follow-up versions if you so wish:

- Johri, A., Olds, B. M., & O'Connor, K. (2014). Situative frameworks for engineering learning research. *Cambridge handbook of engineering education research*, 47-66.
- Secules, S., Pérez, G., Pea, R., & Johri, A. (2023). Critical and Cultural Analysis of Engineering Learning. In *International Handbook of Engineering Education Research* (pp. 199-217). Routledge.

Christian Kautz

An example of the type of work our research group does. It highlights some of the methods we use, such as open-ended written tests, and briefly mentions other methods, such as student interviews. The paper's objectives can serve as an example of our general research goals within the introductory engineering curriculum. The results are also typical for our work in the sense that student difficulties often arise with the most basic aspects of a certain topic and are often an indication of more general reasoning difficulties.

- Schäfle, C., & Kautz, C. (2021). Student reasoning in hydrodynamics: Bernoulli's principle versus the continuity equation. *Physical Review Physics Education Research*, *17*(1), 010147.

David Knight

A recent editorial in JEE provides some pointers for reviewers and links to resources focused on constructive reviewing. Giving and receiving constructive, critical feedback is a skill that is needed for all career paths. Reviewing for journals should not only be thought about as a professional responsibility, but also as a way to develop this critical professional skill. In the editorial, we describe the kinds of feedback that is most helpful.

- Knight, D. B., & Main, J. B. (2024). Reviewing: A skill we can continuously develop. *Journal of Engineering Education, 113*(2), 222-224.

Anette Kolmos

- Kolmos, A., Holgaard, J. E., Routhe, H. W., Winther, M., & Bertel, L. (2023). Interdisciplinary project types in engineering education. *European Journal of Engineering Education*, 49(2), 257–282.
- Habbal, F., Kolmos, A., Hadgraft, R. G., Holgaard, J. E., & Reda, K. (2024). *Reshaping Engineering Education: Addressing Complex Human Challenges*. Springer Nature.

Greet Langie

This paper reflects the research my research team likes to deliver: clear research methodology and results that have practical implications.

- Pinxten, M., Van Soom, C., Peeters, C., De Laet, T., & Langie, G. (2019). At-risk at the gate: prediction of study success of first-year science and engineering students in an open-admission university in Flanders—any incremental validity of study strategies? *European Journal of Psychology of Education*, *34*, 45-66.

Thomas Taro Lennerfors

Here, the writing style is freer than in many academic papers. We should experiment more with alternative forms of writing (and there is of course a huge literature already doing this, in a much more radical way than my own paper).

- Laaksoharju, M., Lennerfors, T. T., Persson, A., & Oestreicher, L. (2023). What is the problem to which AI chatbots are the solution? AI ethics through Don Ihde's embodiment, hermeneutic, alterity, and background relationships. In *Ethics and Sustainability in Digital Cultures* (pp. 31-48). Routledge.

Johanna Lönngren

I spent a lot of time and effort trying to make the methods understandable for those not used to discourse analysis. However, I used the theory (discourse theory) in a quite superficial and pragmatic way, which could also be useful as a basis for discussing the role and use of theory in EER.

- Lönngren, J. (2021). Exploring the discursive construction of ethics in an introductory engineering course. *Journal of Engineering Education*, *110*(1), 44-69.

Sally Male

This paper draws attention to the need to support students to be aware of future roles and the relevance of their studies to these roles. Engineering education is about development - not just acquiring knowledge and skills.

- Male, S. A., & Bennett, D. (2015). Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning. *Australasian Journal of Engineering Education*, *20*(1), 59-69.

Diana Adela Martin

I submitted this during my Ph.D., based on the literature review of my thesis. It took two years for the article to see publication after several rounds of peer-review, totalling 7 reviewers. I make this suggestion looking backwards and remembering how challenging it was as a doctoral student to incorporate the – sometimes diverging – feedback and revisit the story that the manuscript initially told. Over the two years, through this invisible collaboration with reviewers alongside the feedback of my supervisors, a new aim and structure came to light. Since publishing, the article has gathered more than 16,000 views, was picked up by several news outlets, and is my most cited publication to date – contributing also to the invitation to join the editorial board of the journal which published it. This is my way of saying: believe in the work you are doing as doctoral researchers, find ways to finetune it and strengthen it, and don't give up! The reviewers and editors can be your supporters.

- Martin, D. A., Conlon, E., & Bowe, B. (2021). A multi-level review of engineering ethics education: Towards a socio-technical orientation of engineering education for ethics. *Science and Engineering Ethics*, *27*(5), 60.

Abel Nyamapfene

My latest paper with Dr Natalie Wint gives insights into the current state of engineering education research in the UK, and it also showcases how researchers can collaborate effectively via current social media tools. When we started the work leading to the paper, Natalie and I had never met. It was during the COVID period. By the time we completed the paper, we were close friends, and – guess what? – we were now working at the same institution.

- Wint, N., & Nyamapfene, A. (2023). The development of engineering education research: a UK based case study. *European Journal of Engineering Education*, *48*(2), 197-220.

Corrinne Shaw

This article comes from an ongoing interdisciplinary collaboration for research and reflexive practice. It provides a useful framing for pedagogical practice in ethics education in first-year engineering.

- Ngoepe, M. N., le Roux, K., Shaw, C. B., & Collier-Reed, B. (2022). Conceptual tools to inform course design and teaching for ethical engineering engagement for diverse student populations. *Science and Engineering Ethics*, *28*(2), 20.

Roland Tormey

Even if the topic of this paper itself doesn't interest you, you will see how we defined a clear research question, designed an approach to answer it, analysed the data, drew conclusions, and specified the limitations. Actually, I hope the topic will interest you – I think what we managed to do was ridiculously cool and unexpected.

- Kotluk, N., & Tormey, R. (2024). The impact of different methods of increasing the intensity of compassion in engineering ethics cases. *European Journal of Engineering Education*, 1-17.

Maartje van den Bogaard

- Van den Bogaard, M., Yeter, I. H., & Strobel, J. (2021, October). A literature overview of differences between engineering education and other disciplinary education. In *2021 IEEE Frontiers in Education Conference (FIE)* (pp. 1-4). IEEE.

Jan van der Veen

This is a multiple-case study design. I learned so much by collecting lots of data and then make a story that highlights some aspects relevant for the audience.

- MacLeod, M., & Van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. *European Journal of Engineering Education*, *45*(3), 363-377.

Esther Ventura-Medina

This article looks into 'how' students work in teams. 'How' questions are more often approached better through qualitative methods and methodologies. This work exemplifies how naturalistic data can provide insights when studying a situation.

- McQuade, R., Ventura-Medina, E., Wiggins, S., & Anderson, T. (2019). Examining self-managed problem-based learning interactions in engineering education. *European Journal of Engineering Education, 45*(2), 232–248.

Bill Williams

This looks at aspects of engineering practice that are still under-researched by educationalists.

- Trevelyan, J., & Williams, B. (2018). Value creation in the engineering enterprise: an educational perspective. *European Journal of Engineering Education, 44*(4), 461–483.

2.2 Reading Recommendations from the Experienced Researchers

Next, the senior researchers were asked to give input following the prompt to:
Recommend one paper, not your own, for a starting Ph.D. student.
This resulted in a comprehensive collection of publications with some notable overlaps.

Jonte Bernhard

- Case, J. M. (2019). A third approach beyond the false dichotomy between teacher- and student-centred approaches in the engineering classroom. *European Journal of Engineering Education, 44*(5), 644-649.

Tom Børsen

When I did my Ph.D. in university education, this chapter helped me navigate in the different paradigms of qualitative research:

- Lincoln, Y. S., Lynham, S. A., & Guba, E. G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisited. *The Sage Handbook of Qualitative Research, 4*(2), 97-128.

Jenni Case

Mike Klassen's Ph.D. on engineering accreditation is one of the most interesting recent dissertations in the field. I recommend an early journal paper that he published in Higher Education:

- Klassen, M., & Sá, C. (2020). Do global norms matter? The new logics of engineering accreditation in Canadian universities. *Higher Education, 79*(1), 159-174.

Shannon Chance

A new open-source handbook (authored and edited by many of the seniors in this room) which will be published in the next few months:

- Chance, S., Børsen, T., Martin, D., Tormey, R., Lennerfors, T. T., & Bombaerts, G. (Eds.). (forthcoming). *The Routledge International Handbook of Engineering Ethics Education.*

Tinne De Laet

This paper links to a recommendation I would make to everyone: when researching a particular topic, also read from a field beyond engineering education research.

- Fleur, D. S., Bredeweg, B., & van den Bos, W. (2021). Metacognition: ideas and insights from neuro-and educational sciences. *npj Science of Learning 6*(1), 13.

Xiangyun Du

- Direito, I., Chance, S., & Malik, M. (2021). The study of grit in engineering education research: a systematic literature review. *European Journal of Engineering Education, 46*(2), 161-185.

Kristina Edström

Identify interesting people and follow their new work. This was published just a month ago:

- Martin, D. A., & Bombaerts, G. (2024). What is the structure of a Challenge Based Learning project? A shortitudinal trajectory analysis of student process behaviours in an interdisciplinary engineering course. *European Journal of Engineering Education*, 1–31.

Aditya Johri

These books are freely available online:

- National Research Council, et al. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition (Vol. 1).*
- National Academies of Sciences, et al. (2018). *How people learn II: Learners, contexts, and cultures.*

Christian Kautz

This paper may serve as a general reminder not to rely on ideas that appear plausible or obvious in education without testing them:

- Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2008). Learning styles: Concepts and evidence. *Psychological science in the public interest*, *9*(3), 105-119.

David Knight

- Cohen, M. D., March, J. G., & Olsen, J. P. (1972). A garbage can model of organizational choice. *Administrative science quarterly*, 1-25.

Anette Kolmos

- Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education*.

Greet Langie

- Direito, I., Chance, S., & Malik, M. (2021). The study of grit in engineering education research: a systematic literature review. *European Journal of Engineering Education, 46*(2), 161-185.

Thomas Taro Lennerfors

- Biesta, G. (2020). Risking ourselves in education: Qualification, socialization, and subjectification revisited. *Educational theory, 70*(1), 89-104.

Johanna Lönngren

- Farnsworth, V., Kleanthous, I., & Wenger-Trayner, E. (2016). Communities of Practice as a Social Theory of Learning: a Conversation with Etienne Wenger. *British Journal of Educational Studies, 64*(2), 139–160.

Sally Male

This paper is an output of a Ph.D. in engineering education:

- Godfrey, E., & Parker, L. (2010). Mapping the cultural landscape in engineering education. *Journal of Engineering education*, *99*(1), 5-22.

Diana Adela Martin

I want to recommend articles by a few (very) recent Ph.D. graduates who are doing admirable work and which, in my assessment, demonstrate their expertise:

- Routhe, H. W., Holgaard, J. E., & Kolmos, A. (2024). Students' learning of management and leadership in engineering education–a literature review. *European Journal of Engineering Education*, *49*(3), 540-576.
- Guanes, G., Leonard, A., & Dringenberg, E. (2023). Undergraduate students' espoused beliefs about different approaches to engineering design decisions. *Journal of Engineering Education*, *112*(4), 938-962.
- Matemba, E., Smith, L., Wolff, K., Inglis, H., Mogashana, D., Jansen, L Hattingh, T., Raji, A., Musa, T. & Nyamapfene, A. (2023). Reflecting on a community of practice for engineering education research capacity in Africa: who are we and where are we going? *Australasian Journal of Engineering Education*, *28*(1), 74-84.

Abel Nyamapfene

Jenny Case has this knack of taking "received wisdom" and turning it on its head to provide another way of seeing and dissecting a problem. Her work epitomises originality, criticality and insightfulness, attributes that are not always present in EER:

- Case, J. M. (2019). A third approach beyond the false dichotomy between teacher- and student-centred approaches in the engineering classroom. *European Journal of Engineering Education, 44*(5), 644–649.

Corrinne Shaw

This is a useful resource for postgraduate students in engineering education. As EER is an emerging field, systematic literature review is a structured way to access appropriate literature for postgraduate study:

- Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education*, *103*(1), 45-76.

Roland Tormey

Those from engineering and natural sciences often find it hard to see that qualitative research requires a careful and rigorous design, data collection and analysis. Very few writers convey this care and rigour in engineering education as well as Johanna:

- Lönngren, J. (2021). Exploring the discursive construction of ethics in an introductory engineering course. *Journal of Engineering Education*, *110*(1), 44-69.

Maartje van den Bogaard

Both these discuss what educational research is / could be, and what / who it is for:

- Biesta, G. J. J. (2020). *Educational research: An unorthodox introduction*. London: Bloomsbury.
- Labaree, D. F. (2012). A sermon on educational research. *International Journal for the Historiography of Education, 2*(1), 74.

Jan van der Veen

If you are interested in project based, problem based, and challenge based… This gives a thorough overview of types of interdisciplinary projects. Make sure your audience understands the context of your study:

- Kolmos, A., Holgaard, J. E., Routhe, H. W., Winther, M., & Bertel, L. (2024). Interdisciplinary project types in engineering education. *European Journal of Engineering Education*, *49*(2), 257-282.

Esther Ventura-Medina

Research design is key to doing good educational research. Part 2 of this book offers a good read on this area and links nicely research questions and approaches. This is a good reference book to go to for both starters and experienced researchers:

- Creswell, J. W. & Creswell, J. D. (2022). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 5th Ed.* Los Angeles, CA: SAGE.

Bill Williams

- Case, J. M., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education*, *100*(1), 186-210.

2.3 Advice from Experienced Researchers

Seniors were also asked to give one general tip for a starting Ph.D. student.

Jonte Bernhard

Think through YOUR research question(s), i.e. find interesting problems YOU want to investigate. In my opinion the quality of the insights generated is more important than mechanically following a method.

Tom Børsen

Remember, it is your project.

Jenni Case

Read! Read! Read! This is the time of your life to catch up on all that reading you never did as an engineering student. Read widely. Don't just read the stuff that is published in EER journals. Also - be fussy. Follow the things that excite and interest you. There is so much out there, so if something is not grabbing you, put it down (you might return to it but you might not). Research is about exploring things where we don't have the answers. Wrestle with what questions are out there. Find the studies that you think are doing great things (and really grappling with unanswered questions) and start dreaming on what you will do to add to this literature. But don't just dream... Write! Write! Write!

Shannon Chance

Find and cultivate mentors. When you're ready and have enough time to review a manuscript for EJEE, email us (Diana Martin and I have a particular interest in mentoring reviewers), and we will try to match you with a topic of interest.

It's never too early to think about where you want to go after the Ph.D. Consider attending the workshop I'll lead with other seniors in the room, during SEFI, on securing international fellowships for research (Chance et al., 2024), including post-doctoral funding (jobs and fellowships). And during SEFI, you can be on the lookout for people and research centers where you'd like to work a while!

Tinne De Laet

Be open to other disciplines, paradigms, and people! Be welcoming and supportive to others, in short: treat others like you want to be treated.

Xiangyun Du

Feel safe to be creative. A Ph.D. project is a process to construct your own academic identity.

Kristina Edström

Read the old classics and read new works. Notice what you like about the writing: what makes it convincing, what helps the reader, what shows honesty and transparency, what is the contribution, and what stays with you long after. Notice also how you don’t want to write.

Aditya Johri

A good dissertation is a dissertation done.

Christian Kautz

1. Find a topic that genuinely interests you. A dissertation project is a lot of work, and you will very likely experience "ups" and "downs". A topic that you really care about will make it easier to get through harder times.
2. Find a group of people with whom you can talk about your research, ideally even about fairly specific aspects of it. I know of only a few successful and relevant research projects that were carried out by a single person without exchanging important ideas with others.
3. If you have any desire to stay in academia, gather experience in teaching, possibly even larger student groups. There is little need for pure educational researchers who have never put their ideas on teaching into practice.

David Knight

Try to remain centred on a love of and thirst for learning through your doctoral programs and beyond.

Anette Kolmos

Much advice can be given, but I think the most important is to try to boil complex thinking down to simple messages. The articles which will be remembered are those with core and clear messages. It means that when you start articles or other writings, try to formulate the message in laymen’s words and build up the argumentation to support your message.

Greet Langie

Be confident! When your Ph.D. is almost finished, you are the expert in this specific field!

Thomas Taro Lennerfors

Think big. Do not get stuck in a narrow issue / field / discussion. This will prepare you for a long career after the Ph.D.

Johanna Lönngren

Take care of yourself and talk about your struggles with people you trust. Doing a Ph.D. can be very taxing, and if you experience challenges, you're not alone. No one benefits from you pushing yourself too hard and getting burned out!

Sally Male

Remember to test everything well – e.g., questionnaires, interview protocols.

Diana Adela Martin
This group of Ph.D. researchers is here: this is your community. My advice will always be to value collaboration and community-building over competition. You can achieve so much together by developing joint projects, co-writing articles, and submitting grant applications, in a process that, in time. leads to friendships. Academia can be pretty toxic, hostile, lonely and ego-driven, and it is through these accumulated small changes in attitude that we grow together and grow the field of EER.

Abel Nyamapfene
Be yourself, enjoy the ride, and do not be afraid to be different, after all, it's diversity which advances originality in engineering education research.

Corrinne Shaw
Spend time on crafting your research question so that it has appropriate scope and contribution for your degree.

Roland Tormey
Locate yourself in the emotional trajectory of your project (social, epistemic, achievement...), and give yourself time to have the emotions you experience.

Maartje van den Bogaard
Write ugly English: getting clarity on your own logical argumentation is not easy. What really helps, I found, is to force yourself to write short sentences only. Go for logical argumentation, not for eloquence. That will come later, or it will not come at all, and it's of lesser importance than getting your argument straight and communicating it clearly, even if the English is ugly.

Jan van der Veen
Focus: zoom in. You have to write only one thesis.

Esther Ventura-Medina
Whatever your research question(s) is(are), make sure that your approach (i.e., quantitative, qualitative or mixed) is aligned to the question(s) and it is fit for purpose.

Bill Williams
Find your community.

2.4 Group Notes

The groups wrote collaborative notes during their time together and then prepared notes using an online file. These were valuable yet lengthier than could be included here.

2.5 Take-Home Messages

As the final activity of the day, the organisers invited each participant to share one nugget of wisdom gained as a take-home message from the DS. This final plenary allocated each attendee maximum one minute to present their personal message. Some selected messages from doctoral students and seniors appear below:

“We are not alone and our impact is together with those who are working on similar projects. Together we create the space to step into. And together we transform what is there for others to walk on.”

“It was very valuable to hear from Ph.D. students about their topics, problems and solutions I can try to use in my doctoral research.”

“Engineering education research is like a poke bowl where everyone comes in with diverse disciplinary backgrounds and experiences, but it’s this mix that makes the poke bowl so delicious, because everyone brings something unique to the table.”

“This community has an incredibly engaged and supportive culture which is a real asset and so fully on display at the doc symposium.”

“I should think about the impact I want to have and have that drive the research questions and methods. Dive deep into the existing literature. I want to be critical of the existing literature: adopt a post-positivist mindset.”

“There are so many connections (theoretically, methodologically, in terms of process, concerns, etc) between the PhD projects (and other research) in (and beyond) this community. Although sometimes we focus on differentiating ourselves from others through different concepts, methodologies, being unique etc, the core ideas and concerns are often quite similar and can bring us together even more. Unveiling those connections is perhaps best done through oral communication and spending time together, with an attitude of openness and willingness to learn, rather than protecting our own turf.”

“Serendipity remains really important: a lot of work has been done in many places, yet it’s not always easy to find information. We need to (continue to) talk with a wide audience because it is often the way to learn about initiatives/papers/projects/etc. that might be instrumental for our work.”

“I think one of my big takeaways from this symposium is to be a lot more intentional and focused - and kind - with my time and my writing. Approaching what I hope will be the end of my PhD, another takeaway is to take hold of the idea that ‘you can always do more’ and realise, at a certain point, that what you’ve actually done is enough.”

“The importance of definitions. Defining words like ‘effective’ or ‘improve’, and deciding what those words mean inside my project is really important and should be more of a priority!”

“Life is a bit random and non-linear. Look out for the opportunities while following (exploring) a path that you find interesting, but not to forget that interest can be developed over time. Be mindful about your bigger goals and aspirations. Remind yourself of ‘the thing’ that keeps you moving? Don’t worry too much about the performance-related outcomes, do the things you like and do them well, you’ll be fine.”

“Read a lot, find good empirical models, and get inspired by them. If you can copy them, even better. Always keep writing, especially while doing empirical work. And try to fill a gap but don’t fall into a hole – coming up with a good research question will help you achieve this better than almost any other aspect of research.”

“The field of EER is relatively new and is still developing so it’s ok to be confused about approaches, theories, methodologies etc.”

“My main takeaway is that framing and contextualising matters a lot. Think about the audience and think about why your work/the case is informative and relevant for others and what factors you are addressing.”

“Across national contexts there is huge variation in what a PhD is, how it is supported and assessed, in the structure of academic careers and of university programs. It’s great to be in a space where this variation is fully on display, and watching people navigating the career possibilities in their context.”

“Research is not linear, it’s iterative. Don’t get too fixated on one framework. Listen to your data. No need to kill all your darlings, but be open to adopting new ones.”

“I learned that many people here are swimming - or drowning - in an ocean of data. It might be difficult to know where to start. One of the seniors helped me realize we do not have to cram all this data in one paper. Think about different parts, and especially different stories. Cause I also learned that to make your research impactful, there is power in storytelling.”

“Trust the process! Rejections, confusing results and feeling stuck are part of it and can open new doors and lead to new research questions and future work.”

“I continue to be extremely impressed at the depth of thinking among graduate students at this event – connecting with this group has been a favorite activity for me over the past two years. I also appreciate the ways in which projects seem to have an implementation/change element to them and think as a community we need to make sure we are situating our work within organizational/institutional contexts.”

3 REFLECTIONS AND WAY AHEAD

The 8th SEFI Doctoral Symposium, like its predecessors, provided a key event for the engineering education research community. The symposium continues to grow in both size and impact, reflecting the increasing maturity and global reach of the field. This year, 31 Ph.D. students and 23 established scholars contributed to a vibrant and dynamic exchange of ideas. When one of the participants at the 2023 DS called SEFI “her village”, we began to see that the community keeps growing, perhaps becoming a little town, yet still a cosy and welcoming one.

Many insights and experiences shared by participants highlighted the diverse and interdisciplinary nature of engineering education research. From the importance of finding one’s niche and leveraging unique backgrounds to the value of networking and collaboration, the symposium provided rich learning opportunities. The metaphor of engineering education research as a “poke bowl” aptly captured the essence of this diversity, where each participant’s unique contributions enhanced the collective experience.

The vibrant sense of community that characterised this year’s symposium is a testament to the strength of the SEFI network. The symposium demonstrated the supportive and engaged culture of the SEFI community overall. It fostered a mutual exchange of ideas, and the cultivation of new connections was seen as invaluable by all participants. It was also noteworthy that senior mentors and organizers expressed appreciation for the opportunity to both guide and learn from the junior researchers. As we reflect on the symposium, we are inspired by the dedication and passion of this community. The take-home messages from participants emphasised the importance of perseverance, critical thinking, and the continuous pursuit of knowledge. The symposium not only provided a platform for sharing research but also for personal and professional growth. A healthy sense of belonging and the shared commitment to advancing the field were palpable throughout the event.

In reflecting on the 2024 event, the organisers find themselves delighted with the expanded capacity of this community to conduct impactful research and committed to supporting the unique abilities and perspectives each member brings. We look forward to staying connected with this year's participants, and we eagerly anticipate the continued growth and success of the Engineering Education Research community. Together, we are shaping the future of engineering education research and creating a supportive, inclusive, and dynamic community.

4 ACKNOWLEDGMENTS

The authors wish to thank every participant in the DS, from its inception in 2016 to this 2024 event. The activity's success is a direct result of the engagement and enthusiasm of juniors and seniors alike. We also thank all the local and international organising committees over the years. This year, Roland Tormey and his team gave outstanding support. We thank the SEFI staff and board for entrusting us with the facilities and resources to help make this event possible.

REFERENCES

Bernhard, J., & Baillie, C. (2016). Standards for quality of research in engineering education. *International Journal of Engineering Education, 32*(6), 2378-2394.

Bernhard, J. (2015). Engineering education research as engineering research. In S. Hyldgaard Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, & B. Newberry (Eds.), *International perspectives on engineering education: Engineering education and practice in context, volume 1* (pp. 393-414). Springer.

Biesta, G. (2020). Risking ourselves in education: Qualification, socialization, and subjectification revisited. *Educational theory, 70*(1), 89-104.

Biesta, G. J. J. (2020). *Educational research: An unorthodox introduction*. London: Bloomsbury.

Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education*, *103*(1), 45-76.

Børsen, T. Serreau, Y., Reifshneider, K., Baier, A., Pinkelman, R., Smetanina, T., & Zandvoort, H. (2021). Initiatives, experiences and best practices for teaching social and ecological responsibility in ethics education for science and engineering students. *European Journal of Engineering Education, 46*(2), 186-209. https://doi.org/10.1080/03043797.2019.1701632

Carstensen, A.-K., & Bernhard, J. (2019). Design science research – a powerful tool for improving methods in engineering education research. *European Journal of Engineering Education, 44*(1-2), 85-102. https://doi.org/10.1080/03043797.2018.1498459

Case, J. M., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education*, *100*(1), 186-210.

Case, J. M. (2019). A third approach beyond the false dichotomy between teacher- and student-centred approaches in the engineering classroom. *European Journal of Engineering Education, 44*(5), 644-649. https://doi.org/10.1080/03043797.2019.1657632

Case, J., & Blackie, M. (2022). Engineering Education Research for educational change: the possibilities of critical realism for conceptualising causal mechanisms in education. *Southern Journal of Engineering Education, 1*, 61-74.

Chance, S., Børsen, T., Martin, D., Tormey, R., Lennerfors, T. T., & Bombaerts, G. (Eds.). (forthcoming). *The Routledge International Handbook of Engineering Ethics Education.*

Chance, S., Duffy, G., & Bowe, B. (2020). Comparing grounded theory and phenomenology as methods to understand lived experience of engineering educators implementing problem-based learning. *European Journal of Engineering Education, 45*(3), 405-442. https://doi.org/10.1080/03043797.2019.1607826

Chance, S. M., Johri, A., Cruz Moreno, S. I., Direito, I., Polmear, M., Kovacs, H., & Joshi, R. (2024). Securing fellowships for engineering education research. The 52nd Annual Conference of the European Society for Engineering Education (SEFI 2021), 2-5 September, Lausanne, Switzerland.

Chen, J., Du, X., Jiang, D., Guerra, A., & Nørgaard, B. (2024). A review study with a systematic approach: pedagogical development for educators in higher engineering education. *European Journal of Engineering Education*, *49*(2), 299-329. https://doi.org/10.1080/03043797.2023.2290032

Cohen, M. D., March, J. G., & Olsen, J. P. (1972). A garbage can model of organizational choice. *Administrative science quarterly*, 1-25.

Creswell, J. W. & Creswell, J. D. (2022). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 5th Ed.* Los Angeles, CA: SAGE.

Direito, I., Chance, S., Clemmensen, L., Craps, S., Economides, S., Isaac, S., Jolly, A-M., Truscott, F., & Wint, N. (2021). *Diversity, equity, and inclusion in engineering education: an exploration of European higher education institutions' strategic frameworks, resources, and initiatives*. The 49th Annual Conference of the European Society for Engineering Education (SEFI 2021), 13-16 September, Berlin, Germany.

Direito, I., Chance, S., & Malik, M. (2021). The study of grit in engineering education research: a systematic literature review. *European Journal of Engineering Education, 46*(2), 161-185. https://doi.org/10.1080/03043797.2019.1688256

Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education*.

Edström, K. (2018). Academic and professional values in engineering education: Engaging with history to explore a persistent tension. *Engineering Studies*, *10*(1), 38-65. https://doi.org/10.1080/19378629.2018.1424860

Farnsworth, V., Kleanthous, I., & Wenger-Trayner, E. (2016). Communities of Practice as a Social Theory of Learning: a Conversation with Etienne Wenger. *British Journal of Educational Studies, 64*(2), 139–160.

Fleur, D. S., Bredeweg, B., & van den Bos, W. (2021). Metacognition: ideas and insights from neuro-and educational sciences. *npj Science of Learning, 6*(1), 13.

Godfrey, E., & Parker, L. (2010). Mapping the cultural landscape in engineering education. *Journal of Engineering education*, *99*(1), 5-22.

Guanes, G., Leonard, A., & Dringenberg, E. (2023). Undergraduate students' espoused beliefs about different approaches to engineering design decisions. *Journal of Engineering Education*, *112*(4), 938-962.

Habbal, F., Kolmos, A., Hadgraft, R. G., Holgaard, J. E., & Reda, K. (2024). *Reshaping Engineering Education: Addressing Complex Human Challenges*. Springer Nature.

Johri, A., & Olds, B. M. (2011). Situated engineering learning: Bridging engineering education research and the learning sciences. *Journal of Engineering Education, 100*(1), 151-185.

Johri, A., Olds, B. M., & O'Connor, K. (2014). Situative frameworks for engineering learning research. *Cambridge handbook of engineering education research*, 47-66.

Karadechev, P., Petersen, L. S., & Børsen, T. (2021). *Interdisciplinary competencies in the study program of Techno-Anthropology*. Aalborg University Press.

Klassen, M., & Sá, C. (2020). Do global norms matter? The new logics of engineering accreditation in Canadian universities. *Higher Education, 79*(1), 159-174.

Knight, D. B., & Main, J. B. (2024). Reviewing: A skill we can continuously develop. *Journal of Engineering Education, 113*(2), 222-224.

Kolmos, A., Holgaard, J. E., Routhe, H. W., Winther, M., & Bertel, L. (2023). Interdisciplinary project types in engineering education. *European Journal of Engineering Education*, 49(2), 257–282. https://doi.org/10.1080/03043797.2023.2267476

Kotluk, N., & Tormey, R. (2024). The impact of different methods of increasing the intensity of compassion in engineering ethics cases. *European Journal of Engineering Education*, 1-17. https://doi.org/10.1080/03043797.2024.2341758

Laaksoharju, M., Lennerfors, T. T., Persson, A., & Oestreicher, L. (2023). What is the problem to which AI chatbots are the solution? AI ethics through Don Ihde's embodiment, hermeneutic, alterity, and background relationships. In *Ethics and Sustainability in Digital Cultures* (pp. 31-48). Routledge.

Labaree, D. F. (2012). A sermon on educational research. *International Journal for the Historiography of Education, 2*(1), 74.

Lincoln, Y. S., Lynham, S. A., & Guba, E. G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisited. *The Sage Handbook of Qualitative Research, 4*(2), 97-128.

Lönngren, J. (2021). Exploring the discursive construction of ethics in an introductory engineering course. *Journal of Engineering Education*, *110*(1), 44-69.

MacLeod, M., & Van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. *European Journal of Engineering Education*, *45*(3), 363-377. https://doi.org/10.1080/03043797.2019.1646210

Male, S. A., & Bennett, D. (2015). Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning. *Australasian Journal of Engineering Education*, *20*(1), 59-69. https://doi.org/10.7158/D14-006.2015.20.1

Martin, D. A., Conlon, E., & Bowe, B. (2021). A multi-level review of engineering ethics education: Towards a socio-technical orientation of engineering education for ethics. *Science and Engineering Ethics*, *27*(5), 60.

Martin, D. A., & Bombaerts, G. (2024). What is the structure of a Challenge Based Learning project? A shortitudinal trajectory analysis of student process behaviours in an interdisciplinary engineering course. *European Journal of Engineering Education*, 1–31. https://doi.org/10.1080/03043797.2024.2376222

Matemba, E., Smith, L., Wolff, K., Inglis, H., Mogashana, D., Jansen, L., Gwynne-Evans, A., Campbell, A.L., Kwuimy, C., Nassar, S., Magara, I., Kloot, B., Hattingh, T., Raji, A., Musa, T. & Nyamapfene, A. (2023). Reflecting on a community of practice for engineering education research capacity in Africa: who are we and where are we going? *Australasian Journal of Engineering Education, 28*(1), 74–84. https://doi.org/10.1080/22054952.2023.2233340

McQuade, R., Ventura-Medina, E., Wiggins, S., & Anderson, T. (2019). Examining self-managed problem-based learning interactions in engineering education. *European Journal of Engineering Education, 45*(2), 232–248. https://doi.org/10.1080/03043797.2019.1649366

National Research Council et al. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition (Vol. 1)*. National Academies Press. Available at https://nap.nationalacademies.org/catalog/9853/how-people-learn-brain-mind-experience-and-school-expanded-edition

National Academies of Sciences, et al. (2018*). How people learn II: Learners, contexts, and cultures.* National Academies Press. Available at https://nap.nationalacademies.org/catalog/24783/how-people-learn-ii-learners-contexts-and-cultures

Ngoepe, M. N., le Roux, K., Shaw, C. B., & Collier-Reed, B. (2022). Conceptual tools to inform course design and teaching for ethical engineering engagement for diverse student populations. *Science and Engineering Ethics*, *28*(2), 20.

Pashler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2008). Learning styles: Concepts and evidence. *Psychological science in the public interest*, *9*(3), 105-119.

Pinxten, M., Van Soom, C., Peeters, C., De Laet, T., & Langie, G. (2019). At-risk at the gate: prediction of study success of first-year science and engineering students in an open-admission university in Flanders—any incremental validity of study strategies?. *European Journal of Psychology of Education*, *34*, 45-66.

Routhe, H. W., Holgaard, J. E., & Kolmos, A. (2024). Students' learning of management and leadership in engineering education–a literature review. *European Journal of Engineering Education*, *49*(3), 540-576. https://doi.org/10.1080/03043797.2023.2299279

Schäfle, C., & Kautz, C. (2021). Student reasoning in hydrodynamics: Bernoulli's principle versus the continuity equation. *Physical Review Physics Education Research*, *17*(1), 010147. DOI:10.1103/PhysRevPhysEducRes.17.010147.

Secules, S., Pérez, G., Pea, R., & Johri, A. (2023). Critical and Cultural Analysis of Engineering Learning. In *International Handbook of Engineering Education Research* (pp. 199-217). Routledge.

Sijmkens, E., De Cock, M., & De Laet, T. (2023). Scaffolding students' use of metacognitive activities using discipline-and topic-specific reflective prompts. *Metacognition and Learning*, *18*(3), 811-843.

Trevelyan, J., & Williams, B. (2018). Value creation in the engineering enterprise: an educational perspective. *European Journal of Engineering Education, 44*(4), 461–483. https://doi.org/10.1080/03043797.2017.1421905

Van den Bogaard, M., Yeter, I. H., & Strobel, J. (2021, October). A literature overview of differences between engineering education and other disciplinary education. In 2021 *IEEE Frontiers in Education Conference* (FIE) (pp. 1-4). IEEE. DOI: 10.1109/FIE49875.2021.9637143

Wint, N., & Nyamapfene, A. (2023). The development of engineering education research: a UK based case study. *European Journal of Engineering Education*, *48*(2), 197-220. https://doi.org/10.1080/03043797.2022.2121686

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Using Narratives to Explore Social Influences on the Identities of Women Students in Engineering: Two Case Studies

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ABSTRACT

Despite efforts to attract women into undergraduate mechanical engineering, participation and retention rates remain low. Several studies have identified socio-structural factors that mitigate efforts for inclusion of women and report the challenges for women in navigating the influence of these factors. Considering how the experiences of women within cohorts are nuanced by religious, cultural, and familial circumstances, understanding how women navigate these circumstances to succeed in engineering programs could inform interventions to attract and retain women. This study investigates the influences of family, culture, and social structures with respect to access and participation of women students in engineering

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through the use of narratives drawn from interviews of a selection of young women students at two universities, one located in the Global South and the other in the Global North. The use of narratives is explored as a methodological approach for explaining these complex experiences. It was found that narratives combined with thematic analysis provided a holistic approach to understanding how social structures serve to undermine or support student identities in undergraduate engineering.

1 INTRODUCTION

1.1 Background

Globally, the recruitment of women into engineering degrees has seen a steady increase over the past several decades, though large gender disproportions remain (Hill et al. 2010). The gap in participation in engineering disciplines between men and women exists in both developing and developed countries, with this discrepancy typically attributed to factors related to gender stereotypes and discrimination, lack of opportunities in education, and levels of exposure to engineering (Longe et al. 2019). In addition to these factors, there are studies that consider how other elements related to society, culture, and social situations also play a role in the recruitment and retention of women in the study of engineering. For example, Hill et al. (2010) report that some of these supplemental factors include, but are not limited to, societal and religious beliefs, parental influence, and educational circumstances. These factors, thus, could influence not only students' enrolment decisions and their experiences during their studies, but also their engineering and gender identities, their academic confidence, and their levels of engagement in the classroom.

This paper draws on a doctoral research project aiming to investigate how social structures influence the identities of women students in engineering. This investigation uses concepts from identity theory and narrative inquiry to understand how familial, cultural, and social structures contribute to the expression of these identities. It aims to identify how these known structures, as recounted by Stryker and Burke (2000), influence the negotiation of identities as they are expressed through expected behaviour in various social situations. Consequently, it became beneficial to document and analyse how and to what level these structures influence the experiences and expressions of identity of women students in engineering. Data were collected from women students in engineering at two international universities, one in the Global South and the other in the Global North, and narratives were used to meet this objective. What follows is a discussion of the theoretical concepts that were drawn on for understanding human experience in a social context, and thereafter the approach to the empirical study of the use of narratives is explained.

1.2 Theoretical Framework

In this study, several theories and concepts of identity were drawn upon to refer to appearances, behaviours, and characteristics that define an individual's position or positions in society (Fearon 1999). Most notably, Gee's (2000) work presents the enduring framing that there exist four perspectives attributed to identity, which provide a model to describe a person's character, how they are viewed externally, and can be recognised by others according to a state, position, individual trait, and set of experiences (Gee 2000). In contrast, Giddens (1991) argues that identity does not actually exist solely in the behaviour or opinions of others, but rather through one's ability to maintain the representation of a particular, personal narrative. Similar to Gee's work, Giddens (1991) postulates that a person's story or perceived identity is not fixed and can be ever-changing, interpretive, and transformative. From this, it can be deduced that both Giddens' understanding of a person's narrative and Gee's four perspectives can play a role in understanding how a student expresses their identity and attributes this expression to a number of factors relating to the intrinsic self and extrinsic societal factors.

Stryker and Burke (2000) put together these two strands of identity theory, combining the factors that shape identity from origins of both social structures and the self. These strands are given meaning through an individual's social behaviour, continuously negotiated through an individual's commitment to meeting society's identity standards, as well as their internal processes and self-verifications of perceptions of identity (Stryker and Burke 2000). Social structures, which act as margins enclosing a person's relationships and interactions within overlapping social networks, can shape identity and the story of the self, which in turn is expressed through social behaviour. Internally, identities are negotiated through an intrinsic inclination to align one's self with the perceived identity standards fitting the individual's situation (Stryker and Burke 2000). Together, these strands of identity are transformative and interpretive, acting as agents of identity expression in the interplay between social structures and the individual's internal processes. Ultimately, while not deterministic, social structures contribute influences over the behaviours and identity expressions of individuals.

2 RESEARCH APPROACH

The research approach was guided by Maxwell's (2013) qualitative research design, which allowed for context-driven methods to be used to understand how identities can be influenced by social phenomenon. This iterative, non-linear design process was applied to investigate two research sites represented by two international contexts.

2.1 Universities as Research Sites

In order to understand how social structures influence the identities of women students in engineering, two research sites, one located in the Global North (Düsseldorf, Germany) and one in the Global South (Cape Town, South Africa), were chosen. These sites have some similarities: they boast diverse populations, cultures, and societal norms. Notable differences however, related to regional size, national geographical location, and population allowed for influences attributed to national history, makeup of population, and access to education to be particularly considered.

The city of Düsseldorf lies along the Rhein River and is the capital of the North Rhine-Westphalia state of Germany. It is home to a population of approximately 645 000 people, with roughly 153 100 considered to be foreign, particularly of Japanese, Turkish, and Polish descent (Düsseldorf 2021). Düsseldorf rose to prominence in 1288 as a hub for industry and trade as an inland port, and has transformed from a fishing village into a city known for its fashion, art, and boutique shopping (Britannica 2024). Considered to be an old city of Europe, it remains staunch in its beer-brewing methods and predominantly Christian values (Times 2019). Düsseldorf is home to six prominent, state-run universities, providing instruction in various fields which include architecture, engineering, and business. The language of learning and teaching (LoLT), is predominantly German and, in some instances, English.

Cape Town, in contrast, is a coastal city located in the Western Cape province of South Africa and serves as the legislative capital of the country with a population of approximately 5 million people at current estimation (Review 2024). Significant in its role as the point of arrival of the Dutch colonies in the 1650s owing to its strategic trade position at the southern tip of Africa, Cape Town is rich with diverse populations, flora, and fauna (Axelson 2024). Three decades on from the abolishment of the country's ethnic segregation of apartheid, the consequences of the country's dark history are still felt in the city, with ongoing economic fluctuations fuelling movements towards increased racial freedom and national development. Cape Town, as a city, is home to three public universities, with English as the primary language of learning and teaching, and offers various degree programmes including humanities, medicine, sciences and, in two of the three, engineering.

Two universities, in each research site, were chosen as the context for exploring the use of narratives to understand the socio-structural influences on women's identities.

2.2 Interview Strategy

Following appropriate ethical clearance, women studying at undergraduate level in the overarching discipline of mechanical engineering were selected for inclusion in the sample. These students were invited to participate through email invitations and direct contact through faculty members. No limitations were placed on participants' age, nationality, or heritage with the sample intended to benefit from variety in participants who identified as women. Data were collected through the use of semi-structured individual and group interviews. Each included participant was interviewed once, with a follow-up interview conducted on one occasion to seek clarification. The duration of each interview varied from twenty minutes to more than one hour, and they were conducted by the primary researcher in English. All audio was recorded and subsequently transcribed by a confidential transcriber.

The individual interviews were designed to explore three main areas, with the first focused on gathering preliminary biographical information about the participant, such as age, discipline, and hometown. The second involved questions focused on the participant's journey to and through their engineering degree, and the impact of that decision on themselves and their family, friends, and peers. The final area centred on the participant's experiences as a student in engineering, focusing on their time spent in and out of the classroom, their views on the degree, and any instances in which they were made to feel excluded or marginalised.

The sample included six students from the German site and eight students from the South African site, both numbers that fall within a typical sample size for narrative inquiry and allowing for a deeper, more nuanced level of understanding (Kim 2016). Most interviews were conducted face-to-face on the university campus where the students were based. Only one interview was facilitated online to accommodate a student who was unable to meet in-person. In addition to the individual interviews, the group interviews, one conducted per site, offered additional insights and richer stories of the participants' experiences studying engineering. All interviewees were assured of confidentially and anonymity, and were assigned a pseudonym throughout the findings, as indicated in Table 1 below along with gathered biographical information.

Table 1: Participant Pseudonyms and Biographical Information

Pseudonym	Research Site	Age	Nationality	Heritage
Julia	Germany	23	German	German
Claudia	Germany	21	German	German
Kaya	Germany	23	German	Turkish
Veronica	Germany	28	German	Polish
Astrid	Germany	27	German	German
Nehir	Germany	22	Turkish	Kurdish
Crystal	South Africa	23	Zimbabwean	Zimbabwean
Louisa	South Africa	23	South African	South African
Mbali	South Africa	22	Zimbabwean	Zimbabwean
Yusra	South Africa	21	South African	South African
Teresa	South Africa	23	South African	Malawian
Nandi	South Africa	23	South African	South African
Amira	South Africa	22	South African	South African
Zahra	South Africa	21	South African	South African

2.3 Approach to Data Analysis

The data collected were analysed using methods adopted from narrative inquiry, a type of analysis that focuses on exploring the way in which people experience life, particularly by paying close attention to stories of their everyday lives (Moen 2006). It allowed the researcher to go beneath the surface, collecting data in the form of spoken stories and using them to relate human experiences to their actions and behaviours in a social situation (Walker, 2001). Each participant included in the study had an individual story, personal characteristics, and views of themselves in a given context. Each story remained preserved during analysis as key themes embedded in the narrative were identified. Each narrative was, therefore, considered on its merit, as investigative interest remained firmly in the individual participant's story and thus her own experiences (Polkinghorne 1995). All interviews and associated transcripts were summarised to include and highlight pertinent information about each participant's age, family background, nationality, experiences, ambitions, and values.

3 Preliminary Findings

The narratives were considered to be significant contributions and used to document the processes of navigating legitimate identities. Using each narrative as a stand-alone character summary of each participant's story of self, commonalities were identified as part of a first-pass thematic analysis.

3.1 The Role of Family and Peers

In response to questions about their reasons for choosing engineering, all of the participants referred to the views of their parents and other family members regarding their choices of study, highlighting the significance of their influence towards the participants' student identities. From the German sample, all the interviewees made mention of encouragement they received from the women in their lives to pursue engineering, mothers and older sisters alike. One participant, Julia, stated that her mother encouraged her to use her talents in mathematics to secure a strong degree, while Astrid's mother drew her attention to the country's ongoing campaign that 'Germany needs engineers.' Similarly, from the South African sample, Teresa's sister, already a medical student at the same university, encouraged her to consider engineering as a career because of her interest in designing rollercoasters. The interviewees all noted that their nuclear families were largely supportive of their venture into engineering. Coming from a family of architects, Louisa's parents and older sister steered her away from following the same career, with her father suggesting engineering as a way to supplement her talents in mathematics and art.

All but one participant from both samples reported that they had family members who were engineers, ranging from an older sister to a grandfather, thereby having prior knowledge of engineering as a career. Nehir (Germany), at a young age, found engineering to be very interesting and wanted to be just like her sister, who studied to become an industrial engineer. Yusra (South Africa) referred to her uncle's admirable success in the field as a reason for pursuing engineering. Similarly, Amira (South Africa) cited one of her friend's interests in engineering as the catalyst for her own, stating she thought, "If she can do engineering, I can do it." Though, she did add that the engineers in her family, all of whom were men, never spoke about the profession in a way that made it sound inclusive to women, affecting her interest.

While geographical differences were apparent in the samples, it was interesting to note that foreign nationals studying in each country detailed similar pressures from their parents and extended family to achieve academically and secure well-paying jobs. Veronica (Germany) expressed that her family always promoted the idea that she had to study and get a good job. This she saw as a part of the core values instilled in her that aligned with the historical experiences of her Polish grandparents. Similarly, as part of the South African sample, Mbali, originally from Zimbabwe, admitted that she felt the pressure of being the firstborn in her family to pursue in a 'serious' degree such as engineering. Moreover, Crystal, also from Zimbabwe, drew attention to her parents' swaying her towards a 'safer' qualification. She stated, "My parents were very much wanting all their kids to become doctors. So the next best thing, because I didn't want to do medicine was, 'Why don't you try engineering?'"

3.2 Education, Exposure, and Access

From the narratives of students based in Germany, four of the participants spoke of participating in three-week long vocations with various companies of interest during their high school years. Built into the German secondary school curriculum is the requirement for students who are studying towards the leavers' examination, referred to as Arbitur, which is a level of achievement that allows students to enter into a higher education institution. This instruction was especially useful for Astrid, who, after her experiences working in a dentist's practice and subsequently in an aeronautical company, realised that dentistry was not as dynamic a career as she was seeking. While no similar program was reported by participants from the South African sample, Amira alluded to being involved in extracurriculars related to science, though still remarked, "I don't think that engineering is presented as an option for women, generally." About the suggestion to address the exposure to engineering principles more seriously at secondary school level, Zahra (South Africa) mused that it might actually deter women from pursuing an engineering degree if they were more aware of its potential as a career.

None of the participants from Germany claimed Düsseldorf to be their hometown. Originally from as close as one city away to as distant as the country of Turkey, none of them expressed regret over their decisions to move away from home. Initially having a ninety-minute commute, Kaya moved right near the campus in later years, which she found more comfortable and conducive to healthier student practices. Comparatively, half of the South African sample were born and raised in Cape Town itself, opting to remain living at home with their families for the duration of their undergraduate degrees. Zahra referred to the decision as "beneficial and a big advantage," providing her with the safety of home-cooked meals, the familiarity of her own space, and the network of support provided by her family, which all contributed to her ability to focus on securing her degree. As a downside to this, Louisa felt that not living in student residences hindered her adjustment to campus life, affecting her initial drive to socialise with her classmates. Others from the sample reported choosing to move to Cape Town for the prestige of the university, opting to pursue independent living despite the difficulties of being away from familiarity and family.

In contrast to the structure of the engineering degree in South Africa, a requirement to qualify for graduation in Germany is a formal semester-long internship with a professional engineering company. It is normal practice then, among industry partners, to receive and mentor senior students, providing valuable insight into the engineering workplace. From the interviewees, those who had already completed their internship semesters at the time of the interview had mostly positive experiences to report despite their acknowledgement of the glaring gender disparity at all levels within the companies. This requirement for graduation, however, was significant for Nehir, as the companies in Germany require their interns to speak fluent German, which made it difficult for her to find a position. The same standardisation of practice, however, is not prevalent in the South African engineering sector, where a requirement to graduate is to commit to a prescribed number of weeks of vacation work that covers both practical and management aspects of engineering. Owing to minimal university involvement in vacation work placements, the sample reported mixed experiences. In particular, Mbali mentioned working for a company in her home country with the intention of completing this requirement and found that she was the only woman employed. Unfortunately, she was relegated to only reception work and said she felt devalued, belittled, and not trusted as competent personnel. In another instance, Zahra noted receiving advice from a senior woman engineer, instructing her to be upfront and assertive in interactions with male colleagues in order to avoid being spoken to in a condescending or denigrating manner.

3.3 Financial Considerations

It is well documented that South Africa's higher education system continues to carry the burden of the country's history of legalised racial segregation. There have been numerous campaigns, usually initiated by students, to reduce and subsidise the fees to attend university, addressing barriers to access education for many citizens and foreign nationals. For some, the option to study at all relies on securing sufficient funding. The availability of scholarships and bursaries ultimately factored into the choice to study engineering for Zahra and contributed significantly towards her persistence in the degree. She cited the risk of a loss of funding based on poor academic performance as a strong motivation. She alluded to the financial benefits of having a bursary, which included the promise of employment after graduation, but added that she felt trapped by the contractual obligation as it prevented her from exploring new career paths. Likewise, originally intending to study further abroad, Mbali (South Africa) was forced to be realistic about her tertiary prospects by opting to pursue her education closer to home.

While university fees are significantly subsidised by the German government, the cost of living in Düsseldorf remains substantial despite the diminished fee requirements. All of the interviewees mentioned having part-time jobs to supplement their incomes. This had devastating consequences for Veronica in particular, who said, “Instead of quitting the job, I quit the studies,” because she needed the money. Ultimately, it was her fear of being considered to be a failure in her family that made her persist with the degree. Nehir (Germany) admitted to wanting to leave engineering many times, particularly when facing the workload and academic struggles, but repeatedly told herself she needed to finish, as her parents were still supporting her financially. Julia also signified her own ambitions in pursuing engineering by saying, “I wanted to earn a lot of money.”

3.4 Attitudes to Engineering

Persistence within the degree stemmed from various sources, one of which was determined to be the prestige of the degree and profession. Common across both samples was the notion that being an engineering student carries with it a level of kudos that the participants find desirable.

Another perception of engineering that emerged from the interviews is independence, which Nehir (Germany) alluded to in describing how she and her sisters always wanted to appear “strong because [they] don’t have a brother.” Similarly, Kaya (Germany) aspires to follow in the footsteps of other women engineers, expressing her wish that they had more women lecturers. She stated, “If we had them, that would encourage me more to achieve it, because women identify more with women role models, and men more with male role models, so I think that would make things way easier.”

3.5 Engineering Prejudices

Supplementary to challenges associated with gender, there are other ethnic, racial, economic, and religious women groups that experienced additional barriers and discrimination in engineering. Yusra (South Africa) acknowledged the reality of being a woman in engineering, stating, “If I were to have a family, I wouldn’t want to be someone that like has to split their time 50/50. […] If you’re working in corporate, it’s cut-throat and if someone can be there most of the time, they would rather have that over someone that’s there some of the time.” Mbali (South Africa) agreed with this sentiment, saying, “I have realised that, for women, it is a bit impossible to maintain a career, kids, and a husband. One of them is likely suffering somewhere; you can’t have it all.” It was interesting to note that interviewees from the German sample made little to no reference of such concerns.

None of the participants in the German sample reported any substantial and overt instances of gender discrimination in the engineering classroom. Three interviewees, however, mentioned the existence of religiously and sexually discriminatory messages sent to a social media group consisting of engineers that created discomfort among their cohort and ultimately drew the attention of the head of the faculty. Claudia did note an instance where, as part of a group invitation, she attended a small get together of engineers and, upon arrival, was asked, ‘Ah, a girl; to who of them do you belong?’ She found the implication she could not attend on her own merit extremely offensive. In contrast, the narratives helped the researchers to see that the South African sample had differing experiences in this regard. Nearly all interviewees reported situations that they felt undermined by their peers, particularly when involved in group work. Mbali, Zahra, Yusra, and Amira all made mention of an idea or solution they initially presented being taken into consideration only when repeated by another male student. Amira also found that her contribution and point of view held less value than those of a man.

4 DISCUSSION AND CONCLUSION

This paper presents preliminary findings from a first-pass thematic analysis and forms part of a doctoral research project in which they will be expanded upon. It clearly indicates that using narratives from a selection of young women students from two international contexts proved to be a feasible method to document women students’ stories. Understanding the interplay between socio-structural factors and individual identity is important in informing possible leverage points and interventions to support the retention of women and improve inclusivity in the male-dominated field of engineering. Its use provides a means to understand each participant’s story as a whole, as provided in their own words, thereby adding nuance and meaning to their own experiences as students in engineering. Through the interviews, participants were given space to speak of their lived experiences in engineering, offering insight into the external and internal processes of navigating identity. From the literature, participation in what is viewed as a masculine profession can impact students’ identities, with both men and women associating expressions of their gender identity closely with their fields of study (Walker 2001). As such, the collected narratives were vehicles not only for describing long-range accounts, but also for analysing how social structures contribute to the manner in which participants negotiate their expressions of identity. Drawing back to the two strands of identity referred to in the theory, coupled with Maxwell’s (2013) guided design, the narratives were able to provide context behind participants’ behavioural decisions in social situations.

The narratives also provided insights on the human dimension of student experiences. In addition, it offered rich material as a qualitative analysis tool in exploring the influence of social structures on the identities of women students in engineering, as evidenced by the findings. It was clear that their families, religions and core values played a role in their processes for negotiating their identities. Exposure to engineering principles within their education systems and access to engineering as an option, despite its fee constraints particularly in South Africa, also have significant value. In pursuing engineering, women are already choosing a different path, as they are faced with gender, ethnic, racial, economic, and religious prejudices that can challenge the representation of their identities. The value of these findings exists in its potential contribution towards positively influencing women’s experiences and positions at all levels of engineering, as well as providing useful insight towards advancing the levels of diversity, equality and inclusion in engineering education.

REFERENCES

Axelson, E. 2024. “Cape Town.” Encyclopedia Britannica. 2024. https://www.britannica.com/place/Cape-Town.

Britannica, T. Editors of Encyclopaedia. 2024. “Düsseldorf.” Encyclopedia Britannica. 2024.

Düsseldorf, Landehauptstadt. 2021. “Office for Statistics and Elections.” Landehauptstadt Düsseldorf. 2021. https://www.duesseldorf.de/statistik-und-wahlen/statistik-und-stadtforschung/statistics.

Fearon, James D. 1999. “What Is Identity (As We Now Use the Word)?” Stanford University.

Gee, James Paul. 2000. “Identity as an Analytic Lens for Research in Education.” In *Review of Research in Education*, 25:99–125. https://doi.org/10.3102/0091732x025001099.

Hill, Catherine., Christianne. Corbett, Andresse. St. Rose, and American Association of University Women. 2010. “Why so Few? Women in Science, Technology, Engineering, and Mathematics.” AAUW.

Kim, J.H. 2016. *Understanding Narrative Inquiry: The Crafting and Analysis of Stories as Research*. SAGE Publications, Inc.

Longe, Omowunmi Mary, Oladunni Bimpe Imoukhuede, Adebukola Adebusayo Obolo, and Khmaies Ouahada. 2019. “A Survey on the Experiences of Women in Engineering: An Institutional Study.” *IEEE AFRICON Conference* 2019-Septe (September). https://doi.org/10.1109/AFRICON46755.2019.9133875.

Maxwell, Joseph. A. 2013. *Qualitative Research Design: An Interactive Approach*. 3rd ed. SAGE Publications, Inc.

Moen, Torill. 2006. “Reflections on the Narrative Research Approach.” *International Journal of Qualitative Methods* 5 (4): 56–69.

Polkinghorne, Donald E. 1995. “Narrative Configuration in Qualitative Analysis.” *International Journal of Qualitative Studies in Education* 8 (1): 5–23. https://doi.org/10.1080/0951839950080103.

Review, World Population. 2024. “Cape Town Population 2024.” 2024.

Stryker, Sheldon., and Peter J. Burke. 2000. “The Past, Present, and Future of an Identity Theory.” *Social Psychology Quaterly* 63 (4): 284–97.

Times, Financial. 2019. “DÜSSELDORF AT THE HEART OF EUROPE.” 2019. https://www.locate-dus.com/overview.html.

Walker, Melanie. 2001. “Engineering Identities.” *British Journal of Sociology of Education* 22 (1): 75–89. https://doi.org/10.1080/01425690020030792.

INTERVENTION IN ENGINEERING STUDENTS' MATHS EDUCATION TO OVERCOME THE AFTERMATH OF DISTANCE LEARNING

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ABSTRACT

During the pandemic, many people in secondary school failed to acquire solid and profound knowledge. Teaching maths in remote education with distance learning has been a challenge for both teachers and students. In engineering higher education, several years after the pandemic, we are seeing problems that are having an impact on the overall education not only in the basic subjects but in further engineering subjects. There is a need for an intervention programme that can be applied effectively in large-scale courses where the number of students exceeds 100. Recently, we have created supplementary courses to help students learn the advanced Calculus material more effectively, while ensuring that they can catch up with their secondary school knowledge at their own pace.

This research aims to analyse the changes in student performance of first-year student during the first two semesters of university math courses (Calculus 1 and 2). In our research, we investigated three different groups of students: the “2018 group” studied math traditionally, while the “2020 group” took online education at the end of high school and at the beginning of their university studies. Finally, the “2022 group” spent two years in high school at home in distance learning but started in-person education at the university and had significant problems during the first semester. Therefore, those students participated in an intervention programme. The performance analysis after Calculus 2 shows that we have succeeded in developing an inclusive pedagogical programme that we intend to further develop in the future to reduce drop-out.

1 INTRODUCTION

The effects of the pandemic were immediately felt in higher technical education. Courses with more practical elements during online education had to be significantly transformed. Laboratory exercises could not be held, so students did not gain hands-on experience. During online education, these exercises were almost completely eliminated, which caused serious difficulties for students. After the end of the quarantine, our university offered students the opportunity to make up missed measurements in certain subjects during the summer, but these blocked classes were less effective. This was also confirmed by several recent studies several studies have been published, and it is widely accepted that lock-down cause significant losses in education, (Kuhfeld and Tarasawa 2020), (Kuhfeld et al. 2020), (Kaffenberger 2021).

Another consequence of the sudden closures was that, on more than one occasion, incomplete, quickly put-together teaching materials were produced, which did not really serve independent distance learning. Many had difficulty in preparing themselves from these materials. There were also students and teachers who did not have adequate technical infrastructure, which also hindered effective learning and teaching.

In addition to the short-term effects of the pandemic, we are also facing very serious long-term effects. It is clear from the results of the usual input measures for first-year students that they are experiencing difficulties that cannot be remedied in a short period of time. We need to use intervention procedures that effectively support students' learning processes and thereby improve educational outcomes. The book, edited by Kelum A.A. Gamage, reviews and synthesizes the findings of the international literature on the impact of COVID-19 on global higher education (Gamage, 2022). In the book containing 18 publications edited by Arday, research and data from 16 countries and 5 continents explore the far-reaching impact of Covid-19 on global higher education (Arday, 2022). While, Katsamunska analyses the reaction of the government and higher education stakeholders to the measures implemented in Bulgaria (Katsamunska, 2023).

Programmes providing targeted assistance need to be those that can be delivered to large student populations. Providing online learning resources is such, but they cannot replace face-to-face teacher-student interaction. Intelligent interactive learning interfaces are particularly useful when they personalise learning material and tasks according to the progress of the students. Providing opportunities for group learning and pair learning is also effective. In 2022, we have designed a new intervention programme for our first-year students to help them better adapt to the academic environment, improve their academic performance, and successfully navigate the educational challenges.

1.1 Motivation and goals

This research project is the continuation of our previous research that was presented in the SEFI conferences in 2022 and 2023 (Sipos, 2022), (Berezvai, 2023). In these studies, we analysed the changes in the learning habits and performance of three groups of students: a pre-Covid, a Covid and a post-Covid groups, respectively. It was concluded that in the post-Covid group a significant change was observed in the online learning habits, namely that students spent more time on online learning, but a significant increase in poor results is clearly detectable. Calculus is the most important undergraduate mathematics course in all engineering programmes in Hungary, which aims to ensure the required mathematical foundation for the further engineering subjects. It should be noted that Calculus is typically is taught over 3-4 semesters and includes the topics of algebra, linear algebra and differential equations (see Table 1). Therefore, we found it essential to give a response for the decreasing student performances in Calculus 1 course in order to avoid the drop-out for the Calculus 2 course. The main goal of this contribution is to present the intervention that was applied in the "2022 group" during the Calculus 2 course and to analyse its effect on the performance of students.

Table 1. Curriculum of Calculus 1 and 2 courses

	Calculus 1	**Calculus 2**
Topics	Complex numbers Spatial geometry Numerical series Functions Differentiation Integral calculus	Linear algebra Function series Multivariable functions Multivariable calculus

2 DATA

In this study, three different classes of the mechatronics and energy engineering courses were investigated. The number of groups and the results of the admission and entrance tests are summarised in Table 2 and Fig. 1.

Table 2. Participants of the investigated courses

		2018	**2020**	**2022**
Number of students		120	134	173
Average entrance points		458.62	445.96	454.71
Standard deviation of entrance point		23.22	30.20	26.78
Test 0	Mean and standard deviation	39.38±10.71	46.02±8.84	36.14±12.04
	Percentage of Passed	88%	97%	81.5%
	Percentage of Failed	12%	3%	18.5%

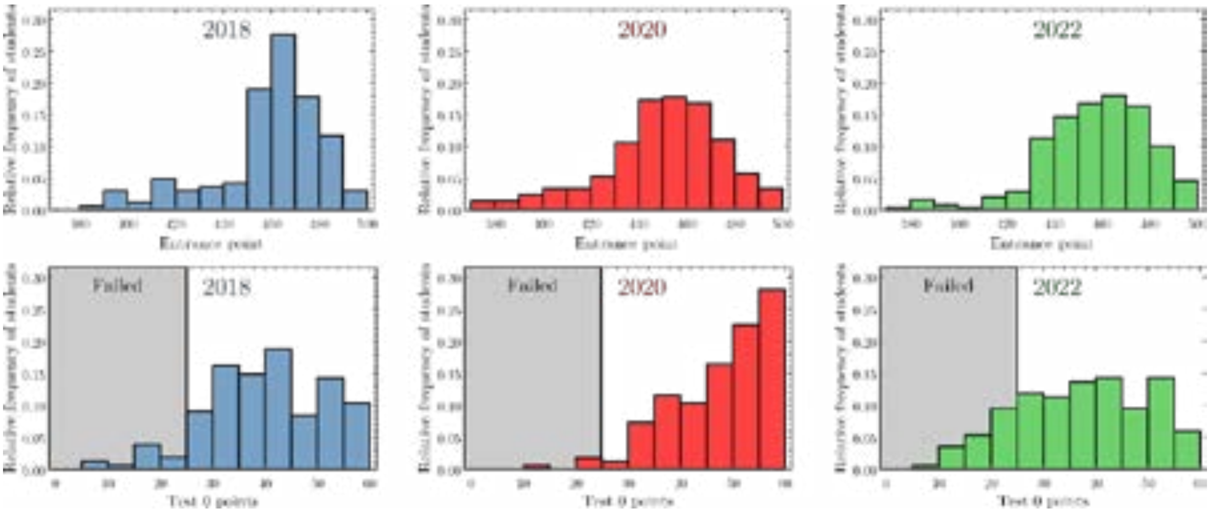

Fig. 1. Relative frequency of a) entrance points (out of 500) and b) entrance test (Test 0) results (out of 60) or all classes 2018, 2020 and 2022 (Berezvai, 2023)

a. The investigated groups

In our research three different classes were analysed: the "2018 group" studied math traditionally, while the "2020 group" took online education at the end of high school and at the beginning of their university studies. Finally, the "2022 group" spent two years in high school at home in distance learning but started in-person education at the university and had significant problems during the first semester.

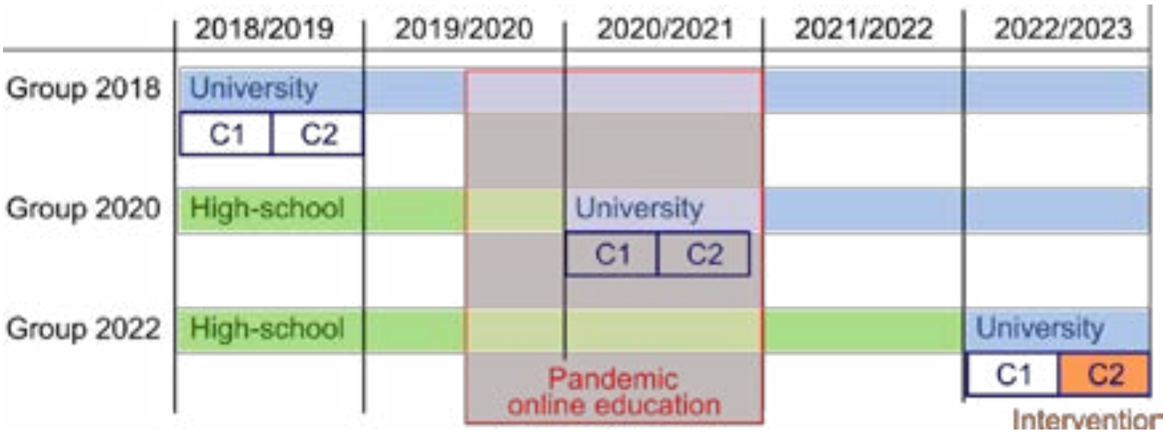

Fig. 2. The temporal distribution of the three groups and the pandemic. (C1 – Calculus 1 course, C2 – Calculus 2 course)

- **The "2018 group" – pre-Covid**

The class of 2018 consists of 120 students with an average admission score of 458.62 points and a standard deviation of 23.22 points. Since nearly all students studied mathematics at an advanced level in high school and furthermore, many of them took advanced A-levels, thus they had no problem in meeting the 40% minimum on the entrance test (Test 0). Only 12 students failed to achieve the required 25 points.

- **The "2020 group" – Covid**

The class of 2020 consists of 134 students with an average admission score of 445.96 points and a standard deviation of 30.20 points. This class received online education from March to May in their final year of high school, and this continued in their first year of university in remote education. Therefore, the pandemic had very minor effect on their high-school backgrounds.

This year, students took the mathematics entrance test (Test 0) online in their homes using the Moodle system of the University. The results were unlikely too good. More than 50% of students got excellent results (above 85%). Only 4 students scored below 40%, one of whom achieved 100% on the make-up test, also online. The results of this assessment cannot be considered relevant to our study.

- **The "2022 group" – post-Covid**

The class of 2022 consists of 173 students with an average admission score of 454.71 points and a standard deviation of 26.78 points. They started university in 2022 in attendance education and received online education in the last two years of high school. These two years are when Hungarian students can choose the two subjects that are relevant for their further studies and study them in higher contact hours in advanced level.

In 2022, the entrance maths test (Test 0) was very poor. Out of 173 students, 32 students failed to score at least 25 points on the in-person test. For this group, the Calculus 1 results (see Fig. 3.) showed significant decline, so for the Calculus 2 course an intervention was applied.

3 METHODOLOGY

The failure of a significant proportion of our students to acquire a solid grounding in mathematics during the pandemic in public education was already apparent from the results of the input measures. This was confirmed by both midterm tests written in the first semester (see Fig. 3) and then by the exam results. The failure rate in Calculus 1 test was significantly higher than in previous years, while expectations of students remained unchanged, with a slight decrease. At the same time, the system of university examinations allows you to retake the midterm-tests more than once. In addition, Calculus 2 can be taken by students who have passed all their midterm tests with at least 40% marks, without the need to pass the exam in the exam period.

Since 2016, the Edubase online learning platform serves the basis of our education (www.edubase.net 2024), (Szilagyi, 2020), (Berezvai, 2019). In EduBase students are assigned weekly homework, interactive exercises and also have the option to engage in additional exercises. With parameterized exercises, there is a technically infinite number of exercises available for practising the different topics throughout the semesters.

Despite the availability of much material to help students catch up individually, including the interactive online practice areas with step-by-step guides, students found it difficult to cope. Catching up and keeping up with current material at the same time proved to be too much of a burden. Where individual difficulties varied, it was practical to use online material supplemented by personal consultations, as there was no way to involve more teachers.

The key solution of the intervention was to reinforce the learning, the understanding and mastering of new (previously unfamiliar) topics. For this, a 90-minute extra course per week was scheduled and offered parallel to the regular Calculus 2 course, which was called as Calculus2+. The Calculus 1 and 2 courses consists of 2x90 minutes of lectures a week and a 90-minute-long practical lesson of problem-solving.

For the Calculus2+ course, we have developed a material that helps to illustrate the theory taught in the lecture through example solutions. In these classes, all students of the class participated together, the lecturer showed examples related to the weekly curriculum and explained the methodology of problem solving. Thus, the students arrived at the problem-solving practical lessons much better prepared, with more opportunity to work independently or in pairs. Group work and pair work help to increase learning efficiency, help students overcome anxiety, motivate them to talk, increase their confidence and develop their social skills. Students can discuss ideas, share knowledge and learn from each other. This can lead to a deeper understanding of the subject matter (McDowel, 2003) (Williams, 2000).

Previously, we had to use face-to-face, frontal teaching on these occasions, because the large amount of material only allowed the instructor to present the basic types of problems that were to be solved each week. The students were then rather passive participants in the lessons. With the new extra Calculus2+ lessons, the additional 90 minutes served as a slower-paced presentation of the similar problems.

4 RESULTS

In the following the statistical summary of the Test results are presented for Calculus 1 and Calculus 2 courses for the three investigated classes (see Table 3. and Fig. 3). The number of students in each course shows that, although there is a high failure rate on the first attempts, only a small number of students dropped out and failed to continue in Calculus 2 due to the many remediation opportunities. Thus, improvement in results is attributed to the outcome of the intervention, not the filtering in Calculus 1.

In Figure 3, the first two rows show the results of the first and second tests in Calculus 1, while the last two rows show the results of the first and second tests in Calculus 2. The results clearly show, that after the well-observable decline of performance in 2022 for Calculus 1 course, a significant improvement of results were detected as result of the intervention. This not only means that the mean value of the tests are improved, but also the standard deviation decreased compared to the Calculus 1 results. This means that the extra Calculus2+ course also had beneficial effects on the heterogeneity of the group.

Table 3. Statistics of the Calculus 1 and Calculus 2 results for all investigated classes

			2018	**2020**	**2022**
Calculus 1	Number of students		120	181	191
	Test 1	Average and SD	64.14 ± 14.17	47.08 ± 17.29	41.89 ± 24.15
		Failed	4.16%	30.93%	40.31%

		Good result	30%	11.04%	10.47%
	Test 2	Average and SD	61.61±17.43	55.02±18.56	25.07±21.03
		Failed	5.83%	13.25%	69.10%
		Good result	21.66%	23.21%	2.09%
Calculus 2	Number of students		112	161	161
	Test 1	Average and SD	59.76±16.72	58.22±15.61	65.27±16.38
		Failed	12.5%	15.61%	9.31%
		Good result	21.42%	23.61%	41.61%
	Test 2	Average and SD	69.68±19.08	45.04±15.33	65.33±20.24
		Failed	4.46%	31.67%	8.69%
		Good result	48.21%	3.1%	47.82%

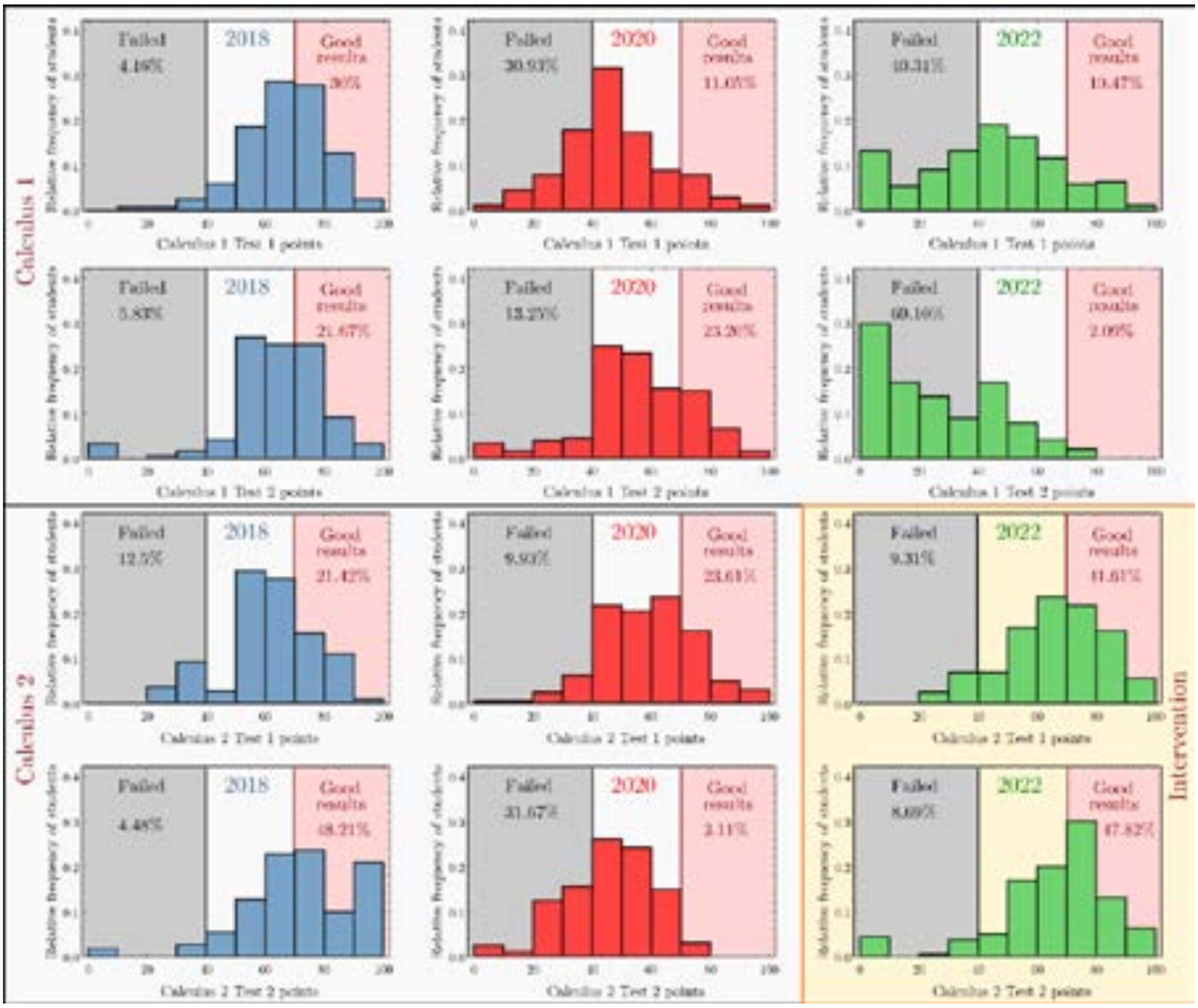

Fig. 3. Relative frequency of Test 1 and 2 in the Calculus 1 and 2 subjects.

5 CONCLUSION

The results illustrate the effectiveness of our intervention programme. It is natural that by increasing the time spent on lectures and learning, our students will achieve better results. However, what makes our results worth mentioning is to show that such a simple intervention can make a difference. Nowadays, frontal teaching is almost a buzzword, even though in many higher education institutions there is no way to provide assistance in small courses, there are not enough instructors and facilities to provide additional small classes. In a university where there are thousands of students per year to be taught effectively, economic issues become an important aspect to be considered. A good combination of large numbers of students and small numbers of students with the opportunity for greater interactivity can provide an economically optimal solution.

Our experience also highlights the importance of the role of the teacher in education. Mathematics is not easy to learn independently, especially for those who have difficulties. The importance of teacher competence may sound trivial, but it was the pandemic that showed that when students were not allowed to go to school, teachers could not help as much, despite the online learning platforms and available digital sources. We can say that students must first be prepared to be able to learn independently. The programme we have developed helps them to do that.

By increasing the number of contact hours, students were able to make more effective use of the interactive, online practice materials, and therefore achieved better results. This form of support was more effective than if we had given our students more material to work on independently.

In the future, we see it as an important task to show students the benefits of increased contact hours at the beginning of their programmes. In the future we aim to extend this method by proposing an extra course immediately after the entrance test based on their measured knowledge, and therefore trying to reduce the trauma of initial failure.*

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REFERENCES

Arday, J., 2022. “Covid-19 and higher education: The times they are a’changin”. *Educational Review*, 74(3), 365-377, https://doi.org/10.1080/00131911.2022.2076462

Berezvai, Sz., Köpeczi-Bócz, Á., Sipos, B. and Szilágyi, B., 2023. “Changes in first-year engineering student’s learning performance in mathematics and engineering subjects at different staged of distance learning”, In: *Proceedings of the 51st Annual Conference of the European Society for Engineering Education, SEFI 2023*, 183-191, https://doi.org/10.21427/CDZ5-E329

Berezvai, Sz., Palya, Zs., Hives, A., Horvath, D. and Szilágyi, B., 2019. “Innovative monitoring of study time and performance and its efficiency in first-semester Calculus course for engineers”, In: Varietas delectat... Complexity is the new normality: Proceedings SEFI 2019, SEFI 47th Annual Conference, Budapest, 16-20 September, 720-728.

Gamage, K. A., 2022. “COVID-2019 Impacts on Education Systems and Future of Higher Education”. MDPI.

Kaffenberger, M. 2021. “Modelling the long-run learning impact of the Covid-19 learning shock: Actions to (more than) mitigate loss”. *International Journal of Educational Development*, 81, 102326. https://doi.org/10.1016/j.ijedudev.2020.102326

Katsamunska, P., 2023. “The Covid-19 Pandemic and the New Age of Higher Education: the Experience of Bulgaria”. Economic Alternatives, 1, 169-177.

Kuhfeld, M., Soland, J., Tarasawa, B., Johnson, A., Ruzek, E. and Liu, J. 2020. “Projecting the Potential Impacts of COVID-19 School Closures on Academic Achievement”. *Educational Researcher* 49,8: 549–565. https://doi.org/10.3102/0013189X20965918

Kuhfeld, M., Tarasawa, B., 2020. “The COVID-19 Slide: What Summer Learning Loss Can Tell Us About the Potential Impact of School Closures on Student Academic Achievement”. *NWEA White Paper*. (last downloaded: 2024.04.07.)

McDowell, C., Werner, L., Bullock, H. E., Fernald, J, 2003. The impact of pair programming on student performance, perception and persistence. In: *25th International Conference on Software Engineering*, 602-607, IEEE.

Sipos, B., Berezvai, Sz. and Szilágyi, B., 2022. “Changes in learning strategy and learning time in the wake of the pandemic”, In: *SEFI 2022 50th Annual Conference of The European Society for Engineering Education Proceedings: Towards a new future in engineering education, new scenarios that European alliances of tech universities open up*, Barcelona, Universitat Politécnica de Catalunya: 720-728.

Szilágyi, B., Berezvai, Sz. and Horváth, D. 2020, “Innovative Monitoring of Learning Habits and Motivation in Undergraduate Mathematics Education”. *ERCIM NEWS*, 120: 35-36.

Williams, L. A., Kessler, R. R., 2000. “The effects of" pair-pressure" and" pair-learning" on software engineering education”. In: *Thirteenth conference on software engineering education and training,* 59-65. IEEE.

A CRITICAL DISCUSSION OF ACTIVE LEARNING IS NEEDED

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Keywords: *Active learning, ICAP-framework, Interaction analysis, Lab-work, Object of learning*

ABSTRACT

Active learning is commonly defined as an instructional approach that actively engages students in the learning process, aiming to foster improved and deeper comprehension. However, a previous study comparing mechanics labs offered students a choice between probe-ware (MBL) labs [FMCE normalised gain: 48%] and experimental problem-solving labs [18% gain]. Although both options were considered to employ active learning, the substantial difference in gains was noteworthy and contradicted existing literature conclusions. Consequently, a follow-up study was conducted. Analysis of video recordings from the labs revealed that students in the problem-solving labs exhibited interactive learning characteristics according to the ICAP framework, but made limited use of physical concepts in their modeling of phenomena. Nonetheless, they successfully achieved the intended goals of developing skills in experiment planning and mathematical modeling of physical systems in the experimental problem-solving labs. This study suggests the necessity to move beyond surface interpretations of "active learning" and delve into the specific ways in which students are actively engaged in a learning environment. Furthermore, it highlights the importance of a critical and thorough discussion of active learning methodologies.

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1 INTRODUCTION

Active learning is commonly defined as an educational approach that involves students actively participating in the learning process, with the aim of achieving enhanced comprehension and retention. However, an earlier investigation (Bernhard 2010, 2011) highlighted an intriguing inconsistency: despite a laboratory course being ostensibly structured around active learning principles, students involved in it performed poorly on assessments measuring their grasp of mechanics concepts. This discrepancy prompted a deeper exploration into students' learning behaviors and activities within the laboratory setting. To gain insight, video-recordings and interaction analyses were conducted. This paper presents some of the key findings derived from this study.

The paper is organised as follows: Section 2 describes the background and theoretical framework of the study, i.e. active learning and variation theory, as well as providing a brief review of the results from the earlier quantitative study, and the research question; Section 3 presents briefly the qualitative methodology used; Section 4 presents the findings of the current study; finally, Section 5 presents an analysis, discussion and conclusion.

2 BACKGROUND

2.1 Active learning

Active learning is commonly believed to foster profound comprehension, deeper engagement with fundamental concepts, and enhanced ability to apply knowledge in novel contexts (e.g., Crawley et al. 2014; Freeman et al. 2014; Prince 2004). Hence, active learning, as a pedagogical approach have garnered significant scholarly focus, is notably recognized as one of the CDIO standards (Crawley et al. 2014) and has been extensively examined in special issues of the European Journal of Engineering Education (De Graaff and Christensen 2004; Lima, Andersson, and Saalman 2017)

However, Despite the widespread interest in active learning, its definition often remains nebulous. Surprisingly, numerous studies fail to provide a clear definition, instead relying on an intuitive, albeit somewhat unsatisfactory, understanding of the concept. The most prevalent definition, drawn from the seminal work of Bonwell and Eison (1991, iii), is: “instructional activities involving students in doing things and thinking about what they are doing”. Similarly, Prince (2004) proposes that “active learning requires students to do meaningful learning activities and think about what they are doing”. It's noteworthy that Freeman et al. (2014), in their meta-analysis, specifically focused only on in-class activities while excluding laboratory exercises. Conversely, Trumper (2003) concentrates on laboratory settings and asserts that successful activities are characterized by “that they are learner-centered. They induce students to become active participants in a scientific process in which they explore the physical world, analyze the data [and] draw conclusions”.

Chi (2009) presents a more precise definition and a more nuanced understanding through the Interactive-Constructive-Active-Passive (ICAP) framework, which categorizes overt learning activities into passive, active, constructive, and interactive domains. Active activities entail physical engagement, while constructive activities involve producing output that extends beyond provided materials. Interactive activities involve collaboration between two or more students, fostering substantive dialogue that incorporates and builds upon each other's contributions. Drawing from literature, Chi suggests that student learning is more effective in interactive activities compared to constructive ones, which are superior to merely active activities, and these, in turn, surpass simple passive learning approaches. In the context of engineering, Menekse et al. (2013) claim to have confirmed Chi's hypothesis for students in a material science course. Moreover, Chi and Boucher (2023, 94) recently argued that evidence demonstrate ICAP-framework "provide [a] heuristics that can help [teachers] differentiate and distinguish between different types of active learning activities in terms of their *effectiveness for improving learning*" (my italics).

2.2 Object of learning

While the object of learning is not foregrounded in the ICAP-framework it is important in Marton's variation theory. Marton (2015, 27, my italics) related learning to what students could *possibly* experience in a particular classroom situation, stating that in a learning situation "the critical aspects that it is *possible* [for a student] to discern … make up the *enacted* object of learning" (cf. Marton, Runesson, and Tsui 2004). Another important distinction in a learning situation is the difference between the *intended* object of learning (the knowledge, values, and skills the teacher or curriculum designer wants the students to learn) and the *lived* object of learning (the critical aspects that *could be discerned* and that the student *actually discerns*, i.e. what the student learns in the end).

2.3 Two supposedly active learning labs

In a previous study conducted by Bernhard (2010, 2011), significant variations in learning outcomes were observed among students enrolled in two distinct laboratory options within the *same* mechanics course. A brief summary of these findings is provided in this section. Engineering students, as part of an introductory physics curriculum, were given the choice between two lab-course options. The conventional labs, known as experimental problem-solving (EPS) labs, were offered as the standard choice. Alternatively, students could opt for labs employing probe-ware technology. Participation in the probe-ware labs was voluntary. Due to legal constraints, students couldn't be randomly assigned to groups, as the EPS labs were designated as the official lab-course according to curriculum documents.

The general organization of the course is outlined in Table 1. All students attended the same 20-hour mechanics lectures and engaged in comparable 12-hour problem-solving sessions with groups of approximately 30 students, facilitated by a doctoral student. The sole difference between the options is the lab-sections that comprised four 4-hour lab sessions, totaling 16 hours of lab work in both groups.

To assess students' comprehension of mechanics in the previous study (Bernhard 2010, 2011), a Swedish version of the Force and Motion Conceptual Evaluation (FMCE) (Thornton and Sokoloff 1998) was administered as both a pre-test and a post-test. The FMCE is a widely utilized and established tool designed to explore students' understanding of one-dimensional kinematics and dynamics through verbal and graphical representations. Table 1 also provides the average scores for both pre- and post-tests, along with the normalized gain and effect size. Normalized gain (Hake 1997) is calculated as g = Actual gain/[Maximum possible gain], where the actual gain represents the disparity between group averages in the pre- and post-tests.

Pre-course conceptual understanding of mechanics, as depicted in Table 1, showed minimal and statistically insignificant differences (t = 0.58, p = 0.36) between the groups and no other overt differences were observed. While the disparities in pre-test scores were negligible, the discrepancies in post-test outcomes are noteworthy. Students engaged in probe-ware labs exhibited a substantial normalized gain of 48%, contrasting sharply with the 18% gain observed in students attending EPS labs – a figure akin to that achieved by traditional labs (Hake 1997). This difference is statistically significant (t = 2.93, p = 0.0003).

Table 1. Organization of the mechanics part of the physics course, and results from the pre- and post-tests using the FMCE (means with standard deviations in parentheses), normalized gains, and calculated effect size from the results in the earlier study (Bernhard 2010).

<table>
<tr><th>Group</th><th>No.</th><th>Lec-tures</th><th>Problem-solving sessions</th><th>EPS-labs (groups of 2–3 students)</th><th>Probe-ware labs (groups of 2–4 students)</th><th>Pre-test %</th><th>Post-test %</th><th>Norm Gain %</th></tr>
<tr><td>EPS-labs</td><td>86</td><td rowspan="2">20 h (all)</td><td rowspan="2">12 h (groups of approx. 30 students)</td><td>16 h (2×[4+4 h])</td><td></td><td>29.3 (16.4)</td><td>42.3 (22.9)</td><td>18.4</td></tr>
<tr><td>Probe-ware labs</td><td>25</td><td></td><td>16 h (4×4 h)</td><td>34.3 (23.1)</td><td>65.8 (21.8)</td><td>47.9</td></tr>
</table>

2.4 Research question

The good conceptual gains for the probe-ware labs in the previous study were somewhat expected as they were a sub-set of previously implemented “conceptual labs” designed to enhance students’ conceptual understanding of mechanics (Bernhard 2010). However, the EPS-labs were supposedly using a form of “active learning” and despite this did not achieve good results on the Force and Motion Conceptual Evaluation (FMCE) (Thornton and Sokoloff 1998). This, seemingly, contradicts the findings in the literature that “active learning” works and would improve learning.

This led to the following research questions:

- How did the students act and interact in the learning environment of the EPS-labs and how did they approach the object of learning?
- Would a closer investigation of students’ interactions confirm or reject the hypothesis that the EPS-labs could be seen as examples of active learning, and how would the labs be classified according to the ICAP framework (Chi 2009)?
- Could students’ achievements on FMCE-test be understood from students’ observed interactions in the EPS-labs?

It was hoped that answers to these three main questions would provide the basis for additional insights into learning in labs and the general concept of active learning.

3 METHODOLOGY

The analysis of learning within the EPS-labs unfolded through several stages. As detailed in section 2.3, students' conceptual understanding was assessed in a previous study via pre- and post-tests employing the FMCE test (Thornton and Sokoloff 1998). The findings of this assessment are elaborated upon in Bernhard

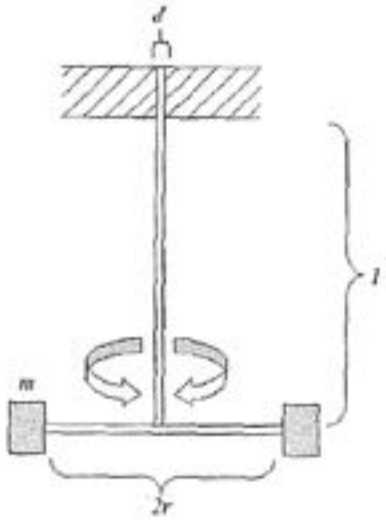
(2010, 2011) and succinctly outlined in Table 1. Moreover, students' activities during certain sessions of the EPS-labs were captured using digital camcorders, yielding 16 hours of video footage. Subsequently, this data was utilized to identify typical interactional patterns and discern evidence supporting or challenging hypotheses concerning the universality of these patterns (Jordan and Henderson 1995) The focus was particularly on observing students' collaborative work dynamics, their actions, relevance, and orientation towards the learning objectives, while also aligning with the ICAP-framework (Chi 2009) for pattern description. After repeated review, select episodes containing noteworthy and comparable activities relevant to the research inquiries emerged. These segments were transcribed to facilitate a meticulous examination of interactional patterns. The transcriptions adhere to the standard conventions of conversation analysis (ten Have 2007), and those included in this paper were ultimately translated from Swedish to English for accessibility.

The study was conducted under the ethical guidelines in place at Linköping University in accordance with Swedish laws. Informed consent forms were signed by each research participant. In this paper, participants have been given pseudonyms to protect their anonymity.

4 RESULTS

Analysis of the video recordings showed that the students’ actions were framed by the task at hand and encounters with the instructions, the technology and experimental setup, the teacher, and other students. Thus, in terms of Chi’s (2009) ICAP framework students’ activities in both sets of labs could be seen as interactive, which further implies that they were also active and constructive. In addition to this, the criteria for active learning proposed by Bonwell and Eison (1991) as well as by Prince (2004) were fulfilled. Yet although the labs fulfilled most of the theoretical criteria to qualify as active learning environments, the way that the students actually worked on their tasks was much more complex and differentiated than might at first be assumed. Some of these complexities will be explored below.

The aim of an EPS-lab is to “highlight what is essential for creating good physics; imagination and initiative to develop hypotheses, use of experimental techniques to test hypotheses, and the ability to find concepts that provide simple descriptions” (course description, author’s translation). The EPS-labs were designed after a proposal by Richards (1971)



a.

$$T = C_1 \frac{1}{d^2}\sqrt{\frac{l(mr^2 + C_2)}{G}}, \text{ where}$$

T = period time,
C_1 = experimental constant,
C_2 = experimental constant (moment of inertia of the rod),
G = shear modulus,
d = diameter of the wire,
l = length of the wire,
m = mass of the additional weights, and
r = distance of the masses from center.

b.

Fig. 1. a) The torsion pendulum setup (drawing from student lab report). b) A mathematical model for the oscillations of this torsion pendulum.

One of the EPS-labs, exemplified by the torsion pendulum lab illustrated in Figure 1a, serves as a prime example. Alongside the torsion pendulum experiment, five additional EPS-labs were conducted, including tasks such as analyzing a sinking boat and observing an oscillating beam. Students collaborated in small groups of 2–3 individuals, tasked with completing two out of the six available labs, each lab session spanning eight hours (4 + 4 hours). Due to space constraints in this paper, the focus will solely be on analyzing and discussing the students' activities within this lab setting. In this specific lab, students were instructed to identify the pertinent physical parameters influencing the oscillation period of the torsion pendulum. They were further tasked with constructing and experimentally validating a mathematical model for predicting the oscillation period, with no additional guidelines provided.

The students had access to two lab sessions, each spanning four hours, with one week between the sessions. In tackling the task of devising a suitable mathematical model, students were encouraged to employ a combination of empirical measurements of the physical system and dimensional analysis.

Fig. 2. Photograph taken during the torsion pendulum lab, depicting students observing the oscillations of the pendulum and measuring its period.

In the initial stages of the EPS-labs, discussions primarily revolved around determining the significance of variables, planning experiments, and devising measurement techniques. Excerpt 1 (Due to space constraints, only one excerpt from the transcripts is provided) exemplifies a conversation between Adam and Bengt, occurring approximately 45 minutes into the first session of the first lab, regarding the measurement of the period time for the torsion pendulum.

Excerpt 1

1.	Bengt	thus we measure (.) we start here
2.	Adam	yes
3.	Bengt	it goes out one time ((swings the rod with masses by holding it in his hand a full period))
4.		(2 s) ((Bengt swings the rod a full period a second time))
5.	Bengt	two
6.		(2 s) ((Bengt swings the rod a full period a third time))
7.	Bengt	three
8.		(2 s) ((Bengt swings the rod a full period a fourth time))
9.	Bengt	four
10.		(2 s) ((Bengt swings the rod a full period a fifth time))
11.	Bengt	five
12.	Bengt	if we should take (.) if we say before it slows down markedly (.) if we take like three swings or something (.) two swings (.) we can do it a few times and take an average

From this excerpt, it may appear as if the conversation lacked interactivity, with Adam seemingly passive, as evidenced by his single-word contribution, "yes." However, approximately half a minute later, Adam takes a more active role by suggesting a method for measuring time, proposing that they record the time whenever the pendulum halts at its maximum excursion. Following some deliberation, they ultimately adopt Adam's suggestion. However, they encounter difficulty implementing this method due to limitations with the available stopwatch. Instead of abandoning their approach, Bengt recalls that his old mobile phone has a feature capable of recording multiple times. Subsequently, they acquire a similar phone from another student in a different lab group, enabling them to proceed with their chosen method.

In their first series of measurements the position r of the masses on the rod was varied with other variables constant. In the second series the length l of the wire was varied with other variables constant. In the third series the diameter of the wire vas varied. In their initial series of measurements, the position r of the masses on the rod was altered while keeping other variables constant. In the subsequent series, the length l of the wire was varied under constant conditions. Finally, in the third series, the diameter of the wire was varied while other variables remained unchanged.

Much of the second session was dedicated to analyzing the data collected during the first session and experimenting with various hypotheses to develop a model for the period time of the torsion pendulum. Adam expressed concerns regarding kinetic energy and sought to incorporate it into the relationship, but struggled to discern how to do so. With a hint from the instructor and the aid of dimension analysis, the students concluded that the shear modulus must be integrated into their model. Towards the conclusion of the second session, the students had formulated the mathematical model depicted in Figure 1b. However, their model overlooked C_2 (representing the moment of inertia of the rod). Even when prompted by the instructor, the students initially failed to recognize that omitting C_2 implied $T = 0$ when no masses were attached to the rod, contradicting observable phenomena. Through Socratic dialogue, the students eventually acknowledged the necessity of including C_2 and finalized the model depicted in Figure 1b. Some groups, where the instructor overlooked this issue during the session, submitted reports with models lacking C_2.

5 ANALYSIS, DISCUSSION AND CONCLUSION

The primary *intended object of learning* in the EPS-labs were aimed at nurturing students' skills in experiment planning and physical system modeling. Conversely, in the probe-ware labs detailed in Table 1, the focus shifted towards fostering students' conceptual understanding. Analysis of the study's data reveals that the EPS-labs effectively achieved their intended goals of experiment planning and mathematical modeling of physical systems. Consequently, students demonstrated *enacted* and *lived object of learning* aligned closely with the *intended object of learning*.

Looking at the students' actions in line with Chi's (2009) ICAP framework, it is apparent that the students in the EPS-labs were steered to construct experiments and mathematical models. The content of students' interactions with each other clearly reflected these differences.

During the laboratory sessions, students exhibited misconceptions regarding fundamental physical concepts. The probe-ware labs were intentionally structured to address and challenge such misconceptions while fostering conceptual under-standing (Bernhard 2010). Conversely, in the EPS-labs, these misconceptions were not explicitly addressed, as indicated by the results in Table 1. Consequently, it appears that students could potentially develop a satisfactory mathematical model of a physical system despite lacking a robust understanding of the underlying concepts. However, upon analyzing the students' performance in the EPS-labs, it becomes evident that deficient conceptual understanding sometimes impeded their modeling process. It suggests that with a more thorough conceptual grasp, students might have formulated a suitable model more efficiently and attained a deeper comprehension.

Variation (Marton 2015) was significant in both the EPS-labs and the probe-ware labs. However, in the probe-ware labs, variation was intentionally integrated into the task structure to facilitate students' comprehension of concepts (Bernhard 2010). Conversely, in the EPS-labs, students themselves introduced variation through their experimental planning, aiding them in identifying pertinent physical parameters. Thus, in both scenarios, variation served to heighten students' awareness of key aspects related to the intended object of learning, aligning with variation theory.

Lastly, it is crucial to underscore the significant role played by the instructors. In both sets of labs it was observed that they assisted students in recognizing and emphasizing important aspects that might have otherwise been overlooked. Moreover, through Socratic dialogues, the instructors scaffolded students' reasoning, facilitating their understanding and learning process.

While the probe-ware labs, as indicated by the data in table 1, exhibited clear superiority in fostering conceptual understanding, it would be erroneous to conclude that these labs were universally superior to the EPS-labs in all aspects. The effectiveness of each type of lab depends greatly on the intended learning objectives. Engineering education should aim to cultivate not only conceptual understanding but also proficiency in experimental planning and mathematical modeling. Thus, when designing lab courses, deliberate decisions must be made regarding the desired outcomes and the activities in which students should engage.

Indeed, Streveler and Menekse (2017) advocate for a more nuanced approach to active learning, urging the engineering education community to precisely articulate the active learning strategies they employ to inform wiser instructional design. Furthermore, Bernstein (2018) contends, in his paper titled "Does active learning work? A good question, but not the right one," that the focus should shift from merely assessing whether active learning works to identifying “which active learning methods, delivered by which teachers, in which contexts, lead to educationally significant, long-term benefits for which students, and are the benefits meaningfully superior to those of traditional teaching methods?” (p. 293).

The conclusions drawn from the case presented in this study align with the perspectives of Streveler and Menekse (2017) and Bernstein (2018), emphasizing the necessity of moving beyond superficial understandings of "active learning." When designing learning environments, it's essential to focus not only on prescribed methods of active learning found in literature but also on how students are genuinely learning and what specific learning objectives they are expected to achieve.

Therefore, as the title of this paper suggests, a critical and nuanced discussion and examination of "active learning" is imperative.

REFERENCES

Bernhard, Jonte. 2010. "Insightful learning in the laboratory: Some experiences from ten years of designing and using conceptual labs." *European Journal of Engineering Education* 35 (3): 271-287. https://doi.org/10.1080/03043791003739759.

Bernhard, Jonte. 2011. "Investigating student learning in two active learning labs: Not all “active” learning laboratories result in conceptual understanding." ASSE Annual Conference, Vancouver, June 26-29.

Bernstein, Douglas A. 2018. "Does active learning work? A good question, but not the right one." *Scholarship of Teaching and Learning in Psychology* 4 (4): 290-307. https://doi.org/10.1037/stl0000124.

Bonwell, Charles C, and James A Eison. 1991. *Active Learning: Creating Excitement in the Classroom. 1991 ASHE-ERIC Higher Education Reports*. Washington, DC: ERIC.

Chi, Michelene T. H. 2009. "Active-constructive-interactive: A conceptual framework for differentiating learning activities." *Topics in Cognitive Science* 1 (1): 73-105. https://doi.org/10.1111/j.1756-8765.2008.01005.x.

Chi, Michelene T. H., and Nicole S. Boucher. 2023. "Applying the ICAP framework to improve classroom learning." *In their Own Words: What Scholars and Teachers Want you to Know about the Why and How to Apply to Science of Learning in your Academic Setting. Washington DC, USA: Society for the Teaching of Psychology*: 94-110.

Crawley, Edward F., Johan Malmqvist, Sören Östlund, Doris R. Brodeur, and Kristina Edström. 2014. *Rethinking Engineering Education: The CDIO Approach*. 2nd ed. New York: Springer.

De Graaff, Erik, and Hans Peter Christensen. 2004. "Editorial: Theme issue on active learning in engineering education." *European Journal of Engineering Education* 29 (4): 461-463. https://doi.org/10.1080/03043790410001716310.

Freeman, Scott, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. 2014. "Active learning increases student performance in science, engineering, and mathematics." *Proceedings of the National Academy of Sciences* 111 (23): 8410-8415. https://doi.org/10.1073/pnas.1319030111.

Hake, Richard R. 1997. "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses." *American Journal of Physics* 66: 64-74.

Jordan, B., and A. Henderson. 1995. "Interaction analysis: foundations and practice." *The Journal of the Learning Sciences* 4 (1): 39-103.

Lima, Rui M., Pernille Hammar Andersson, and Elisabeth Saalman. 2017. "Active learning in engineering education: a (re)introduction." *European Journal of Engineering Education* 42 (1): 1-4. https://doi.org/10.1080/03043797.2016.1254161.

Marton, Ference. 2015. *Necessary conditions of learning*. New York: Routledge.

Marton, Ference, Ulla Runesson, and Amy B M Tsui. 2004. "The Space of Learning." In *Classroom discourse and the space of learning*, edited by Ference Marton and Amy B M Tsui, 3-40. Mahwah: Lawrence Erlbaum.

Menekse, Muhsin, Glenda S. Stump, Stephen Krause, and Michelene T. H. Chi. 2013. "Differentiated overt learning activities for effective instruction in engineering classrooms." *Journal of Engineering Education* 102 (3): 346-374. https://doi.org/10.1002/jee.20021. http://dx.doi.org/10.1002/jee.20021.

Prince, Michael. 2004. "Does active learning work? A review of the research." *Journal of Engineering Education* 93 (3): 223-231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x.

Richards, M J. 1971. "An ABC of dimensional analysis." *Physics Education* 6 (4): 244-249.

Streveler, Ruth A., and Muhsin Menekse. 2017. "Taking a closer look at active learning." *Journal of Engineering Education* 106 (2): 186-190. https://doi.org/10.1002/jee.20160. http://dx.doi.org/10.1002/jee.20160.

ten Have, Paul. 2007. *Doing Conversation Analysis: A Practical Guide*. 2nd ed. Los Angeles: SAGE.

Thornton, Ronald K, and David R Sokoloff. 1998. "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the evaluation of active learning laboratory and lecture curricula." *American Journal of Physics* 66 (4): 338-352.

Trumper, Ricardo. 2003. "The physics laboratory: Historical overview and future perspectives." *Science & Education* 12 (7): 645-670. https://doi.org/10.1023/A:1025692409001.

STUDENTS' REFLECTIONS ON PROGRESSION IN THEIR EDUCATION PROGRAMME

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ABSTRACT

This study investigates how students reason about progression in an engineering programme. Here progression refers to the idea of setting up the educational programme so that learning activities build on previous ones and prepare for future ones, allowing students to gradually develop their competence and ultimately achieve the programme goals. It is not trivial to build progression into education programmes, and in particular, there may be differences between how the educators intended the curriculum to work and students' actual experiences. This study is based on 60 reflections on progression, written by engineering students. They were analysed thematically to identify the aspects viewed as important to create a good progression in the programme. The following categories were identified: teaching and assessment, repetition, making clear connections between prior and continuing courses, realistic progression, personal factors and alternative routes to progression.

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These findings give us better insight into the students' perspectives on requirements for appropriately creating progression in education programmes. After all, the students are the ones who experience the curriculum design and teaching in practice.

1 INTRODUCTION

Progression is an important concept in education, defined by Säfström as "*successively increasing requirements, which are possible to achieve with the help of previously expected learning*" (2017, p. 66). In practice, it refers to how courses within a programme can build on each other to support students in gradually developing their competence during their education.

As students are expected to develop in several areas during their degree, a planned built-in progression through their programme is crucial (Canrinus et al. 2017; Hadfield et al. 2011). This requires good connections between courses which necessitates productive communication and collaboration between the educational leadership and the teachers (Canrinus et al. 2017). However, this is not trivial to achieve. There is often a long wish list of what the students should be able to do upon graduation, and many teaching staff involved may have different ideas about the focus and purpose of the education. Course instructors often have much autonomy and freedom in designing and teaching their courses. In addition, the students enter with differences in knowledge, skills, interests, and motivation, which affects how they can tackle their education.

When discussing progression, it is important to make the distinction between the planned progression within the programme, i.e., *the intended curriculum*, and the students' actual experiences, i.e. *the attained curriculum* (van den Akker 2003). In this paper, we will investigate which aspects students see as important for creating progression within their education based on their experience. While students are naturally less familiar with theoretical aspects of course and curriculum design, they are the ones who have a first-person insight into what it means to attend the programme. Students are therefore important informants when it comes to understanding what is required to create a well-built progression in a programme. To increase our understanding, we are guided by the following research questions:

1. *Which factors do engineering students find important to ensure a well-designed built-in progression?*
2. *How do these factors promote and/or prohibit the progression?*

We hope that this study will be helpful for both teachers in course planning and for educational leaders who have an overview of and responsibility for planning clear progression throughout the programme.

2 BACKGROUND

While it is easy to agree upon the importance of progression in educational programmes, Säfström (2017) points out that it often is unclear how the progression is planned out and which aspects of learning the progression refers to. In a previous study, Björn et al. (2023) found several uses of progression in the academic literature and proposed a disambiguation of the term. In this paper, we focus on one of the meanings, namely the built-in progression in the educational programme.

Progression is often seen as a deepening of students' knowledge and skills, but Harden (2007) conceptualises this further. He presents a model consisting of four dimensions: breadth, difficulty, application, and skill. *Breadth* focuses on expanding the students' area of competence by learning about new subjects or areas in which previous competencies can be useful. It is therefore different from *difficulty* (or *depth*) in which the student immerses themself in a narrower area. *Application* concerns students' ability to implement, or apply, their theoretical competencies in practice while *skill* concerns the student's ability to use their competencies effectively. Skill can, for example, regard students' ability to complete tasks faster, with fewer errors, or with less supervision.

To build progression effectively into educational programmes, it is important to understand in which areas and how it needs to take place as well as understand what promotes and hinders it. These are topics on which students could be important informants. Speight et al. (2020) emphasise the value of listening to students, who often are well-informed and able to bring new perspectives to the table. Although taking student perspectives is not uncommon in qualitative research, a small number of studies have taken student involvement further by inviting students to participate in curriculum design (Bovill, Morss, & Bulley 2009; Tuhkala, Ekonoja, & Hämäläinen 2021).

3 METHODOLOGY

3.1 Context

The context of this study is the computer science and engineering programme at KTH Royal Institute of Technology, a five-year programme integrating a BSc and an MSc. Since 2010, the BSc has contained a mandatory so-called *Programme-Integrating Course* (PIC) running through all three years. The PIC aims to create a common thread through the programme by covering important topics without an obvious place in the programme and allowing the students to reflect (Kann 2019).

In the PIC, students are divided into groups (of about 16), mixing the students from different years, and assigned a mentor who is involved in the programme. In addition to a few year-specific activities, the course consists of four seminars per year. Each seminar has a specific theme with an associated reading and reflection assignment (of 500-1000 words) that is submitted and subject to peer feedback before the seminar.

3.2 Data selection and analysis

The data in this study was generated in the programme integrating course. It consists of reflections written by students for a seminar in 2023 on the topic of prior knowledge and progression. As preparation, the students read a text about the planned progression in the program written by a course teacher (the third author). The text addressed, among other topics, why certain courses are required before others and presented statistics on exam results for students who passed the prerequisite course compared to those who did not. In addition to this text, the students also read parts of an article by Valstar et al. (2019) which dealt with the influence of prior knowledge on study results within a computer science course. In their texts, the students then reflected on how courses are or are not connected, the importance of prior knowledge and how deficiencies in these can be handled as well as who or who is responsible for this. They also reflected on how the programme is or is not designed to help them develop their programming skills.

In total 349 students gave consent for us to analyse their anonymised reflections.

To be able to analyse the reflections in-depth, we limited ourselves to 20 randomly selected reflections per grade (years 1–3). We started by analysing 10 reflections from each grade and noticed that we had reached saturation when analysing the remaining reflections.

The students' reflections were then used as a basis for answering the research question through a thematic analysis guided by Braun and Clarke (2006). The first author began the analysis by reading through the reflections and conducting a first coding. The codes were then discussed, after which some of them were merged, some were removed, and some new areas were noted for a more careful exploration during the next read-through. Coding then continued while reviewing potential categories to group the codes into. This continued for several iterations before arriving at and naming the categories presented in the results below.

4 IMPORTANT FACTORS FOR CREATING PROGRESSION WITHIN THE PROGRAMME

In this section, we present the categories most relevant for answering the research questions, also illustrating them with quotes from the reflections.

4.1 Teaching and assessment

Some students comment that the knowledge and skills on which the progression is based must not only be taught but also assessed. Some mention instances when they did not learn or quickly forgot knowledge and skills that later became prerequisites for another course because these were never assessed or were not assessed to the level that the continuation course required. They also find it difficult to use the prior knowledge in other or extended contexts if they do not know it well enough, as this student points out:

> *"Of course, I have not had A's in all courses, and getting a pass in a course is not necessarily a receipt that one possesses the knowledge well enough to apply it in another context."*

4.2 Repetition

Students point out that it is very easy to forget between courses, and it is difficult to build on forgotten prior knowledge. They emphasise that their programme is both broad and intense, which means that there is much to remember from course to course. This is even more difficult when there is a long pause between continuation courses and the courses where the prior knowledge was introduced. The students therefore stress the importance of repeating, reminding, and refreshing. This student recommends as normal practice in the courses to make room for catching up and linking back to previous knowledge:

> *"In a well-planned course, there should be some leeway to deal with this kind of problem [students struggling to remember previous content] without affecting the rest of the course."*

Many students argue that it is especially their responsibility to refresh in cases where they did not study well enough in the prerequisite course but still passed. However, many also believe that it is impossible to remember everything and that universities also have a responsibility to activate the previous knowledge, or at least make clear what the prerequisites for the course are so that they can study on their own. Several students also asked for material to rehearse prior knowledge, although some commented that it might be too much to ask. However, many, including the student below, emphasise that they much prefer to know what knowledge and skills are used in the continuation course, instead of just a list of the formal prerequisite courses:

> *"At the university, you have a big responsibility yourself to make sure that you have made sufficient preparations for a course, especially if you take them outside of a programme. But in order for it to work, it must be very clear what prior knowledge is actually required, so it is an important task for teachers."*

4.3 Making clear connections

It is easier to see relationships between different elements of the educational programme when they are well established, which is true for those who have a more complete picture of the situation (like the teachers). This is not the case, however, for students when they are in the process of learning, and they therefore point out that it is important that the teacher helps them make the connection between the prior knowledge and skills and the new material. Some factors also *hinder* the students from seeing the connections between course content in different courses. For example, a student comments:

> *"KTH should somehow try to standardize the notation used in mathematics at KTH. Maybe it's just me who finds it complicated when different courses write the same thing but in different ways, which makes it a little harder to recognize earlier material."*

In this case, the student struggled connecting knowledge and skills between courses, because the student did not recognize that they dealt with the same areas.

Apart from teachers helping students see the connection between different courses, students also commented that the prerequisite knowledge must be taught. The student below points out that this requires communication between the teachers:

> *"Then I also believe that the teachers between the different courses have the responsibility to communicate with each other about how their courses are structured and what is in focus, which can lead to a reduction in incorrect assumptions regarding what prior knowledge the students have from the previous courses."*

Some students also point out that in some cases there is no strong connection between the official prior knowledge and the continuation course because the latter does not use the prior knowledge in a way that there is a progression or that it is necessary to complete the task. The student below comments that they think this was the case with the course in sustainable development, which is a prerequisite course for their bachelor's thesis.

> *"I doubt that you fail to reason about sustainability [in the thesis] without a pass in that course, quite honestly."*

4.4 Realistic progression

It is important that the progression is well-planned and clear on paper, but it must also be feasible. Students must be given time to learn. The duration of the programme is only five years, which limits the amount of content that the courses can be expected to cover. Some students particularly point out how easy it is to forget between courses, which means that there must be time to both repeat and connect prior knowledge with the new material. This is highlighted, among other things, by the student below.

> *"The mathematics I study right now feels very distant, and even though I feel that I understood a lot of the material during the time I took the course, I am not at all sure that the same applies at the moment. The whole thing is made worse by putting the math skills into a completely new context."*

In addition to having time to learn, several students comment that it also is important to take into account *where they are when they start* a new progression chain. Among other things, several students bring up programming as an example of this because it is an area in which they officially do not need any prerequisites when starting their education. Some students comment that they do not think this is true and that their programming education started at too high a level or at too high a pace. However, other students used the programming courses as an example of when the university has taken their previous knowledge into account, such as the student below:

> *"[The] programme [is] designed in such a way as to take into account the fact that all students who start their studies have different academic backgrounds. Already at the start of semester 1, you had a choice to make regarding which programming group you preferred."*

4.5 Personal factors

Students also bring up different personal factors that can affect how they progress in their studies. These can be anything from interest and motivation to a sense of belonging and mental health. Although it is desirable that the students have an interest in the course content and motivation to learn, this cannot be taken for granted and can be a reflection of the teaching. Struggles in these areas can be detrimental and they can affect the students' opportunity to learn and the quality of their learning. The student below comments that their interest in a subject can determine how well they learn and remember:

> *"While I may like the information presented in the course if I don't have an interest in and feel an intrigue for the subject in question, then I will not try to get into it and understand it on a fundamental level. I will learn well enough that I manage to pass the exam or assignment, but then I will forget about it; you practice short-term memory, but not long-term memory."*

Students point out that their life outside of college also can affect their learning since they might be busy with other things. For example, some students may need to work alongside their studies or spend time on other aspects of life. Students may also suffer from physical and/or mental health issues. The student below shares an example where their studies have been affected by private life.

"During this semester, I have unfortunately had difficulties in dealing with my college work. I have had a very turbulent period in my life that occupied most of my thinking and hence my ability to study."

4.6 Alternative routes

Several students remind us that there are alternative paths for progression in the programme. As mentioned under realistic progression, students can enter the programme with very different prior knowledge. This can be seen as the point of origin of the progression and it is from here the student begins their journey through the programme. However, this is only the first stop when it comes to alternative routes. Some students comment that later courses also could be affected by prior knowledge that they have acquired outside college. This is highlighted by the student below who believes that it would be good if they could take into account all the knowledge and skills the students possess when choosing a course, not just the knowledge and skills taught in previous courses at KTH.

"On the other hand, I think that the requirements can be a bit firm sometimes. Perhaps you should let students decide for themselves whether they want to take a course, for example, if you have learned the prerequisites in other ways."

Several students also mention that the progression through their degree takes different paths both in connection with elective courses and when choosing a master's degree.

4.7 Deepening and broadening

Many students bring up the importance of both deepening and broadening as dimensions of progression discuss programming. Progression is often associated with increased depth and it is also something that many students bring up in their reflections. They write that they gain in-depth knowledge in various areas the more courses they take and that this is important to increase their programming skills. However, they mention that many of their future problems will also require that they have a broad base to stand on. It is not certain that the students will have all the knowledge and skills needed to solve the problem, but a broader base can help them understand the problem better and thus more easily find out from which angle it needs to be approached. Below is a quote from a student who describes how the programme contributes to both depth and breadth.

"In every programming course I've taken, you've always had to learn something new, whether it's [programming paradigm, algorithms, data structures and complexity]. Does this then mean that I am a world champion in Haskell and Java? No. But if in the future I need to use Java streams or other functional elements, I will have a basic understanding of how to think. This will make it faster and easier to read about those parts in the future. Every course I've taken where I've had to write a few lines of code, regardless of language […], I've gained a deeper understanding of programming as a whole."

4.8 Theory vs. practice

Although the programme has many practical elements, it also contains a lot of theory. Some students find it difficult to see how all theory contributes to advancing their programming skills and feel that some of the time would be better spent if they were instead allowed to program more. Others instead see the benefit of the amount of theory in the programme and claim, that it is what makes this an advanced and professional degree as the high-status title suggests. Some of these students, like the student below, also come up with concrete examples of how the theory can help them to develop in programming.

> *"Being exposed to complicated concepts also helps, I think. An example I can offer is when I was reading about <Comparable> in Java and started reading some complicated programming explanations. Instead, when I scrolled down it said to simply treat all functions related as if they were a relation (more specifically a partial order), which made the concept click for me. I read about relationships in the basic and arithmetic course."*

5 DISCUSSION

The results indicate that the students, as a group, are well-informed participants who can share useful insights regarding important factors regarding built-in progression. It is, however, worth noting that the students did read preparatory material with a focus on the importance of prior knowledge to progress from prerequisite courses to continuing courses, and this may have coloured their reflections. The material also pointed out that progression can be both broadening and deepening, which some students referred to, however, most comments addressing this aspect of progression appeared as personal reflections and were not directly related to the preparatory text. The *Deepening and broadening* category addresses two of Harden's (2007) dimensions of progression. However, the other dimensions, application and skill, can also be seen in the students' reflections, especially in relation to programming. For example, both *application* and *skill* are brought up in the theme *Theory vs. practice*.

Although the students had not been introduced to Biggs's (1996) constructive alignment, the category *Teaching and assessment* shows resemblance with the theory. Some students brought up a wish for a close alignment between the teaching and learning activities and the assessment, to ensure they had learned what is necessary for their progression in the programme. These necessary prerequisites could be interpreted as the intended learning outcomes. In the category *Making clear connections*, several students push the idea of alignment further by discussing the alignment between courses. This allows for a clearer progression throughout the programme (McMahon & Thakore 2006). Further, in *Realistic progression*, some students address the potential discrepancy between the planned progression and their actual progression which relates to the danger of viewing constructive alignment from a quality assurance perspective rather than a student-centred constructivist teaching approach (Loughlin, Lygo-Baker, & Lindberg-Sand 2021).

In cases where the students need support to remember important prerequisites, *Repetition* could be seen as a contribution to *Making clear connections* between knowledge and skills in different courses. If the prerequisites weren't appropriately *taught or assessed* the need for repetition will likely be greater. Different *Personal factors* could create further need for repetition.

Some students also commented that *Personal factors* can affect their progression because they can impact students' ability to follow the programme. While some of these factors can be difficult to influence as a teacher, it is still important to try and understand and show empathy. The students may not be able to follow the planned progression. If the students also are taking *Alternative routes* through their education there may be an additional need for repetition since they might have different prerequisites entering the course as seen in one of the quotes that illustrated the theme *Realistic progression*. *Realistic progression* also highlights the gap between intended curriculum and the attained curriculum (van den Akker 2003).

6 CONCLUSION AND ACKNOWLEDGEMENTS

We find that the students show good insight into factors required to ensure well-built-in progression within the programme. They address many significant aspects related to progression such as: *Teaching and assessment*, *Repetition*, *Making clear connections*, *Realistic progression*, *Personal factors*, *Alternative routes*, *Deepening and broadening* and *Theory vs. practice*. Their reflections tend to align with theoretical conceptualisations of progression, and they also provide insight into situations when the programme does not fully live up to the theory. Although it is believed that the students in this study are probably more informed about progression than the average engineering student, we conclude that students can be important informants when it comes to better understanding the programme from the inside.

The authors would also like to thank all the students who gave us permission to read and analyse their reflections in connection with this study.

REFERENCES

Biggs, John. 1996. 'Enhancing Teaching through Constructive Alignment'. *Higher Education* 32 (3): 347–64. https://doi.org/10.1007/BF00138871.

Björn, Camilla, Kristina Edström, Liv Gingnell, Marie Magnell, and Joakim Lillieskföld. 2023. 'The Nature of Progression between Yearly Project Courses'. In *In Proceedings of the 19th International CDIO Conference*. NTNU Trondheim, Norway.

Bovill, Catherine, Kate Morss, and Catherine Bulley. 2009. 'Should Students Participate in Curriculum Design? Discussion Arising from a First Year Curriculum Design Project and a Literature Review'. *Pedagogical Research in Maximising Education*.

Braun, Virginia, and Victoria Clarke. 2006. 'Using Thematic Analysis in Psychology'. *Qualitative Research in Psychology* 3 (2): 77–101.

Canrinus, Esther T, Ole Kristian Bergem, Kirsti Klette, and Karen Hammerness. 2017. 'Coherent Teacher Education Programmes: Taking a Student Perspective'. *Journal of Curriculum Studies* 49 (3): 313–33.

Hadfield, Steve, Dino Schweitzer, David Gibson, Barry Fagin, Martin Carlisle, Jeff Boleng, and Dave Bibighaus. 2011. 'Defining, Integrating, and Assessing a Purposeful Progression of Cross-Curricular Initiatives into a Computer Science Program'. In *2011 Frontiers in Education Conference (FIE)*, T3J-1. IEEE.

Harden, Ronald M. 2007. 'Learning Outcomes as a Tool to Assess Progression'. *Medical Teacher* 29 (7): 678–82.

Kann, Viggo. 2019. ‘Programme Integrating Courses Making Engineering Students Reflect’. In *Theorizing STEM Education in the 21st Century*. IntechOpen. https://doi.org/10.5772/intechopen.88253.

Loughlin, Colin, Simon Lygo-Baker, and Åsa Lindberg-Sand. 2021. ‘Reclaiming Constructive Alignment’. *European Journal of Higher Education* 11 (2): 119–36. https://doi.org/10.1080/21568235.2020.1816197.

McMahon, Tim, and Hemal Thakore. 2006. ‘Achieving Constructive Alignment: Putting Outcomes First’. *Quality of Higher Education* 3: 10–19.

Säfström, Anna Ida. 2017. ‘Progression i Högre Utbildning’. *Högre Utbildning* 7 (1): 56–75.

Speight, Sarah, Gillian Moreira, and Dag Husebo. 2020. ‘Listening to Students for Tomorrow, Today: Engaging Students to Define the Future of Higher Education’. *Student Engagement in Higher Education Journal* 3 (1): 96–114.

Tuhkala, Ari, Antti Ekonoja, and Raija Hämäläinen. 2021. ‘Tensions of Student Voice in Higher Education: Involving Students in Degree Programme Curricula Design’. *Innovations in Education and Teaching International* 58 (4): 451–61.

Valstar, Sander, William G Griswold, and Leo Porter. 2019. ‘The Relationship between Prerequisite Proficiency and Student Performance in an Upper-Division Computing Course’. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, 794–800.

van den Akker, Jan. (2004). "Curriculum Perspectives: An Introduction." In: *Curriculum Landscapes and Trends*. Edited by Jan van den Akker, Wilmad Kuiper, and Uwe Hameyer. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-1205-7_1

EXPLORING GENDER DIFFERENCES IN PROFESSIONAL COMPETENCIES IN ENGINEERING STUDENTS. INSIGHTS FROM THE PREFER MATCH TEST

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ABSTRACT

Despite efforts to increase gender diversity in engineering, significant gaps persist. This study investigates gender differences in professional competencies among engineering students, aiming to address potential barriers to gender inclusivity in the field. Utilizing the PREFER model, three distinct engineering roles were examined: Product Leadership, Operational Excellence, and Customer Intimacy. Through a situational judgment test, participants rated the appropriateness of responses to practical scenarios, allowing for an evaluation of competency levels. Results reveal that female students scored higher in competencies associated with customer-oriented roles, such as empathy or client focus, while male students excelled in innovation and process optimization competencies, such as creativity and vision. However, most competencies showed no significant gender differences, suggesting that gender disparities in engineering competencies may be less pronounced than traditionally assumed. These findings highlight the need for engineering education

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programmes to integrate professional competency development, ensuring a comprehensive skill set for all students and preparation for diverse career paths. Addressing these differences through educational curricula could promote gender equality and enhance the attractiveness of engineering for a broader audience. Future research should explore cultural nuances and potential biases in assessment methodologies to further understand gender dynamics in engineering education and foster a more inclusive environment.

1 INTRODUCTION

Despite efforts to increase diversity in engineering, the number of females in engineering is increasing very slowly. For example, in the US, the percentage of engineering bachelor's degrees earned by women has increased from 18% in 1998 to 22% in 2018 (NCSES 2021). In Europe, similar trends are observed with 32,8% of women graduates in tertiary STEM education in 2021. However, there are large differences between countries. The highest shares of female STEM graduates in 2021 were recorded in Romania (42,5%) and Poland (41,5%), the lowest in Belgium (27,4%), Germany and Spain (both 27;7%) (Eurostat 2024).

1.1 Engineering image

A factor hindering the attractiveness of engineering is the harsh technical image, often linked to masculinity. This is also reflected in the gender differences per field. Fields that relate to biology, sustainability or biomedical are generally more attractive for females in contrast to the more traditional fields in engineering such as manufacturing (Tazo et al. 2020; KU Leuven 2024), showing that females identify differently with engineering (Faulkner 2007). The European Commission developed a roadmap with actions to strengthen women's and girl's participation in STEM studies and careers, like the manifesto for gender-inclusive STEM education and careers. One of the actions is to explicitly include arts, social sciences and humanities in STEM education and emphasize the importance of transversal competencies, creativity, and innovation to broaden the image of engineering and increase attractiveness (European Commission 2022).

1.2 Confidence in engineering competence

Increasing the focus on professional competencies is needed. Engineering students acknowledge the importance of professional competencies but can be unsure about which competencies are most relevant or about the required level of performance (Flening et al. 2021; Direito, Pereira, and De Oliveira Duarte 2014; Karataş, Bodner, and Unal 2016).

Engineering competencies and identities are inseparably linked and shape each other simultaneously (Tonso 2014). Naukkarinen and Bairoh (2021) showed that early career female engineers in Finland perceived the importance of social and altruistic aspects, such as communication, ethics, and sustainability, as greater than men do. They perceived the importance and the development of their managerial skills higher than men whereas men perceived competencies related to technical innovations, such as creativity and entrepreneurial capacities to be better. In a US study, Cech et al. (2011) found that female students had less confidence that, after graduation, they would end up in an engineering career they belong in and that they would have the expertise and competencies required for practice in the profession. Building on this work, a Belgian study with engineering students and graduates indicated that a better understanding of the broad field in engineering practice and required competencies enhances students' confidence in their future role and talents and support graduates in making better career choices (Craps 2022). Therefore, it is important to raise awareness about the broad range of engineering jobs and roles, and make more explicit that engineering competencies comprise technical and professional skills (Berdanier 2022).

1.3 Integrating heterogeneity in engineering education

Faulkner (2007) stated that 'promoting heterogeneous images of engineering will create space for a more diverse range of people to become engineers'. Craps et al. (2020) found in their literature review that few research focused on the diversity in engineering roles. The PREFER model is a reference in this regard (Craps et al. 2021). The framework presents a simple, dynamic model representing three roles that early career engineers can take on (engineers in a role focusing on radical innovation, on process optimisation and/or on customised solutions). In each role, essential professional competencies are identified. The model builds upon earlier work of e.g., Passow and Passow (2017) who offered a concise portrait of generic engineering practice and competencies. It makes explicit that professional competencies vary according to the different roles. Hence, the different engineering roles and competency profiles broaden the image of engineering and the option to identify more with one role over another while feeling like a 'real' engineer.

Based upon the PREFER model, tests were developed to support students in discovering their preferred engineering role (PREFER Explore) (Carthy et al. 2019) and in getting insight in different professional competencies (PREFER Match) (Carthy et al. 2022). Earlier research in Belgium and Ireland showed that the PREFER Explore test, a personal preference test, was gender sensitive with female students showing a greater preference for a customer oriented role than males and males showing a greater preference for process optimisation than females (Carthy et al. 2020). To date, the PREFER Match test, a situational judgment test, was not yet investigated for gender differences.

1.4 Purpose of this study

This study contributes to previous literature by investigating gender differences in professional competencies. Whereas previous studies investigated engineering perceptions on competencies (e.g., Naukkarinen and Bairoh 2021) or self-reported levels of competence confidence (e.g., Craps 2022), this study aims to investigate whether there are gender difference in the competency levels obtained via a situational judgment test (the PREFER Match test).

2 METHODOLOGY

2.1 Participants

Table 1 shows the participants per gender that filled in the online PREFER Match tests (there are three tests, see next paragraph) between February 2020 and February 2024. Only participants who identified as engineering students were included in this study. Students indicated to be in different engineering programmes of whom the majority in civil engineering (28%), architecture/ construction/geomatics (20,5%), chemistry (19%), energy (11%), and biochemistry/biotechnical/biomedical (6,5%). About 70% of the students is from Belgium, 8% from Turkey, 3% from the Netherlands. 17% did not identify their country of study while few students study in the UK, Ireland, Spain, Portugal, Germany, etc. Participants who filled in the background information gave consent to use this data for further research with approval of the KU Leuven Privacy and Ethical Commission was obtained (G-2019 10 1792).

Table 1 Descriptives participants per PREFER Match test and gender.

	Test 1 - Product Leadership		**Test 2 - Operational Excellence**		**Test 3 - Customer Intimacy**	
	n	**%**	**n**	**%**	**n**	**%**
Male	725	69,38	575	69,78	549	68,88
Female	304	29,09	233	28,28	234	29,36
Non-binary	2	0,19	4	0,49	2	0,25
Prefer not to disclosure	14	1,34	12	1,46	12	1,51
Total	1045	100,00	824	100,00	797	100,00

Due to the low number, non-binary participants and participants who did not prefer to share information on gender were excluded from further analyses.

2.2 PREFER Match tests

Per engineering role, a separate test was developed. Because there are three roles identified in the PREFER model, participants filled in one, two or three tests via www.fet.kuleuven.be/prefer. Table 2 shows the available tests with role definitions and the professional competencies that were tested. Definitions of the competencies can be found in Craps et al. (2021).

The tests contextualise each of the essential competencies within a practical situation that a young engineer may encounter. The participants rated the level of appropriateness of responses to the given situation: inappropriate, rather inappropriate, neutral, rather appropriate, appropriate. The level of appropriateness was validated by engineers in the field. As such, the judgment of the participants was compared to that of engineers in the field. A detailed explanation of the development, rationale and scoring key of the test can be found in Carthy et al. (2022) and Pinxten et al. (2020).

The maximum scores for the three roles are different due to the number of competencies (situations) included in the test and due to the different scoring of (rather)(in)appropriate and neutral answers. For comparison, items including a neutral level of appropriateness are rescaled leading to a maximum score of 24 per competence. The maximum role scores are rescaled to 100.

Table 2 Overview of PREFER Match tests and professional competencies tested.

PREFER Match test	**Definition of the role** (Craps et al. 2021)	**Professional competencies** (Craps et al. 2021)
Product Leadership	In this role, the emphasis is on innovation and creativity through research and	Innovation, Creativity, Vision, Perseverance,

	development. These engineers explore new paradigms and identify radical alternative solutions. They translate theoretical ideas into marketable applications that provide added value to (yet) unidentified end users.	Persuasiveness, Initiative, Client focus
Operational Excellence	This role focuses on the smooth design and implementation of operational processes. The engineer locates opportunities to create efficiency gains, fixes flaws, and overseas operations, either in psychical production facilities or in the digital domain.	Positive critical attitude, Planning and organisation, Helicopter view, Team player, Work organisation, Stress resistance, Solution-oriented, Initiative
Customer Intimacy	This role entails close collaboration with clients in complex business environments. These engineers develop a (commercial) relationship with clients, help them express their needs, and provide a technical tailored solution to these needs.	Clear communication, Client focus, Capacity for empathy, Negotiation, Networking and relation building, Focus on results, Solution-oriented, Creativity

2.3 Analyses

For the data analysis, R 4.3.2 was used. First, descriptive analyses were conducted to obtain statistics about the sample. Subsequently, the data was explored by examining the means across the competencies for both male and female participants. Following this initial exploration, independent sample t-tests were conducted at the 0.05 significance level to investigate significant differences in competencies scores between male and female participants.

3 RESULTS

3.1 Differences in competency profiles per role

For the three roles, there were significant differences between the competency profiles of female and male participants, with female students showing a higher score on the competency profile of the customer-oriented role and male students showing a higher score on the competency profile operational excellence (process optimisation). However, the differences are small. For the innovative role product leadership, no differences were observed (see Table 3).

*Table 3 Mean scores competency profiles per role and gender (max. score = 100) (Significant scores in bold, * p < .05, ** p < .01, ***p < .001)*

Role	Male		Female		t-stat	p-value
	Mean	SD	Mean	SD		
Product Leadership	61,84	14,08	61,93	12,6	-4,867	1,31
Operational Excellence*	**63,18**	**17,21**	62,4	17,18	-2,197	**0,028**
Customer Intimacy*	60,07	14,42	**61,32**	**13,13**	-2,049	**0,04**

3.2 Differences in professional competencies

Table 4 shows the mean scores for the different competencies per gender. For more than half of the competencies (13 of 23), no differences were noted. For 10 competencies, small but significant differences were observed. Female students showed higher scores for the competencies perseverance, capacity for empathy and client focus. Male students scored higher on creativity, vision, initiative, client focus (market orientation), helicopter view, team player and stress resistance.

*Table 4 Mean scores in professional competencies per gender (max. score = 24) (Significant scores in bold, * p < .05, ** p < .01, ***p < .001)*

Test	Competence	Male		Female		t-stat	p-value
		Mean	SD	Mean	SD		
Product Leadership	Innovation	16,47	3,94	16,42	3,83	-0,555	0,579
	Creativity**	**16,96**	**3,82**	16,75	3,61	-2,622	**0,009**
	Vision*	**11,09**	**4,5**	10,47	4,48	-2,266	**0,024**
	Persuasion	14,56	4,03	14,94	3,67	-1,399	0,162
	Perseverance**	16,83	4,31	**17,12**	**4,13**	-2,926	**0,004**
	Initiative**	**14,44**	**4,26**	14,37	4,04	-2,851	**0,004**
	Client focus**	**14,03**	**4,00**	13,86	3,48	-2,744	**0,006**
Operational Excellence	Positive critical attitude	14,63	4,31	14,58	4,21	0,578	0,563
	Solution orientation	17,59	3,46	17,40	3,56	-0,808	0,419
	Team player*	**13,34**	**4,55**	13,13	4,35	-2,511	**0,012**
	Helicopter view***	**15,05**	**4,63**	14,47	4,75	-3,221	**0,001**
	Initiative	17,11	3,85	16,85	3,75	-0,296	0,768
	Work organization	14,74	4,48	14,85	4,56	0,283	0,777
	Stress resistance*	**15,59**	**4,64**	15,02	4,82	-2,043	**0,041**
	Planning	13,49	3,71	13,80	3,83	-0,424	0,672
Customer Intimacy	**Client focus***	13,07	4,6	**13,96**	**4,64**	-2,256	**0,024**
	Capacity for empathy**	16,02	4,24	**17,04**	**3,80**	-2,934	**0,003**
	Clear communication	15,42	4,02	15,41	3,73	0,021	0,983
	Creativity	14,10	3,87	14,13	3,6	-0,079	0,937
	Networking	11,84	3,66	12,07	3,39	-0,673	0,501
	Solution oriented	14,10	4,037	14,21	3,68	-0,334	0,738
	Negotiation	15,22	4,60	15,20	4,32	0,078	0,938
	Focus on results	15,38	4,16	15,59	4,20	-0,639	0,523

It was observed that client focus (on the level of market orientation) in an innovative role has a higher score for males, whereas client focus in a customer-oriented role (attuning action to the feelings, needs and wishes of a client) has a higher score for females. Taking initiative in a product leadership role (undertake actions and make proposals on their own initiative) was significant higher for male students. In the operational excellence role, no gender difference was found for this competence (take initiative where they think they spot opportunities to optimise and to increase efficiency and reliability).

It was noted that all competencies scored above average, except for vision (M_{total} = 10.91, SD = 4.49) and networking (M_{total} = 11.92, SD = 3.58).

4 Discussion

Engaging students in the development of professional competencies during education will provide new ways to excel in engineering, in particular for those students who might not feel like ‘real engineers’. This study delved into the examination of gender differences in the professional competencies among engineering students, shedding light on potential areas for improvement and promoting gender equality within the discipline.

Our findings underscore the nuanced nature of gender disparities in professional competencies within engineering education. Female students demonstrated a higher proficiency in competencies associated with customer-oriented roles, in particular in capacity for empathy and client focus. Male students exhibited greater aptitude in competencies linked to innovation and process optimisation such as creativity, vision, or initiative. These findings align with previous research indicating varied gender perspectives and preferences in the engineering domain (Carthy et al. 2020; Craps 2022; Martin Cabezuelo et al. 2024; Naukkarinen and Bairoh 2021). However, differences were small, and the majority of competencies showed no significant gender differences, suggesting that engineering roles are not inherently gendered. Understanding that there are no (stereo)typical male or female engineering roles can enhance the field’s attractiveness to a more diverse audience.

Integrating professional competency development into engineering curricula is imperative to equip students with a comprehensive skill set essential for diverse career pathways (Royal Academy of Engineering 2019). By making competencies explicit and contextualizing them within real-world scenarios, universities can enhance student engagement, motivation, and overall preparedness for the dynamic engineering landscape. Practical steps include incorporating client-focused projects, creativity-enhancing activities, and interdisciplinary collaboration with industry stakeholders.

Challenges remain in effectively integrating professional competencies. For example when the focus of the project is on the deliverables or, even more, when the competencies are perceived as learning from doing (Picard et al. 2021). Certain competencies like vision or networking are not easily trained and assessed in curricula and were shown to have lower student scores in our study. Addressing these challenges requires innovative approaches and support for both students and teachers in training and evaluating competencies. Additionally, efforts to ensure gender-neutral and culturally sensitive assessment tools are essential to accurately evaluate competency levels and mitigate biases in educational settings. The use of the PREFER Match test seems a valuable instrument in providing a realistic reflection of competencies, irrespective of gender by avoiding self-reported measures.

Professional competencies have a strong process component, therefore, student learning requires opportunities for students to focus on such processes, for example in project work (Shuman, Besterfield-Sacre, and McGourty 2005). A limitation of the study is the lack of registration of students' academic year preventing us from understanding how competencies evolve over time. Future research should consider longitudinal studies to track these changes, providing insights into whether observed differences persist, diminish, or become more pronounced throughout their education and into their careers.

While this study contributes valuable insights into gender differences in professional competencies, cultural nuances warrant further exploration. The PREFER Match test, as a situational judgement test, may have cultural biases in what is considered an appropriate response. Future research should aim to compare results across different cultural contexts and engineering disciplines to better understand these variations. The test was validated with representative samples of engineering students and engineers. Consequently, women and other minorities were underrepresented in the validation process. Given the gender differences observed in this study, a next step is to investigate whether the items and cases are gender and culturally neutral and valid involving a larger and more diverse sample of engineers and engineering students. By advancing our understanding of gender dynamics in engineering education, we can foster a more inclusive and equitable environment for aspiring engineers and contribute to the continued advancement of the field.

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REFERENCES

European Commission. 2024. "Towards a manifesto for gender-inclusive STE(A)M education and careers. March 2024. https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/towards-manifesto-gender-inclusive-steam-education-and-careers-2022-10-17_en

Berdanier, Catherine G. P. 2022. "A Hard Stop to the Term 'Soft Skills.'" *Journal of Engineering Education* 111 (1): 14–18. https://doi.org/10.1002/jee.20442.

Carthy, Darren, Sofie Craps, Kevin Gaughan, Heidi Knipprath, Brian Bowe, and Greet Langie. 2020. "Engineering Students Preferred Roles: Are They Stable, Are There Gender Differences?" In *Proceedings of the 48th SEFI Annual Conference 2020 - Engaging Engineering Education*. Twente, The Netherlands: SEFI - European Society for Engineering Education.

Carthy, Darren, Sofie Craps, Langie Greet, Kevin Gaughan, and Brian Bowe. 2022.

“A Situational Judgement Test for Engineers to Evaluate Their Professional Strengths & Weaknesses.” In *SEFI 50th Annual Conference of The European Society for Engineering Education*, 160–70. Barcelona, Spain: Universitat Politècnica de Catalunya. https://doi.org/10.5821/conference-9788412322262.1109.

Carthy, Darren, Maarten Pinxten, Kevin Gaughan, and Brian Bowe. 2019. “Undergraduate Engineers ’ Preferences for a Range of Professional Roles.” *Journal of Sustainable Design and Applied Research* 7 (1(6)).

Cech, Erin, Brian Rubineau, Susan Silbey, and Caroll Seron. 2011. “Professional Role Confidence and Gendered Persistence in Engineering.” *American Sociological Review* 76 (5): 641–66. https://doi.org/10.1177/0003122411420815.

Craps, Sofie. 2022. “Breaking through Stereotypes : Professional Roles for Future Engineers.” KU Leuven.

Craps, Sofie, Maarten Pinxten, Heidi Knipprath, and Greet Langie. 2020. “Exploring Professional Roles for Early Career Engineers: A Systematic Literature Review.” *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2020.1781062.

Craps, Sofie, Maarten Pinxten, Heidi Knipprath, and Greet Langie. 2021. “Different Roles, Different Demands. A Competency-Based Professional Roles Model for Early Career Engineers, Validated in Industry and Higher Education.” *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2021.1889468.

Direito, Inês, Anabela Pereira, and A. Manuel De Oliveira Duarte. 2014. “The Development of Skills in the ICT Sector: Analysis of Engineering Students’ Perceptions about Transversal Skills.” *International Journal of Engineering Education* 30 (6): 1556–61.

Eurostat. 2024. “Women Totalled Almost a Third of STEM Graduates in 2021.” 2024. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240308-2.

Faulkner, Wendy. 2007. “Nuts and Bolts and People’: Gender-Troubled Engineering Identities.” *Social Studies of Science* 37 (3): 331–56. https://doi.org/10.1177/0306312706072175.

Flening, Elias, Fredrik Asplund, Martin Edin Grimheden, Elias Flening, and Fredrik Asplund. 2021. “Measuring Professional Skills Misalignment Based on Early-Career Engineers ’ Perceptions of Engineering Expertise.” *European Journal of Engineering Education*, 1–27. https://doi.org/10.1080/03043797.2021.1967883.

Karataş, F., G. M. Bodner, and Suat Unal. 2016. “First-Year Engineering Students’ Views of the Nature of Engineering: Implications for Engineering Programmes.” *European Journal of Engineering Education* 41 (1): 1–22. https://doi.org/10.1080/03043797.2014.1001821.

KU Leuven. 2024. “Studentenaantallen KU Leuven Academiejaar 2023-2024.” 2024. https://www.kuleuven.be/prodstudinfo/PDF_Publiek/50000050/Studentenaantallen KULeuven - alle studenten met vergelijking.pdf.

Martin Cabezuelo, R., J.M. Meseguer Duenas, J. Molina Mateo, A. Vidaurre Garayo, N. Navajas Pertegas, J.A. Gomez Tejedor, S. Quiles Casado, J. Riera, M.A. Serrano Jareno, and I. Tort Ausina. 2024. “Gender and Teamwork: A Case Study in a Subject in an Engineering Degree.” In *INTED2024 Proceedings - 18th International*

Technology, Education and Development Conference, 2268–73. Valencia, Spain. https://doi.org/10.21125/inted.2024.0626.

National Center for Science and Engineering Statistics (NCSES). 2021. “Women, Minorities, and Persons with Disabilities in Science and Engineering.” 2021. https://ncses.nsf.gov/pubs/nsf21321/report/field-of-degree-women#engineering.

Naukkarinen, Johanna, and Susanna Bairoh. 2021. “Gender Differences in Professional Identities and Development of Engineering Skills among Early Career Engineers in Finland.” *European Journal of Engineering Education*, 1–17. https://doi.org/10.1080/03043797.2021.1929851.

Passow, Honor J., and Christian H. Passow. 2017. “What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review.” *Journal of Engineering Education* 106 (3): 475–526. https://doi.org/10.1002/jee.20171.

Picard, Cyril, Cécile Hardebolle, Roland Tormey, and Jürg Schiffmann. 2021. “Which Professional Skills Do Students Learn in Engineering Team-Based Projects?” *European Journal of Engineering Education* 0 (0): 1–19. https://doi.org/10.1080/03043797.2021.1920890.

Pinxten, Maarten, Darren Carthy, Michael Tack, Elies Hendrickx, Sofie Craps, and Greet Langie. 2020. “PREFER MATCH Test. Manual Situational Judgement Test.” Leuven, Belgium. https://iiw.kuleuven.be/english/prefer/instructor/manuals/manual-prefer-match-test.pdf.

Royal Academy of Engineering. 2019. *Engineering Skills for the Future. The 2013 Perkins Review Revisited*. www.raeng.org.uk/perkins2019.

Shuman, Larry J., Mary Besterfield-Sacre, and Jack McGourty. 2005. “The ABET ‘Professional Skills’ - Can They Be Taught? Can They Be Assessed?” *Journal of Engineering Education* 94 (1): 41–55. https://doi.org/10.1002/j.2168-9830.2005.tb00828.x.

Tazo, Maria Inmaculada, Ana Boyano, Unai Fernandez-Gámiz, and Amaia Calleja-Ochoa. 2020. “The Gender Perspective of Professional Competencies in Industrial Engineering Studies.” *Sustainability (Switzerland)* 12 (7). https://doi.org/10.3390/su12072945.

Tonso, Karen L. 2014. “Engineering Identity.” In *Cambridge Handbook of Engineering Education Research*, edited by Aditya Johri and Barbara Olds, 267–82. Cambridge University Press.

STUDENT TEACHERS' PERCEIVED IMPORTANCE AND (TEACHING) SELF-EFFICACY TOWARDS ENGINEERING IN SECONDARY EDUCATION: PRELIMINARY VALIDATION OF A TEST INSTRUMENT

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***Conference Key Areas**:* The attractiveness of engineering education / Building the capacity and strengthening the educational competences of engineering educators
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ABSTRACT

Pre-university engineering education, providing youngsters with experiences in engineering design, may contribute to attracting more people with appropriate preparation and motivation to engineering. For qualitative engineering education in secondary school, key actors are STEM teachers, who unfortunately do not always have an engineering background. As teachers' classroom implementation is known to be influenced by their attitudes, (pre-service) teacher education has the responsibility to provide teachers with the necessary experiences to prepare them for pre-university engineering teaching and to cultivate a positive attitude towards engineering (design). However, no validated instruments currently exist to measure student teachers attitudes towards engineering education, that can assist pre-service teacher training programmes to assess whether they succeed in achieving this goal. This study aims to evaluate the construct validity of a survey composed of items from previously validated instruments for a new target group of pre-service STEM teachers. Exploratory and confirmatory factor analyses show an underlying factor

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structure that is partially in line with the factor structure from the original instruments. The findings of this study may be used to further assess construct validity with larger sample sizes, to assess concurrent and predictive validity, and to study the evolution of student teachers' attitudes towards pre-university engineering education and the impact of intervention on these attitudes.

1 INTRODUCTION

Pre-university engineering education has the potential to let pupils experience engineering design as well as the broadness of engineering (Richards and Donohue 2015; de Vries, Gumaelius, and Skogh 2016) and may therefore help attract pupils to engineering programs, which is essential to address the shortage of STEM professionals, especially engineers, on the labour market (Phelps, Camburn, and Min 2018). Furthermore, many pupils who do not opt for engineering studies require a basic understanding of what an engineer does and of the impact of engineering on the world of STEM professionals and on society. Despite pre-university engineering education being part of the curriculum in some regions, engineering is not an established school subject in most countries (de Vries, Gumaelius, and Skogh 2016). Surfing on the success of integrated STEM education (abbreviated iSTEM) (Johnson, Moore, and Peters-Burton 2021) may aid to implement engineering education more broadly in (general and non-technical) secondary education. While various avenues exist for meaningful STEM integration, numerous authors have compellingly advocated for a central place of engineering design tasks in iSTEM projects (Roehrig et al. 2021; Fan, Yu, and Lin 2021), as these tasks inherently facilitate seamless integration among the different STEM disciplines. A central engineering design task guides pupils through problem solving and inquiry processes, which helps them develop 21st century competences (Roehrig et al. 2021).

Teachers' attitudes influence the implementation of new educational approaches (Pintó 2005; Roehrig, Kruse, and Kern 2007), such as iSTEM or pre-university engineering education. In this study and in line with previous research, "attitude" is defined as the overall evaluation of an object on several dimensions (Ajzen 2005; Maio and Haddock 2009; Thibaut et al. 2018a). A conceptual framework for teachers' attitudes towards science was proposed by van Aalderen-Smeets and van der Molen (van Aalderen-Smeets and van der Molen 2015) and further build upon for iSTEM education by Thibaut et al. (Thibaut et al. 2019). This tripartite framework includes a cognitive dimension (perceived relevance), an affective dimension (anxiety) and a perceived control dimension (self-efficacy (SE)). To our knowledge, no similar framework exists for pre-university engineering education.

For iSTEM teaching, positive correlations were found between non-teaching work experience, experience in teaching iSTEM, experience in teaching engineering, participation in professional development and perceived relevance of technology and science on the one hand with teachers' attitudes on the other hand, using the tripartite framework (Thibaut et al. 2018b). Fewer years of teaching experience, experience in teaching technology and participation in professional development were associated with more positive teacher attitudes towards problem-centred and design-based learning (Thibaut et al. 2019). Pre-service teacher training should take these findings into account when designing teaching/learning experiences for student teachers.

Very often, students currently studying to become a teacher in science, technology or mathematics have not experienced these new educational approaches such as iSTEM and pre-university engineering education when they were secondary school pupils. Nevertheless, many of them are expected to teach iSTEM after graduation, in which engineering design tasks are often central (Fan, Yu, and Lin 2021; Roehrig et al. 2021), even if they do not have an engineering background. Pre-service teacher training is therefore tasked with the challenging responsibility to provide these student teachers with first-time, low-threshold, comforting experiences that introduce them to the engineering design process but at the same time prepare them for iSTEM/pre-university engineering teaching. Given the important impact of teachers' attitudes on implementation of novel approaches, valid and reliable research instruments are needed to assess the impact of teaching/learning approaches on student teachers' attitudes. To our knowledge no such instrument assessing students teachers' attitudes towards pre-university engineering design exists up to date.

In this work in progress report, we build upon the tripartite framework (van Aalderen-Smeets and van der Molen 2015). To avoid eliciting generic responses, we required that the survey to be used contains enough detail about specific aspects of engineering (design). Therefore, and because constructing a valid survey is time-consuming, we choose to build upon existing instruments assessing attitudes towards engineering, rather than modifying existing surveys measuring teachers' attitudes towards iSTEM education. However, when an existing research instrument is used with a new target group and/or when items are omitted, its validity should be re-established (Sperber 2004; DeVellis 2017). The research goal of this study is to assess the factor structure and construct validity of a survey aimed at measuring student teachers' attitudes towards engineering, specifically: the importance student teachers attribute to engineering, design and technology (perceived relevance), student teachers engineering design SE and student teachers teaching engineering SE (self-efficacy).

2 METHODOLOGY

2.1 Measures

In line with the tripartite framework assessing perceived relevance, anxiety and self-efficacy, we made maximal use of three previously validated surveys to measure the importance student teachers attribute to engineering (Hong, Purzer, and Cardella 2011), as well as their engineering design SE (Mamaril et al. 2016) and teaching engineering SE (Yoon Yoon, Evans, and Strobel 2014). The affective dimension of the framework of van Aalderen-Smeets and Walma van der Molen (van Aalderen-Smeets and van der Molen 2015) was not included, since no validated instrument was found to measure engineering design anxiety.

First, to assess the student teachers' perceived relevance of engineering, we included items from the Design, Engineering and Technology (DET) survey (Hong, Purzer, and Cardella 2011) relating to the factor 'Importance of DET'. Items referring to learning more about DET through various resources, such as in-service education, workshops, college courses, etc. were omitted. For pre-service teachers taking a mandatory iSTEM didactics course that partially addresses learning more about these topics, these items were judged to be less relevant. Second, engineering design SE was assessed using all four items related to the ‘design’ factor in the Engineering Skills Self-Efficacy (ESS) scale from Mamaril (Mamaril et al. 2016). Third and last, all but one item associated with the ‘Engineering PCK Self-Efficacy’ factor from the Teaching Engineering Self-efficacy Survey (TESS) were included (Yoon Yoon, Evans, and Strobel 2014). The omitted item was considered irrelevant for student teachers as it inquired about taking the necessary time to plan engineering lessons, which is the main assignment of the iSTEM didactics course in which time is allocated for exactly this goal. The list of items included in the survey (back-translated from Dutch to English) is included in Table A1 in the appendix.

In accordance with (Yoon Yoon, Evans, and Strobel 2014) who provided argumentation for the type of scale used (Boone, Townsend, and Staver 2011), 6-point Likert-type scales were used for all items (strongly disagree, moderately disagree, disagree slightly more than agree, agree slightly more than disagree, moderately agree, strongly agree). This is in agreement with the scales used by (Mamaril et al. 2016) as well, while (Hong, Purzer, and Cardella 2011) used 4-point Likert-type scales.

Although these surveys were previously validated with undergraduate engineering students (Mamaril et al. 2016) or in-service elementary (Hong, Purzer, and Cardella 2011) or K-12 (Yoon Yoon, Evans, and Strobel 2014) teachers, re-validation with the target group of pre-service (master level) teachers is necessary due to possible differences between target groups, due to the grouping of items from multiple surveys, and due to the omission of a number of judged-to be irrelevant items.

2.2 Participants

In Flanders (Belgium), teachers are educated both on Bachelor (teaching either in primary or lower secondary school) and Master level (teaching 14-18 year olds in higher secondary education). KU Leuven has ten Masters of Teaching, including the Master of Teaching in Sciences and Technology (MoT S&T) of 60-120 ECTS depending on prior education. Most students enrolled in this program already have a Master’s degree in mathematics, (computer) science or engineering, and take the shortened track of 60 ECTS. Given the high demand for iSTEM teachers, even among students with no engineering background, all student teachers in KU Leuven’s MoT S&T take an obligatory course on integrated STEM education (6 ECTS, n=79 students still enrolled in February ‘24). The course consists of two parts: (1) iSTEM didactics, in which students get acquainted with iSTEM projects and the underlying principles, and design their own iSTEM project, and (2) an internship in which student teachers implement the designed iSTEM project with secondary school pupils of 14 to 18 years old. All student teachers enrolled in the iSTEM course were asked to participate in a survey (see Measures) using Microsoft Office 365 forms in the course of October, before their first iSTEM experiences. Pseudonymized responses were collected, in line with the ethics committee approval (G-2021-3888-R3). 67 student teachers (response rate: 85%, 52.6% male - 47.4% female, 21-58 y/o with avg: 29 y/o, sd: 8.4 y) completed the survey, in which response to all items was mandatory. The number and percentage of student teachers with their prior field of study is shown in Table 1. Although the sample size is small, it makes up approximately one in eight of the total population of MoT S&T students in Flanders in the academic year 2023-2024 (Departement Onderwijs en Vorming 2024). Furthermore, while larger sample sizes are customary for the validation of newly constructed surveys, simulations in (Jackson, Voth, and Frey 2013) indicate that a sample size of 25 *may* already be sufficient in case of high factor loadings, which are expected in our case (Table 1, with p/f=6 or 13,3 factors and α=0.8). The survey validation is still preliminary as we plan to further survey student teachers in the next academic year to further increase the sample size.

Table 1: Amount and percentage of student teachers with prior field of study.

	N	Percentage
Bio-engineering	12	17.91%
Biology, biotechnology, (bio)chemistry, geology, geography	15	22.39%
Engineering	29	43.28%
Mathematics, physics, informatics	9	13.43%
Veterinary	1	1.49%
Pharmacy	1	1.49%

2.3 Analyses

All analyses were executed in R v.4.2.3. (R Core Team 2023). Due to the limited sample size, the 6-point Likert-type scales, and non-normally distributed data (assessed using the Shapiro-Wilk test), the data were treated as ordered categorical variables. Descriptive statistics (mean, standard deviations, interitem polychoric correlations and item-to-(expected) scale correlations) were calculated. As the primary objective of the study is to evaluate the construct validity of a survey composed of items sourced from previously validated surveys, confirmatory factor analysis seems most appropriate. However, to explore the factor structure emerging from the collected data, we first carried out an exploratory factor analysis, using the same dataset.

2.3.1 Exploratory Factor Analysis (EFA)

Due to the limited sample size (n=67), the Kaiser-Meyer-Olkin test indicated it was inappropriate to analyse all 25 items at once. Results of the KMO test (KMO=0.75) and Bartlett's test of sphericity ($p<0.05$) indicated however that EFA was appropriate for two subsets of the data: a first subset containing the first 13 items, relating to perceived importance of engineering education, and a second subset including the last 12 items relating to (teaching) engineering SE. We carried out the EFA using the polychoric correlation values.

2.3.2 Confirmatory Factor Analysis (CFA) and Reliability estimation

Using the *lavaan* package, a weighted least squares (WLSMV) estimator was used for the confirmatory factor analysis, together with the *ordered* parameter set to true. Goodness-of-fit was examined with: RMSEA ≤ 0.06, SRMR ≤ 0.08, CFI ≥ 0.95, TLI ≥ 0.95 and chi-square/df ratio ≤ 3 (Hu and Bentler 1999; Brown 2015; Kline 2016). For each item, the overall reliability (Cronbach's alpha) for the factor structure without that item included, was calculated. After finalization of the factor structure and items, reliability coefficients alpha and omega (McDonald 1999) were calculated for each factor using the *omega* function from the *psych* package. Average variance extracted (AVE) was also calculated for each factor to assess the convergent validity.

3 RESULTS

3.1 Exploratory Factor Analysis (EFA)

Descriptive statistics are included in Table A1 in the appendix. For both subsets of the data (see Subsection 2.3.1), the point of inflection of a scree plot and Kaiser's criterion (the number of eigenvalues greater than one (Kaiser 1960)) indicated that the optimal number of factors was two. The EFA factor loadings (also included in Table A1) were partly in line with the three expected factors based on the existing instruments. However, the scree plot and the EFA factor loadings indicated that the first expected factor ('importance') split into two factors, one relating to the specific learning goals envisioned for the pupils (f1 in Table A1) and the other one relating more to the general motivation for and content in STEM and engineering education (f2 in Table A1). The second ('engineering design SE' – f3 in Table A1) and third ('teaching engineering SE' – f4 in Table A1) expected factor were partially recovered based on the EFA, although some items (TSE1 and TSE2) related to the third expected factor ('teaching engineering SE') loaded better on the second ('engineering design SE'). The phrasing of items TSE1 and TSE2 is also more in line with (general) engineering SE rather than teaching engineering SE. The rather low factor loadings and item-to-scale correlations for items IMP8 (0.43), IMP11 (0.33) and TSE1 (0.44) resulted in specific attention to these items during the remaining analysis.

3.2 Confirmatory Factor Analysis and Reliability estimation

First the default model, consisting of the three factors ('importance', 'engineering design SE', and 'teaching engineering SE') assembled from the pre-existing surveys, was constructed. Second, four CFA models based on the four-factor structure emerging from the EFA ('importance specific learning goals for pupils', 'motivation and content in STEM teaching', 'engineering SE' and 'teaching engineering SE') were made. Model 2 included all items from the survey. In models 3-4-5, respectively item IMP11, IMP8 and TSE1 were excluded due to the observed low factor loadings, low item-to-scale correlations and increased values for alpha-if-item-not-included.

Scaled fit indices are included in Table 2. CFI and TLI indicate a good model fit for all CFA models. The RMSEA value is borderline for appropriate model fit for Models 1-4 (Brown 2015), while the SRMR value is appropriate for good model fit, especially for Model 3. Model 3, with item IMP8 omitted, was selected as the best CFA model. While most items loading onto factor 2 relate to motivations for teaching STEM related to industrial and societal needs in connection to engineering, item IMP8 probes a more general motivation to make learning fun. Factor loadings and standard errors for the final CFA model (Model 3), as well as factor descriptions, factor reliability and AVE for each factor, are included in Table 3.

Table 2: CFA models with the Goodness-of-Fit indices (n=67).

Fit index	Model 0	Model 1	Model 2	Model 3	Model 4
Chi square	389.681	345.183	330.124	313.689	295.100
df	272	269	246	246	224
p-value	<0.001	0.001	<0.001	0.002	0.001

RMSEA	0.081	0.066	0.072	0.065	0.069
90% CI	(0.062-0.098)	(0.043-0.085)	(0.05-0.09)	(0.04-0.085)	(0.045-0.090)
CFI	0.963	0.976	0.974	0.979	0.978
TLI	0.959	0.973	0.97	0.976	0.975
SRMR	0.096	0.084	0.083	0.080	0.081
Nr factors	3 (default)	4 (EFA model)	4 (EFA model)	4 (EFA model)	4 (EFA model)
Nr items	25	25	24 (IMP11 excl)	24 (IMP8 excl)	24 (TSE1 excl)

4 SUMMARY

This study assessed the construct validity of a survey measuring teachers' attitudes based on a tripartite framework (van Aalderen-Smeets and van der Molen 2015). The survey consists of items assembled from previously validated instruments, but was administered to a new type of target group of master level student teachers. Despite the relatively limited sample size, CFA models with satisfactory convergence could be constructed, probably because items from previously validated instruments with high factor loading were used. However, based on the literature describing the existing instruments (Hong, Purzer, and Cardella 2011; Mamaril et al. 2016; Yoon Yoon, Evans, and Strobel 2014), we expected to find a three-factor model, consisting of the factors 'importance', 'engineering design self-efficacy' and 'teaching engineering self-efficacy'. The EFA and CFA results indicate good model fit, however, for a four-factor model, with factors 'importance attributed to learning goals for pupils', 'motivation and content in STEM teaching', 'engineering SE' and 'teaching engineering SE', with the omission of one survey item (IMP8) probing more general dispositions towards STEM teaching.

As – to our knowledge - there are no established test instruments available assessing student teachers attitudes towards pre-university engineering, the current study does not investigate concurrent or predictive validity, which could be investigated in the future. The sample size was also too small for cross-validation based on subsamples or measurement invariance across gender or prior field of study.

We aim to further validate the presented survey with larger sample sizes of student teachers. The validated survey will further be used to study the evolution of student teachers' attitudes towards engineering (design). Qualitative measures, such as interviews with student teachers, should provide more in-depth information, complementing the findings resulting from the quantitative approach using the survey.

Table 3: Parameter estimates of the final CFA Model (Model 3).

	CFA FL (stand)	SE (stand)	Item-to-scale *r*	Alpha without		CFA FL (stand)	SE (stand)	Item-to-scale *r*	Alpha without
Factor 1: importance attributed to learning goals for pupils (omega=0.92; alpha=0.89; AVE=0.81)					**Factor 3: engineering self-efficacy (omega=0.95; alpha=0.88; AVE=0.80)**				
S2_IMP1	0.85	0.04	0.74	0.87	**S2_SE1**	0.84	0.04	0.75	0.85

S2_IMP2	0.79	0.05	0.69	0.88	S2_SE2	0.96	0.03	0.85	0.84
S2_IMP3	0.87	0.04	0.76	0.87	S2_SE3	0.84	0.04	0.69	0.86
S2_IMP4	0.88	0.04	0.81	0.86	S2_SE4	0.90	0.03	0.79	0.85
S2_IMP5	0.73	0.06	0.65	0.88	S2_TSE1	0.49	0.09	0.43	0.90
S2_IMP9	0.86	0.05	0.74	0.87	S2_TSE2	0.76	0.06	0.66	0.87
S2_IMP11	0.60	0.10	0.45	0.90					
Factor 2: motivation and content in STEM teaching (omega=0.90; alpha=0.82; AVE=0.78)					Factor 4: teaching engineering self-efficacy (omega=0.97; alpha=0.93; AVE=0.92)				
S2_IMP6	0.90	0.06	0.68	0.77	S2_TSE3	0.88	0.04	0.80	0.92
S2_IMP7	0.81	0.06	0.67	0.77	S2_TSE4	0.90	0.04	0.83	0.91
S2_IMP10	0.69	0.08	0.56	0.80	S2_TSE5	0.77	0.06	0.70	0.93
S2_IMP12	0.69	0.07	0.53	0.81	S2_TSE6	0.84	0.05	0.78	0.92
S2_IMP13	0.78	0.07	0.66	0.77	S2_TSE7	0.90	0.03	0.81	0.92
					S2_TSE8	0.93	0.02	0.85	0.91

REFERENCES

Aalderen-Smeets, Sandra I. van, and Juliette H.Walma van der Molen. 2015. “Improving Primary Teachers’ Attitudes toward Science by Attitude-Focused Professional Development.” *Journal of Research in Science Teaching* 52 (5): 710–34. https://doi.org/10.1002/tea.21218.

Ajzen, I. 2005. *Attitudes, Personality and Behavior.*

Boone, William J., J. Scott Townsend, and John Staver. 2011. “Using Rasch Theory to Guide the Practice of Survey Development and Survey Data Analysis in Science Education and to Inform Science Reform Efforts: An Exemplar Utilizing STEBI Self-Efficacy Data.” *Science Education* 95 (2): 258–80. https://doi.org/10.1002/sce.20413.

Brown, T. A. 2015. *Confirmatory Factor Analysis for Applied Research*.

Departement Onderwijs en Vorming. 2024. “Opleiding HO in Cijfers.” Opleiding HO in Cijfers. 2024. https://onderwijs-tableau.vlaanderen.be/t/EXTERN/views/OpleidingHOincijfers/HOME?%3Aembed=y&%3AisGuestRedirectFromVizportal=y.

DeVellis, Robert F. 2017. “Scale Development Theory and Applications (Fourth Edition).” *SAGE Publication* 4:256.

Fan, Szu Chun, Kuang Chao Yu, and Kuen Yi Lin. 2021. “A Framework for Implementing an Engineering-Focused STEM Curriculum.” *International Journal of Science and Mathematics Education* 19 (8): 1523–41. https://doi.org/10.1007/s10763-020-10129-y.

Hong, Tao, Şenay Purzer, and Monica E. Cardella. 2011. “A Psychometric Re-Evaluation of the Design, Engineering and Technology (DET) Survey.” *Journal of Engineering Education* 100 (4): 800–818. https://doi.org/10.1002/j.2168-9830.2011.tb00037.x.

Jackson, Dennis L., Jennifer Voth, and Marc P. Frey. 2013. “A Note on Sample Size and Solution Propriety for Confirmatory Factor Analytic Models.” *Structural Equation Modeling* 20 (1): 86–97. https://doi.org/10.1080/10705511.2013.742388.

Johnson, Carla C., Tamara J. Moore, and Erin E. Peters-Burton. 2021. *STEM Road Map 2.0: A Framework for Integrated STEM Education in the Innovation Age*. *STEM Road Map 2.0: A Framework for Integrated STEM Education in the Innovation Age*. https://doi.org/10.4324/9781003034902.

Jöreskog, K. G., and D Sörbom. 1984. *LISREL 6 : Analysis of Linear Structural Relationships by Maximun Likelihood, Instrumental Variables and Least Squares Methods.*

Kaiser, Henry F. 1960. “The Application of Electronic Computers to Factor Analysis.” *Educational and Psychological Measurement* XX (1): 141–51.

Maio, G. R., and Geoffrey. Haddock. 2009. *The Psychology of Attitudes and Attitude Change.*

Mamaril, Natasha A., Ellen L. Usher, Caihong R. Li, D. Ross Economy, and Marian S. Kennedy. 2016. “Measuring Undergraduate Students’ Engineering Self-Efficacy: A Validation Study.” *Journal of Engineering Education* 105 (2): 366–95. https://doi.org/10.1002/jee.20121.

McDonald, R.P. 1999. *Test Theory. A Unified Treatment*. *Mahwah, NJ: Lawrence Erlbaum*. https://doi.org/10.2307/1167177.

Phelps, L Allen, Eric M Camburn, and Sookweon Min. 2018. “Choosing Stem College Majors: Exploring the Role of Pre-College Engineering Courses.” *Journal of Pre-College Engineering Education Research* 8 (1): 1–24. https://doi.org/10.7771/2157-9288.1146.

Pintó, Roser. 2005. “Introducing Curriculum Innovations in Science: Identifying Teachers’ Transformations and the Design of Related Teacher Education.” *Science Education* 89 (1): 1–12. https://doi.org/10.1002/sce.20039.

R Core Team. 2023. “R: A Language and Environment for Statistical Computing.” R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Richards, Larry G, and Susan K Donohue. 2015. “Pre-College (K-12) Engineering Education: Getting Them Early... and Keeping Them!” In *Proceedings - Frontiers in Education Conference, FIE*, 2015-Febru:1–4. IEEE. https://doi.org/10.1109/FIE.2014.7044309.

Roehrig, Gillian H., Emily A. Dare, Joshua A. Ellis, and Elizabeth Ring-Whalen. 2021. “Beyond the Basics: A Detailed Conceptual Framework of Integrated STEM.” *Disciplinary and Interdisciplinary Science Education Research* 3 (1). https://doi.org/10.1186/s43031-021-00041-y.

Roehrig, Gillian H., Rebecca A. Kruse, and Anne Kern. 2007. “Teacher and School Characteristics and Their Influence on Curriculum Implementation.” *Journal of Research in Science Teaching* 44 (7): 883–907. https://doi.org/10.1002/tea.20180.

Sperber, Ami D. 2004. “Translation and Validation of Study Instruments for Cross-Cultural Research.” *Gastroenterology* 126 (1): 124–28. https://doi.org/10.1053/j.gastro.2003.10.016.

Thibaut, Lieve, Heidi Knipprath, Wim Dehaene, and Fien Depaepe. 2018a. “The Influence of Teachers’ Attitudes and School Context on Instructional Practices in Integrated STEM Education.” *Teaching and Teacher Education* 71:190–205. https://doi.org/10.1016/j.tate.2017.12.014.

Thibaut, Lieve, Heidi Knipprath, Wim Dehaene, and Fien Depaepe. 2018b. “The Influence of Teachers’ Attitudes and School Context on Instructional Practices in Integrated STEM Education.” *Teaching and Teacher Education* 71:190–205. https://doi.org/10.1016/j.tate.2017.12.014.

Thibaut, Lieve, Heidi Knipprath, Wim Dehaene, and Fien Depaepe. 2019. “Teachers’ Attitudes Toward Teaching Integrated STEM: The Impact of Personal Background Characteristics and School Context.” *International Journal of Science and Mathematics Education* 17 (5): 987–1007. https://doi.org/10.1007/s10763-018-9898-7.

Vries, Marc J de, Lena Gumaelius, and Inga-Britt Skogh. 2016. *Pre-University Engineering Education*. *Pre-University Engineering Education*.

Yoon Yoon, So, Miles G. Evans, and Johannes Strobel. 2014. “Validation of the Teaching Engineering Self-Efficacy Scale for K-12 Teachers: A Structural Equation Modeling Approach.” *Journal of Engineering Education* 103 (3): 463–85. https://doi.org/10.1002/jee.20049.

APPENDIX

Table A1: Survey items (back-translated to English – [] indicate small changes compared to original instruments) with descriptive statistics: mean (M), standard deviation (SD), interitem and item-to-scale correlations, and EFA factor loadings (fx = factor x).

		M	SD	IMP1	IMP2	IMP3	IMP4	IMP5	IMP6	IMP7	IMP8	IMP9	IMP10	IMP11	IMP12	Item-to-scale r	EFA FL
IMP1	I would like to be able to teach my students to understand the use and impact of design, engineering and technology	4.93	0.96	-												0.69	0.79 (f1)
IMP2	I would like to be able to teach my students to understand the science underlying design, engineering and technology	5.00	0.98	0.62	-											0.57	0.87 (f1)
IMP3	I would like to be able to teach my students to understand the design process	4.90	0.89	0.75	0.68	-										0.67	0.89 (f1)
IMP4	I would like to be able to teach my students to understand the types of problems to which design, engineering and technology can be applied	5.01	0.95	0.80	0.67	0.76	-									0.76	0.88 (f1)
IMP5	I would like to be able to teach students to understand the process of communicating technical information	4.81	0.89	0.58	0.53	0.75	0.66	-								0.61	0.7 (f1)
IMP6	My motivation for teaching STEM [science] is to promote an understanding of how design, engineering and technology affects society	4.90	1.09	0.59	0.46	0.49	0.68	0.46	-							0.71	0.59 (f2)
IMP7	My motivation for teaching STEM [science] is to prepare young people for the world of work	4.67	1.19	0.40	0.43	0.49	0.43	0.41	0.55	-						0.64	0.77 (f2)
IMP8	My motivation for teaching STEM [science] is to promote an enjoyment of learning	5.16	1.00	0.42	0.27	0.38	0.45	0.46	0.44	0.50	-					0.42	0.43 (f2)
IMP9	I would like to be able [My motivation for teaching science is] to help students develop an understanding of the technical world	5.03	0.87	0.65	0.66	0.65	0.79	0.64	0.65	0.54	0.50	-				0.75	0.63 (f1)
IMP10	My motivation for teaching STEM [science] is to educate scientists, engineers and technologists for the industry	4.60	1.17	0.36	0.24	0.38	0.35	0.30	0.33	0.77	0.31	0.37	-			0.50	0.74 (f2)
IMP11	Design, engineering and technology has positive consequences for society	5.57	0.58	0.51	0.56	0.44	0.49	0.28	0.47	0.44	0.35	0.48	0.51	-		0.48	0.53 (f1)
IMP12	I believe design, engineering and technology should be integrated into the primary and secondary school [K-12] curriculum	4.66	0.95	0.47	0.24	0.32	0.41	0.40	0.70	0.43	0.48	0.59	0.35	0.30	-	0.51	0.74 (f2)
IMP13	In a STEM [science] curriculum, it is important to include the use of engineering in developing new technologies	4.79	0.96	0.46	0.29	0.55	0.54	0.40	0.66	0.48	0.29	0.52	0.50	0.35	0.66	0.61	0.69 (f2)

		M	SD	SE1	SE2	SE3	SE4	TSE1	TSE2	TSE3	TSE4	TSE5	TSE6	TSE7		Item-to-scale r	EFA FL
SE1	I can identify a design need	4.10	0.99	-												0.74	0.91 (f3)
SE2	I can develop a design solution	3.90	1.07	0.79	-											0.87	0.84 (f3)
SE3	I can evaluate a design	4.01	1.11	0.67	0.78	-										0.72	0.60 (f3)
SE4	I can recognize changes needed for a design solution to work	4.06	1.09	0.79	0.90	0.74	-									0.82	0.96 (f3)
TSE1	I can discuss how engineering is connected to my daily life	4.73	0.81	0.37	0.42	0.30	0.45	-								0.38	0.44 (f3)
TSE2	I can recognize and appreciate the engineering concepts in all subject areas	4.41	1.03	0.69	0.64	0.55	0.55	0.56	-							0.66	0.51 (f3)
TSE3	I can employ engineering activities in the classroom effectively	3.52	1.24	0.46	0.60	0.54	0.51	0.34	0.55	-						0.79	0.94 (f4)
TSE4	I can craft good questions about engineering for my students	3.51	1.11	0.48	0.64	0.62	0.53	0.26	0.59	0.89	-					0.81	0.97 (f4)
TSE5	I can discuss how given criteria affect the outcome of an engineering project	3.94	1.11	0.52	0.60	0.61	0.54	0.39	0.62	0.60	0.77	-				0.72	0.6 (f4)
TSE6	I can guide my students' solution development with the engineering design	3.71	1.19	0.55	0.70	0.49	0.55	0.22	0.51	0.72	0.69	0.61	-			0.76	0.77 (f4)
TSE7	I can gauge student comprehension of the engineering materials that I have taught	3.78	1.17	0.58	0.70	0.68	0.58	0.36	0.60	0.69	0.70	0.59	0.78	-		0.81	0.72 (f4)
TSE8	I can assess my students' engineering products	4.00	1.26	0.52	0.69	0.71	0.61	0.39	0.63	0.73	0.72	0.65	0.80	0.88		0.85	0.78 (f4)

EXPLORING THE EFFECT OF CHANGES IN THE FORMULATION OF LEARNING OUTCOMES ON THE TEACHING AND LEARNING OF ETHICS IN ENGINEERING PROGRAMMES IN SOUTH AFRICA

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ABSTRACT

Accreditation documents provide direction for engineering programmes as regards the balance of credits, the knowledge profile and coherent design and of the resourcing and sustainability of the programme. These documents have considerable strategic impact on the identification of learning objectives, the assessment process and, consequently, on the quality of teaching and learning within engineering programmes. This paper uses discourse analysis to examine changes in the formulation of accreditation documents outlining graduate attributes for university-based engineering programmes in South Africa over a twenty-four year period. It examines the potential effect of these changes on the formulation of learning objectives and assessment relating to the teaching and learning of ethics within engineering programmes at South African universities.

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1 INTRODUCTION

The paper sets out to examine how changes in policy documents relating to the accreditation of engineering programmes potentially affect the way ethics is taught and assessed within engineering programmes. This builds on the analysis by Gwynne-Evans et al. (2021) as regards the significance of ethics across the graduate attributes in the South African accreditation standards.

This analysis will be done through an examination of the shifts in emphasis in these accreditation documents over time, looking specifically at changes in:

- how knowledge is conceptualised in these documents,
- the formulation of programme level outcomes and graduate attributes,
- the scope of what is addressed in the learning outcomes, including level descriptors, range statements, associated assessment criteria and developmental considerations.

This paper builds on work by Junaid et al. (2021; 2022) that examined how engineering ethics is portrayed in accreditation documents, extending the European analysis to a global perspective. The earlier research examined current accreditation documents from a range of countries to determine trends or differences across countries and aimed to profile similarities and differences in the way ethics is framed in policy documents in a global context. In both the earlier European and the global analyses, the methodology required a comparison of the definitions of key terms in and across accreditation documents; a tabulation of the learning outcomes that refer to ethics, distinguishing between implicit and explicit references, and the examination and analysis of the verbs used to formulate these learning outcomes relating to ethics (Junaid et al. 2021, 2022). Junaid et al. (2021; 2022) drew attention to the way that higher education institutions rely on their respective national accreditation documents as one of their primary resources in programme content and development. This, in turn, draws attention to the way in which programme developers are dependent on the use of language in these documents, including the definitions provided together with the format of learning outcomes, as integral to the process of formulating the engineering curriculum.

This research will examine changes in the South African engineering accreditation policy documents that relate to ethics, over a period of twenty-four years, covering the seven versions of the accreditation standards published during this time. It addresses the research question:

"How do the changes in the definition of graduate attributes over time in a particular context potentially impact the teaching of ethics within engineering programmes?"

This distinguishes the regulator's responsibility for administering and communicating the accreditation criteria for engineering programmes from the responsibility of the higher education institutions to engage with the requirements outlined in the documents so as to articulate learning objectives, to design input and interventions that lead to the assessment of the graduate attributes at exit level. It sets out to identify changes to existing terms and categories in the accreditation standards documents over the years in the different versions of the documents and to examine the potential significance of these changes. The engineering programme involves a structured, integrated teaching and learning arrangement with a defined purpose and pathway that leads to a qualification (ECSA, 2023:10), in terms of specific educational objectives that graduates of a programme must accomplish (ECSA, 2023:7).

2 METHODOLOGY

This analysis uses discourse analysis to build on the research method of the Junaid et al. (2021; 2022) papers, where, instead of examining accreditation documentation in a multi-country analysis, seven different versions of the South African accreditation documentation relating to engineering programme standards are examined.

Discourse Analysis is utilised as an analytical tool to demonstrate how language works to expand and restrict meaning within texts. Discourse is positioned as:

"an ensemble of ideas, concepts and categories through which meaning is given to social and physical phenomenon, and which is produced and reproduced through an identifiable set of practice" (Hajer & Versteeg, 2005:175).

Discourse analysis is proposed as a tool that enables analysis to go beyond the mechanics of the text to include the context and historicity of the text and to enable the examination of contested power relationships (Jorgensen & Phillips, 2002). It builds on and strengthens the internal cohesion between collective forms of reasoning manifested in the societal structures, practices and institutions, including that of policy documents (Rozema & Bond, 2015:67) and codes of conduct.

It recognises the policy making process takes place within a context where meaning is symbolic, inherited and stable, where change itself may be seen to signal significance. This process of discourse analysis recognises that documents communicate both through the stability of the document format over time, as well as in the changes to these documents. It is potentially the changes that signify shifts of meaning and emphasis relating to these terms. As such, the discourse analysis will draw on the structure used by Junaid et al. (2021; 2022) but will execute it differently, focusing in on the changes to the documents over the years and interpreting these changes as significant in terms of the context of engineering practice in South Africa.

The documents examined are the seven versions of the accreditation standards for university programmes within engineering in South Africa, covering a period of twenty-four years, from the passing of the Engineering Professions Act in 2000 to August 2023 (ECSA, 2000; 2004; 2012; 2014; 2019; 2020; 2023).

2.1 Classification of key terms and categories in the documents

Whereas many of the terms are standard across the different versions of the accreditation documents, there are areas where there have been significant changes or where the use of a particular term or concept distinctively contributes to the overarching argument of the document.

The term *exit level outcomes (ELOs)* used in version 2 and 3 to describe the required outcomes of engineering programmes is replaced by *graduate attribute* (GA) in the fourth and following versions (ECSA, 2004; 2012; 2014). Both terms are formulated in terms of a number from one to eleven – relating the required outcomes to the specific exit level outcome or graduate attribute. These learning outcomes are depicted in terms of categories that include:

- Name
- Description
- Range statement
- Associated knowledge & attitude
- Associated assessment criteria
- Developmental considerations.

While the range statement category is consistent across the different versions for all the graduate attributes except ELO/GA1, the associated assessment criteria, knowledge and attitudes and the development considerations appear predominantly in the more recent versions of the documents.

2.2 Identification of explicit and implicit references to ethics

Each of the seven versions of the accreditation standards documents will be examined to see where the following terms that relate explicitly to ethics and professionalism are used:

- Ethics/Ethical/Ethically
- Professional/Professionally/Professionalism.

In addition to these terms, terms that are implicitly related to ethics, that occur in the accreditation document and that are synonyms to those appearing in the table formulated by Junaid et al. (2021), will be traced to see where and how often they occur in the South African Accreditation Standards. The additional terms that implicitly relate to ethics and that can be identified in at least one of the seven versions of the Accreditation Standards examined will be:

- Responsibility/Responsibilities
- Exercise judgement
- Law/Rules/Codes
- Sustainable/Sustainability
- Inclusion/Inclusive/Inclusivity
- Diversity
- Holistic
- Social/Society/Societal
- Safety
- Risk
- Critical thinking
- Values
- Technology/Technologies.

This recognises that several concepts that would potentially be included, such as *social justice* or *ubuntu*, were not found in the documents and so were not included.

2.3 Analysis of the verbs used in ethics-related learning outcomes

Verbs used in the formulation of the ethics-related learning outcomes will be examined to determine the range of actions and reflections required of graduate students. Changes in the formulation of verbs will be examined in terms of how this affects the level and range of what the student is expected to achieve.

3 Results

3.1 The South African Accreditation Standard documents

In terms of South African legislation in the Engineering Professions Act of 2000 (South Africa, 2000), the Engineering Council of South Africa (ECSA) is the professional body mandated to accredit engineering programmes that prepare students for registration as candidate engineers and both to register and regulate the conduct of registered engineers as professionals by assessing their conduct. The ECSA Accreditation Standards form part of a collection of documents that deal with the regulation and administration of engineering education within the public and government sector. As such the language is primarily aligned with the language of public administration and regulation.

The language of the formulation of the original document outlining the Standards for Accredited University Engineering Bachelors' Degrees sets out to be functional and objective. It defines the purpose of the document as ensuring the "outcomes of a university bachelor's degree programme … that is acceptable for accreditation as meeting the educational requirements toward registration with ECSA as a Professional Engineer" (ECSA, 2000:1). This original purpose is updated in the second version to include building "the necessary knowledge, understanding, abilities and skills required for further learning towards becoming a competent practicing engineer" (ECSA, 2004:1). This revised formulation provides a foundation for assessment that goes beyond theoretical knowledge and skills to include values and attitudes. This distinction provides a foundation for expanding the scope of knowledge and assessment beyond theoretical or scientific knowledge and skills to include practical knowledge (Wolmerans, 2022) that responds to context and experience, incorporating and building on values and attitudes. This shift creates the space to moves the focus of the engineering programme from transferring rational and objective knowledge and technical skill to a more responsive, experiential process where developing mindsets and agency are recognised as equally important to the technical or knowledge outputs.

3.2 Identification of key terms and categories used in the South African accreditation documents that impact how ethics is positioned

The ECSA Accreditation Standards are formulated in terms of specific categories and criteria. At a most basic level, *standards* comprise statements of outcomes to be demonstrated and the levels of performance and content baseline requirements in the context of engineering educational programmes (ECSA, 2023: 10).This distinguishes the "*required outcome*" and the "*exit level outcome*" from the "*graduate attribute*" as the "statement of the learning outcomes that a student must demonstrate at the exit-level to qualify for an award of a qualification; these actions indicate the student's capability to fulfil the educational objectives" (ECSA, 2023: 8). This shift from *exit level outcomes* of a **programme** to *graduate attributes* of the **engineering graduate** reinforces the expansion of the accreditation standards to incorporate values and attitudes alongside knowledge and skills. Despite the change of term, the significance of the reference of *exit level outcome* and *graduate attribute* has not been clearly differentiated in the re-formulation of the outcomes as attributes.

Across the seven versions of the accreditation standards, there is noticeable stability in the formulation of these learning outcomes over time, where, for instance, the description of Engineering Professionalism as "Demonstrate *critical awareness* of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence", stays constant over five versions of the accreditation standards (ECSA, 2004; 2010; 2014; 2020; 2021).

These *standards* further distinguish categories including the:

- *range statement* for each particular learning outcome that "provides a context in which assessment may take place against an outcome and is expressed in

terms of situations, activities, tasks, methods and forms of evidence” (ECSA, 2023:10)
- the *assessment criteria* as “set of measurable performance requirements which indicates that a person meets a specified outcome at the required level. (ECSA, 2023: 7)
- the *associated knowledge and attitudes* as a classification of knowledge content into defined types (ECSA, 2023*)* and
- the *developmental considerations* (ECSA, 2023: 7) first operationalized in version 7 across GAs 7-10 and not yet defined.

Table 1 below depicts the occurrence of concepts relating to ethics across the seven versions of the ECSA accreditation standards.

Table 1: Analysis of the occurrence of concepts relating to ethics in the learning outcomes or graduate attributes of the 7 versions of the ECSA Accreditation Standards

Note: Exit level outcomes/Graduate attributes are referred to in terms of their number, 1-11.

Concepts relating to ethics in the different versions of the E-02-PE Accreditation Standard	Version1 2000	Version 2 2004	Version3 2012	Version 4 2014	Version 5 2020	Version 6 2021	Version 7 2023
Ethics/Ethical/Ethically	10/10	9/10	7/9/10	9/10/10	9/10/10	9/10/10	8/10/10
Profession/Professional/ Professionalism	6/10	6/6/6/10/10/10	6/6/6/7/10/10	6/6/6/10/10/10	6/6/6/10/10/10	6/6/6/10/10/10	6/6/6/7/8/10/10/10
Responsibility/ Responsibilities		9/9/10/10	7/9/9/10/10	9/9/10/10	9/9/10/10	9/9/10/10	7/8/10
Exercise judgement	3/10	3/10	10	10	10	10	10*
Social/Society/Societal	7/7/7/7	3/7/7/7/7/9	7/7/7/7/9	7/7/7/7/9	7/7/7/7/9	7/7/7/7/9	1/3/6/7/7/7/7/7/7
Sustainable/sustainability			7	7/7/7	7/7/7	7/7/7	1/7/7/7/7
Safety	3/6	3/5/7	5/7	7	7	7	3/7/7/7
Risk	2	2	5	7	7	7	7
Critical thinking							4/9
Law/Code/Rules	2/2/3	2/2/3	1				10
Value/values	7	7					8
Diverse/Diversity							8/10
Inclusive/Inclusively/Inclusion							6/8/10
Holistic							1
Technology/Technologies	5/7	5/5/7	5/5	5/5			9
Sub-total of references to concepts relating to ethics	19	31	27	28	24	24	45

*In the current version ”exercise” has been replaced by “good” judgement.

From the table, the cumulative number of references to concepts relating to ethics can be seen. Whereas the sub-totals stay relatively stable across the documents, with a mid-peak for the second version, there is a significant increase in references in the most recent version of the document. It is evident from table 1 that the latest version of the specified learning outcomes has a far wider range of graduate attributes that incorporate concepts that relate to ethics. The accreditation standards have shifted to seeing ethics as relevant across a wide range of learning outcomes.

3.3 Verbs used in ethics-related learning outcomes in the South African accreditation documents

Level descriptors measure learning demands regarding types of problems, knowledge required, skills and responsibility (ECSA, 2023: 7). The level of achievement shifts from ensuring the graduate “*is competent*” (V1, ECSA, 2000) to “*demonstrates competence*” (V2, ECSA, 2004) for eight of the ten learning outcomes. The shift between the two formulations is subtle, where “*is competent*” suggests a completed achievement, in contrast the revised "*demonstrates competence*" signals both the need for active evidence and, with the present form of the verb, invites continued engagement in the learning process beyond the immediate assessment process. This formulation "demonstrates competence" is used across the majority of the learning outcomes and remains stable across the middle five versions of the standards. Two learning outcomes most obviously connected to ethics, GA7 and GA10, include the word "ethics" or "ethical" in their range statements, and are distinctive in their formulation: rather than requiring *competence*, GA10 requires "*critical awareness of the need to* act professionally and ethically and to exercise judgment and take responsibility within own limits of competence" and GA7 requires "*critical awareness of* sustainability and the impact of engineering on the environment (ECSA, 2004; 2012; 2014; 2019; 2020).

The removal of the verb "to exercise judgement" in the most recent version of GA10, replaces it with the verbs "apply", "commit to" and "adhere to" (ECSA, 2023). "Good judgement" is referenced in the same graduate attribute as a developmental consideration, without clear defining how this is determined. Noteworthily, despite the apparent widening of references to concepts relating to ethics in the documents, the verbs used in the new graduate attribute remove the reference to exercising judgement that is at the heart of ethical decision-making (Gwynne-Evans et al., 2021). This limits the practice of engineering professionalism to application and compliance rather than developing the capacity to make responsible decisions.

This examination of the effect of changes in the use of verbs relating to learning outcomes relating to ethics, demonstrates the importance of a scrutiny of small changes that, potentially, have significant impact on the engineering curriculum and on the learning that is being curated.

3.4 Changes in the conception of knowledge in the accreditation documents

In the documents, engineering is conceptualised as a problem-solving activity, requiring competence to "identify, assess, formulate and solve convergent and divergent engineering problems creatively and innovatively" (ECSA, 2000:1). Subsequent formulations presume a "conscious and logical approach" that relies on the application of engineering knowledge, skills and generic competencies (ECSA, 2023:5). The adjectives used to characterise the problem-solving process include a "fundamentals-based, first principles analytical approach" and "a systematic, theory-based formulation of engineering fundamentals required in the engineering discipline" (ECSA, 2023:17), characterising knowledge as ordered, rational and predictable. These formal characteristics of knowledge are contrasted with the "awareness of the power of critical thinking and creative approaches to evaluate emerging issues" that address complex problem-solving. This involves "wide-ranging and/or conflicting technical, non-technical issues (such as ethical, sustainability, legal, political, economic, societal) and consideration of future requirements", that have "no obvious solution and require abstract thinking, creativity and originality in analysis to formulate suitable models" and may require innovative strategies to address "problems not encompassed by standards and codes of practice for professional engineering" that require "collaboration across engineering disciplines… and diverse groups of stakeholders with widely varying needs" (ECSA, 2023:17). This conceptualisation juxtaposes a view of knowledge as fixed and finite with the recognition of the need for knowledge that is transformative and emerging.

4 Conclusions

In the absence of a definition of ethics in the accreditation standards and in the ECSA Code of Conduct (2017), this analysis will be viewed as contributing to the formulation of a working definition of ethics within engineering in the South African policy context. As such the analysis provides evidence of shifts in the regulator-based requirements for teaching and assessing ethics across the engineering programme. These shifts are impacted by two areas that potentially affect the formulation of the requirements for engineering programme accreditation: how the concept of complexity is positioned and what is considered knowledge.

In the past versions of the accreditation standards, engineering professionalism, as GA10, required that students "demonstrate critical awareness of the need to act professionally and ethically and to exercise judgement and to take responsibility within own limits of competence". This definition encapsulated several concepts that fall outside of the rational and scientific discourse that is associated with engineering and outside the technical management discourse of public administration. The formulation of GA10 was consistent across five of the seven version of the accreditation documents (ECSA, 2004; 2012; 2014; 2019; 2020), where "the need to act professionally and ethically and to exercise judgement and to take responsibility" signalled a conception of knowledge that incorporates norms and values and requires the exercise of judgement rather than mere compliance.

This analysis recognises that policy documents make epistemological and ontological claims that subtly influence how the policy document communicates. As such, it is evident that the vocabulary and concepts encapsulated in engineering accreditation standards necessarily impacts the curriculum and the focus and objectives of learning within the engineering programme.

Engineering ethics is a complex construct that straddles a number of disciplines including philosophy, psychology, law, economics and engineering. As such, engineering ethics needs to be recognised as both integral and peripheral to the practice of engineering, requiring that engineers step beyond the scientific and rational constructs of the sciences to imagine and create a world that incorporates concepts and values such as "diversity", "justice" and "integrity" and "sustainability".

Reference list

Engineering Council of South Africa (ECSA). *Standards for Accredited University Engineering Bachelors Degrees*, *Document PE-61, Revision 1, 20 July 2000*. Johannesburg: Engineering Council of South Africa, 2000.

Engineering Council of South Africa (ECSA). *Whole Qualification Standard for Bachelor of Science in Engineering (BSc(Eng)/Bachelors of Engineering (BEng): NQF Level 7, Document: PE-61/E-02-PE, Revision 2, 26 July 2004*. Johannesburg: Engineering Council of South Africa, 2004.

Engineering Council of South Africa ECSA). *Qualification Standard for Bachelor of Science in Engineering (BSc(Eng)/Bachelors of Engineering (BEng): NQF Level 8,* *Document: E-02-PE, Revision 3, Draft E, 21 June 2012.* Johannesburg: Engineering Council of South Africa, 2012.

Engineering Council of South Africa ECSA). *Qualification Standard for Bachelor of Science in Engineering (BSc(Eng)/Bachelors of Engineering (BEng): NQF Level 8, Document: E-02-PE, Revision 4, 31 July 2014.* Johannesburg: Engineering Council of South Africa, 2014.

Engineering Council of South Africa ECSA). *Qualification Standard for Bachelor of Science in Engineering (BSc(Eng)/Bachelors of Engineering (BEng): NQF Level 8*, *Document: E-02-PE, Revision 5, 17 April 2019.* Johannesburg: Engineering Council of South Africa, 2019.

Engineering Council of South Africa (ECSA). *Qualification Standard for Bachelor of Science in Engineering BSc (Eng))/Bachelor of Engineering (BEng): NQF Level 08, Document E-02-PE*, *Revision 6, 1 September 2020.* Johannesburg: Engineering Council of South Africa, 2020.

Engineering Council of South Africa (ECSA). *Qualification Standard for Bachelor of Science in Engineering BSc (Eng))/Bachelor of Engineering (BEng). NQF Level 08, Document E-02-PE*, *Revision 7, 24 August 2023.* Johannesburg: Engineering Council of South Africa, 2023.

Engineering Council of South Africa (ECSA). 2018. Guide to the Competency Standards for Registration as a Professional Engineer R-08-PE Revision 2: 22 May. Johannesburg: Engineering Council of South Africa, 2018.

Engineering Council of South Africa (ECSA). Policy on Accreditation of Engineering Programmes E-01-POL Revision 1, 18 May 2022. Johannesburg: Engineering Council of South Africa, 2022.

Engineering Council of South Africa ECSA). *Criteria for Accreditation of Engineering Programmes, Document E-03_CRI-P, Revision 4, 15 October 2020.* Johannesburg: Engineering Council of South Africa, 2020b.

Gwynne-Evans, A., M. Chetty, and S. Junaid. “Repositioning ethics at the heart of engineering graduate attributes.” *Australasian Journal of Engineering Education 26, 1 (2021): 7-24*.

Hajer, M. and W. Versteeg. “A decade of discourse analysis of environmental politics: achievements, challenges, perspectives.” *Journal of Environmental Policy and Planning* 7, 3 (2005): 175-184.

Jorgensen, M., & L. J. Phillips. “*Discourse Analysis as Theory and Method*.” London: Sage, 2002.

Junaid S**, H.** Kovacs, D. A. Martin, Y. Serreau. “What is the Role of Ethics in Accreditation Guidelines for Engineering Programmes in Europe?” In *SEFI 2021 - 49th Annual Conference Proceedings of the European Society for Engineering Education: Blended Learning in Engineering Education: challenging, enlightening – and lasting? Berlin, Germany (virtual), 13-16 September*, pp. 268-276.

Junaid, S., A. Gwynne-Evans, H. Kovacs, J. Lönngren, J. F. Mejia, et al. “What is the role of ethics in accreditation documentation from a global view?” In *SEFI 2022 - 50th Annual Conference of the European Society for Engineering Education:*

Towards a new future in engineering education, new scenarios that European alliances of tech universities open up Barcelona, Spain, 19-22 Sep 2022, 369-378.

Rozema, J. G. and A. J. Bond. “Framing effectiveness in impact assessment: Discourse accommodation in controversial infrastructure development.” *Environmental Impact Assessment Review* 50, (2015): 66-73.

South Africa. *Engineering Professions Act, Number 46 of 2000,* Government Gazette 426, Number 1821, 1 Dec 2000. Pretoria: South Africa, 2000.

Wolmarans, N. “Recontextualising professional knowledge: a view on ‘practical knowledge’.” *Teaching in Higher Education*, 27: 8, 2022, 1042-1057. DOI: 10.1080/13562517.2022.2119078.

An exploratory analysis of student behaviour, performance and evaluation in hybrid and blended first year bachelor calculus course

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ABSTRACT

There are significant benefits to be gained by incorporating a more flexible combination of synchronous and asynchronous online study activities into academic courses. However, a common concern is that students miss out on relevant campus activities and valuable information. This can pose challenges, particularly for first year students. Therefore, the implementation of an online format for a first year mathematics course warranted close monitoring and evaluation of student behaviour and performance. Following the students during a whole semester we found that students selecting the online course and online activities were slightly older students. The course format did not affect the students exam performance, and students in the online class felt equally well supported, had similar experiences of mastery and expectations for succes.

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1 INTRODUCTION

1.1 Background

Many universities have adopted various forms of technology-mediated course delivery to improve student access to courses, course lectures and course materials (Rasheed, Kamsin and Abdullah, 2020). By offering a broad range of synchronous and asynchronous activities both online and in-class, students can study whenever and wherever they prefer. Such a flexible offer to students may combine the benefits of in-class and online courses: students can study at their own pace, experience more autonomy in planning and selecting study activities and they can join both on-campus activities and online fora to connect to other students, teaching assistants and the teachers. Furthermore, online course content can be enriched (e.g., subtitling), allows students to use multiple input devices (e.g., voice-operated) in different languages, and use other tools for narration and/or translation. As such, online course content can create more accessible and inclusive education.

There are different terms for slightly different forms of orgnisation of classes or courses with online components: Blended and Hybrid learning are often used interchageably to indicate courses that combine in class and online learing activities, whereas flipped classrooms is a particular organisation of these components such that instructional digital content, often in the form of videos is provided to students to study at home. And class time is then used for engaging in interactive activities. Reviews of blended and hybrid learning show positive effects of incorporating online components in a course (e.g., Balakrishnan et al., 2021; Bernard et al., 2014; Liu et al., 2016). And this is also true for the flipped classroom approach (Lo and Hew, 2019), although some reviews show no significant difference between flipped and traditional classrooms (Chen, Lui, and Martinelli, 2017).

In conclusion, there are significant benefits to be gained by incorporating a more flexible combination of synchronous and asynchronous online study activities into academic courses. However, a common concern is that the introduction of online studying might lead students to miss out on-campus activities. Hence, on-campus tasks that would otherwise be carried out by the educators or peers, such as goal setting and progress evaluation, fall on the students themselves when the instruction is followed only through online education (Williams, Pollard, Takala, and Houghton, 2019). This shift can pose challenges, particularly for first year students. Another concern revolves around the fact that online study activities are often added on top of the existing in-class activities, leading to increased course workloads for students. Therefore, when implementing a flexible course schedule that includes online activities, it becomes essential to closely monitor and evaluate student behaviour and performance to ensure their successful adaptation to the new learning format.

1.2 The Current Study

The current study focuses on the introduction of online synchronous and asynchronous activities for a first year bachelor mathematics course. Students can enrol in the online course or decide to enrol in an on-campus version of the course. Once enrolled in a specific class, students can still choose to follow online or in-class activities organised by other teachers in other classes, although it is expected that most students will follow the program as prescribed by the class and teacher they selected.

In the study, we monitor what activities students select, how much time they spend on each of these activities, if they feel supported and capable of following the course, and their performance on the exam. We are interested whether the format of the study activities (online, in class, synchronous, asynchronous) is related to student behaviour, or student outcomes (feeling supported and capable, exam results).

1.3 Research questions

The objectives of this study are to address the following research questions:

1. Are certain students – older, repeating students - overrepresented in the group of students selecting online study activities?
2. Does student performance vary based on different study formats? When controlling for time-on-task, is there a performance difference that can be attributed to the study format chosen, whether it be online or in-class?
3. Is there a correlation between the study format and students' perceptions of feeling supported and confident to successfully completing the course?

2 METHODOLOGY

2.1 Participants

During the autumn semester 2023/24 170 first year bachelor students who enrolled in either an online (N= 31, age *M*= 19.9) or on-campus (N=139, age *M*= 18.3) Math course consented to participate in this study. Both the online and the on-campus course were taught by the same teacher, using the same course materials (online book, exercises). Students were be paid for their contribution, and a bonus was be given to students who finished all weekly self-reports.

2.2 Procedure and measurements

To assess the relationship between study format (online, in-class) and student outcomes (feeling supported, feeling capable, exam performance), we collected the following data:

- At the start of the course:
  - students' age
  - whether they'd taken the course the year before (repeating students)
- Weekly self-reports from students:
  - the time they spend on the different study activities
  - how supported they feel by the teacher, TA's and peers
  - whether they had any experiences of mastery
  - if they think they can complete the course successfully.
- At the end of the course:
  - exam score

For the analysis of the weekly self-reports, we only took into account the students that had filled in at least 8 weekly reports.

3 RESULTS

3.1 Descriptives

Table one provides an overview of data on the student's study behaviour and the student outcomes.

Table 1. performance total group of students who consented

	Online group	In class group	
# students	31	139	
	mean	mean	sd
Age	19.9	18.3	
% repeat students	61.3	13.6	
Final grade	4.6	4.3	

Table 2. study behaviour of students with at least 8 weekly surveys

	Online group	In class group
# students	22	107
Age (yrs)	19.7	18.4
% repeat students	63.6	14.9
Final grade (1-6)	4.6	4.3
Time online (mins/wk)	122.9	67.7
Time in class (mins/wk)	49.7	183.7
Time on exercise (mins/wk)	149.3	142.6
Feeling supported (1-5)	4.0	4.0
Experience mastery (1-5)	4.4	4.1
Expectation of success (1-5)	4.3	3.8

3.2 Correlations

*Table 3. Correlations between study behaviours (time for campus activites, for online activities, for individual exercise) and student outcomes (feeling supported, experience of mastery, expecting successful completion, exam grade). * significant at p<= .05, **significant at p<= .001, *** significant at p<= .0001*

	Exam grade	Time in class	Time online	Time on excercise	Feeling supported	Experience of mastery	Expect succesful completion
Age	0.02	**-0.40***	**0.30***	**-0.24**	-0.07	0.03	0.12
Exam grade		-0.10	-0.03	0.12	0.15	**0.31***	**0.37***
Time in class			**-0.57***	0.02	0.04	**-0.23**	**-0.32***
Time online				0.17	0.06	**0.19***	0.16

Time on exercise	0.08	-0.04	-0.09
Feeling supported		0.43**	0.18
Experience of mastery			0.63***

3.3 Analysis of Covariance

Table 4. Results of Mancova with Student Outcomes (exam grade, feeling supported, feeling of mastery and expectation of success) as dependent variables, Group(Online or in Class) as Factor and Total Time spent on Study Activities (online, in class and independent exercise) as covariate.

Multivariate tests		**value**	***F***	***df1***	***df2***	***p***
Group	Wilks' Lambda	0.92	2.41	4	117	**0.05**
total_time	Wilks' Lambda	0.95	1.43	4	117	0.23
Univariate tests	**Dependent**	***SS***	***df***	***MS***	***F***	***p***
Group	Grade	2.09	1	2.09	1.94	0.17
	Feeling supported	0.01	1	0.01	0.01	0.92
	Experiences of mastery	1.26	1	1.26	4.96	**0.03**
	Expectation for success	4.09	1	4.09	8.40	**0.00**
Total_time study activities	Grade	1.21	1	1.21	1.13	0.29
	Feeling supported	0.02	1	0.02	0.03	0.86
	Experiences of mastery	0.82	1	0.82	3.23	0.07
	Expectation for success	0.26	1	0.26	0.05	0.82
Residuals	Grade	129.32	120	1.08		
	Feeling supported	89.34	120	0.74		
	Experiences of mastery	30.51	120	0.25		
	Expectation for success	58.54	120	0.49		

3.4 Research Questions

Question 1: Are certain students – older, repeating students - overrepresented in the group of students selecting online study activities?

Looking at Table 1 we can see a higher percentage of repeating students in the online group than in the in-class group, and that the average age of students from the online group is slightly higher than students from the in class group. Table 3 shows us that student age is positively correlated (r =.30, p < .0001) with time spent on online activities.

Question 2. Does student performance vary based on different study formats? When controlling for time-on-task, is there a performance difference that can be attributed to the study format chosen, whether it be online or in-class?

The analysis of covariance (Table 4) with Student Outcomes as dependent variable and Group (online, in class) and Total Time on Study Actitivities as covariate shows a main effect of group (*Wilks' Lambda* = 0.92, F= 2.41, p<0.05). Subsequent univariate tests show signitificant differences between the online and the in class group on experiences of mastery and expectation for succes, with the online group scoring slightly higher on both.

Question 3. Is there a correlation between the study format and students' perceptions of feeling supported and confident to successfully completing the course?

Table 3 shows us that the different Student Outcomes are correlated: students' experiences of mastery and expectatons of success are significantly correlated to exam grade (r= 0.31, p<0.001; r= 0.37, p<0.001 respectively). But correlations between Study Activities and Student Outcomes are less straightforward: there are negative correlations between time in class and experience of mastery (r= -0.23, p<0.01) and expectation for success (r=-0.32, p<0.001), and a weak but posive correlation between time online and experience of mastery (r= 0.19, p<0.05).

4 DISCUSSION

This study is undertaken to monitor and evaluate whether students that select an online class and online activities throughout the semester feel equally supported and perform equally well as students who are enrolled in the on campus course. We were curious to know whether the students who select the online format are different from the students who prefer in class activities. We found that the online group was a little older than the in-class group, and there were more repeating students in the online class.

The students that participated in this study could freely choose to which course they would enrol, and even during the semester it was possible for them to freely choose between several types of online and in-class activities. That is why we collected the time spent on each of the activities each week. Both the student outcomes on group level and the correlations between time spent on learning activities and student outcomes show that student grades and their feelings of being supported are not different for online or in class students; and the online students score only slightly higher on their feelings of mastery and expectation for success than in-class students.

Previous studies have shown that including online learning activities or content in a course generally improves learning outcomes. This study shows only slight differences in some student outcomes, but not in grades. However, we don't feel that our results diverge from earlier research. First of all, previous studies often compared blended/hybrid/flipped formats with the classroom instruction, whereas in the current study students were free to choose both online and in-class activities, and we can see that both groups have included online activities during the semester. Secondly, the students in the online group spent about 60 minutes per week less on total study activity, while achieving similar results, suggesting the online group was more efficient. However, the caveat is that our students could select the format themselves and this autonomy may have been a relevant factor in our findings.

Concluding, offering a broad range of synchronous and asynchronous activities both online and in-class offers students the flexibility that seems particularly appreciated by slightly older and repeating students, while they feel equally supported and perform at equal level.

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REFERENCES

Balakrishnan, Athira, Sandra Puthean, Gautam Satheesh, Unnikrishnan M. K, Muhammed Rashid, Sreedharan Nair, and Girish Thunga. 2021. "Effectiveness of Blended Learning in Pharmacy Education: A Systematic Review and Meta-Analysis." *PLOS ONE* 16 (6): e0252461. https://doi.org/10.1371/journal.pone.0252461.

Bernard, Robert M., Eugene Borokhovski, Richard F. Schmid, Rana M. Tamim, and Philip C. Abrami. 2014. "A Meta-Analysis of Blended Learning and Technology Use in Higher Education: From the General to the Applied." *Journal of Computing in Higher Education* 26 (1): 87–122. https://doi.org/10.1007/s12528-013-9077-3.

Chen, Fei, Angela M Lui, and Susan M Martinelli. 2017. "A Systematic Review of the Effectiveness of Flipped Classrooms in Medical Education." *Medical Education* 51 (6): 585–97. https://doi.org/10.1111/medu.13272.

Liu, Qian, Weijun Peng, Fan Zhang, Rong Hu, Yingxue Li, and Weirong Yan. 2016. "The Effectiveness of Blended Learning in Health Professions: Systematic Review and Meta-Analysis." *Journal of Medical Internet Research* 18 (1): e4807. https://doi.org/10.2196/jmir.4807.

Lo, Chung Kwan, and Khe Foon Hew. 2019. "The Impact of Flipped Classrooms on Student Achievement in Engineering Education: A Meta-Analysis of 10 Years of Research." *Journal of Engineering Education* 108 (4): 523–46. https://doi.org/10.1002/jee.20293.

Rasheed, Rasheed Abubakar, Amirrudin Kamsin, and Nor Aniza Abdullah. 2020. "Challenges in the Online Component of Blended Learning: A Systematic Review."

Computers & Education 144 (January):103701. https://doi.org/10.1016/j.compedu.2019.103701.

Williams, Matthew, Emma Pollard, Helena Takala, and Ann-Marie Houghton. 2019. “Review of Support for Disabled Students IN Higher Education in England.” Brighton: Institute for Employment Studies. https://www.officeforstudents.org.uk/media/a8152716-870b-47f2-8045-fc30e8e599e5/review-of-support-for-disabled-students-in-higher-education-in-england.pdf.

Glass Boxing the Black Box: On how Social Reality gets loaded into Engineering Design

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ABSTRACT

In this paper, we report on two design episodes, to describe engineering students' problem-solving practices, and the underlying reasoning processes, associated with solving complex socio-technical challenges. We show that this form of designing requires reasoning about complex, real world phenomena, using multiple and multi-modal representations, manipulated and integrated throughout the designing process. We describe the interactions observed between the reasoning processes, to derive implications for integrating HSS with engineering curricular practices.

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1 Motivation and Background

Designing to solve socio-technical challenges is a highly complex and inherently creative enterprise, requiring the designer to construct several internal and external representations or "models" (e.g., mathematical, geometric, computational, verbal), comprising a combination of abstract and practical concepts, as well as scientific principles and knowledge, spanning across disciplines, to imagine, conceptualize, and reason, to engineer "invisible" phenomena (Boon, 2023). In the literature, the form of reasoning at the core of these modelling activities is classified "socio-technical", and not much seems to have been said about its nature, or the mechanisms that make recognizing the interplay between social and technical factors for, or more importantly, the integration of the resultant interdisciplinary insights into, engineering design (Johnson, Clauson, Leydens, Moskal, Tsai, & Plata, 2022). Studying how this reasoning process is deployed by engineering learners, as reflected in their thinking, problem-solving, and design decision-making, is important therefore, to develop a better understanding of the phenomenon, and to advance it to create effective pedagogical interventions to impart the requisite skills and practices. Our research, albeit preliminary, seeks to address this gap by providing a cognitive characterization of the socio-technical designing practices and cognitive processes of engineering learners, engaged in real-world problem solving. To study these processes, we will adopt the Model-Based Reasoning paradigm (or MBR, see Nersessian, 1999; 2009), which stipulates that conceptual innovation, a requisite for socio-technical designing (Boon, 2023), whether scientific or technological, emerges out of multiple, interconnected, problem-solving episodes, over long spells of time, and maintains that they are shaped by a variety of conceptual, analytical, and material resources and constraints of the environment in which innovators operate. Key cognitive processes prescribed as engaged in MBR include visualization, simulation, and analogical thinking, and are considered to be interconnected, and collectively constitutive of MBR. We consider "tinkering episodes", where learners interact with tools, models, concepts, and other artefacts in the makerspaces, to encompass the creation and incorporation of various internal and external representations, and therefore important sites for witnessing MBR. In our research, we will study: A) the cognitive nature of socio-technical designing, specifically, the sequence of steps entailed in planning and prototyping, and B) the specific episodes of model-based reasoning, with a focus on model construction, and the underlying cognitive and reasoning processes.

2 Study and Methods Overview

We use the case study method to develop our cognitive characterization of socio-technical designing.

2.1 Case Descriptions

The following learner-driven engineering design cases were selected, to study the underlying model-based reasoning processes:

Case A: Comprises data that was collected from a group of 30 engineering students enrolled in a project-based learning (PBL) course within their first semester of study. Unlike the majority of engineering design courses where the emphasis is on (industrial) product development, this PBL course emphasised ideation in relation to problem identification, and allowed students to determine and solve personally meaningful problems, technological or otherwise, through any justifiable technological intervention (e.g., mechanical, electrical etc.) deemed necessary. For their project, the group under observation, identified "indoor toddler safety" as their problem, and developed a toddler safety system to detect and alert guardians, by sounding alarms and sending mobile notifications, for when the toddler was in proximity of a pre-identified dangerous location.

Case B: Here, the design project was conducted in the discipline of Information Technology, and as part of the student's master's thesis (see Muwangi, 2017). Infant abduction from daycare centres located within office workspaces, was the problem being addressed, and the proposed solution entailed a wireless (remote), RFID-based infant-tracking and monitoring system. Significant similarities (e.g., research problem targeted: emphasis on safety, technological functions determined: monitoring, detection, and alerting, and working principle deployed: proximity detection), and differences between the cases (in terms of problem definition, and methodological processes adopted), rendered them appropriate sources for triangulating data to bring out common design and cognitive practices.

2.2 Data Sources and Analysis

We developed the cognitive characterization of socio-technical designing, using the approach outlined in Nersessian (2009, see pp. 133-136). We specifically focussed on designers' problem solving practices, considering it to entail *conceptual representation*, *conceptual change*, and *visualization/imagery*, ubiquitous in engineering design (Dogan & Nersessian, 2005). In our context, we anticipated these to reflect in the way learners identified, defined, and reasoned about the real world, and design problems, constructed arguments to support their design decisions, and constructed numerous representations (e.g., diagrams, models). In case A, audiotaped data of the ideation and prototyping processes (captured during group meetings), videographed data of relevant prototyping episodes, resources consulted (e.g., online/offline articles, reports, product catalogs etc.), and textual and pictorial data (diagrams, project reports, project briefs), were used for analysis. In case B, specific resources consulted (e.g., online/offline articles, reports, product catalogs etc.), and textual and pictorial data (e.g., descriptions of the real world and design problems, specific claims made to support inferences about the problem, deficits with existing technological, required software design etc., nature of the claims made, and diagrams) were used to inform analysis. Note that as data processing and analysis is currently underway for the prototyping phases of the two projects, we will only report on the conceptual designs of technological artefacts developed in cases A and B, using the data as specified.

The problem-solving practices once identified, were subjected to cognitive analysis, using a range of perspectives within the cognitive sciences (e.g., cognitive science of design, cognitive science of science), philosophy of science and engineering, and model-based reasoning in science education, and the learning sciences, to determine the nature of cognitive practices, and the underlying reasoning processes. We used a combination of inductive and deductive methods, to double-fit our data and existing theories of cognition, and thus consider our approach to be “abductive” (Timmermans & Tavory, 2022).

3 FINDINGS

We identified overlaps in the design process and cognition of the 2 design episodes under analysis (Table 1), and report the findings incrementally, beginning with an overview of the design process adopted, followed by an elaboration of the model-building episodes in cases A & B, and finally the cognitive practices and the underlying reasoning processes.

At the level of the design process, socio-technically informed approach begins with the articulation of a *social* problem (e.g., toddler/infant safety) for which a suitable socio-technical artefact is to be designed. A social problem, unlike its counterpart, an ergonomic/logistical issue of social relevance and in need of optimization solutions, which is *framed* by the instructor, often in consultation with other stakeholders (e.g., industry experts, learners), in a “task centric” manner, and specifiable in a “form-function structure” (Pahl & Baitz, 1996), lacks a predetermined set of constraints and requirements, or clear criteria for characterizing existing technological solutions as un/successful (Rittel & Webber, 1973), and must therefore be *translated* into a design problem (see stage 1, Table 1). The socio-technically informed approach thus begins with what we call “task determination” as opposed to “task specification”, where the goal is to understand the real world situation resulting in the undesired outcome to plan intervention mechanisms to be achieved technologically (Boon, 2009), and not specify/formulate the “crux of the task” undergirding a design problem through requirement and constraint identification and/or analysis (Pahl & Baitz, 1996). Another distinguishing feature of the socio-technically informed approach is its focus on situation analysis (Clarke, 2005), where the goal is to (re)construct the mechanism of action resulting in the undesired outcome (e.g., accidental injuries/infant abduction), by identifying relevant situational elements and their relationships (e.g.network of human actors in office and household settings with interdependent actions, commitments for babies' safekeeping), as opposed to task analysis, which entails systematic study of user and product-centric processes/activities underlying task completion (e.g., developing/optimization of company softwares). While task *and* situation analyses yield product-relevant requirements and constraints (see 3A & 3B in Table 1), the latter *also verifies* the technological intervention mechanism identified in the task determination stage of this process, by “empiricalizing” the phenomenon being enacted in the situation under study (stage 2 in Table 1). As for conceptual and prototypal designing (stage 3, Table 1), we found socio-technically informed approach to be similar to its counterpart, entailing the creation, manipulation and use of mental and external representations (e.g., physical, geometric, and schematic models of the artefact, see

Figure 1) to facilitate design decision making (Eckert & Hillerbrand, 2022). However, in addition to the *conceptual* model (i.e., low-fidelity prototype described in 4 A & B in Table 1), we also identified models specific to the socio-technically informed approach, and labelled them *informal* and *empirical* models (see Inference A, and level II inference ii in Table 1).

Informal modelling: begins with problem ideation, and the learners consulting diverse resources and materials: non-academic research reports and articles, newspaper clippings, public opinion polls and surveys, crime reports, product catalogues, and additionally in case A specifically: correspondence with the course instructor, teaching assistants, lab technicians, other engineering faculty, and family members, to meet the twin objectives of a) understanding the situation resulting in the undesired outcome, and consequently, b) identifying suitable technological *solutions* to effect change ("causal models" 1A and 1B, and "technological intervention mechanisms" 2A and 2B in Table 1). It culminates with a (rudimentary) situational representation connecting the undesired outcome to *linearly linked events* occurring within the identified target system (families in households in case A, and working parents, staff in the workspace in B), and a corresponding technological solution (2A and 2B in Table 1), derived through *direct mapping* between the cause (e.g., access to dangerous locations) and the technological solution (e.g., infant tracking, see 1A and 1B in Table 1). Here, the representations of the situational and the corresponding technological intervention are predominantly descriptive (narrative-linguistic), constructed based on public discourses, concepts and ideas of the situation, and through "discursive reconstruction" (see Clarke, 2005).

Empirical modelling: requires deeper, empirical understanding of how the undesired situation unfolds in the social world and within the target system, to *test* and *verify* the fit between the cause and technological action state identified in the preceding step (i.e., 1A and 1B, and 2A and 2B in Table 1, respectively). In case A, this entailed secondary research involving (academic) literature searches to identify: the most prevalent risk/hazard in households, guardians' safety rituals for their toddlers, prevalence of accidental deaths/injuries, and health implications for the users relying on safety-enhancing technological devices (with ultrasonic sensors, for instance). In case B, however, a combination of primary research, conducted using focus-group discussions with employees, field and participant observations, and secondary research methods, such as document analysis (to understand "mechanisms" for enhancing child "protection", existing technological solutions etc.), were deployed. This process culminates with an understanding of the *causal elements and their interaction* within the situation resulting in the undesired outcome, and a list of constraints and requirements for the prototype design, as summarized in Table 1 (see 3A and 3B). Here, descriptions of the causal situation and the corresponding technological solution are also narrative-linguistic, and derived from "process models" of qualitative data (Mohr, 1982), implying that they depict the *structure* of causal action undergirding undesired situations (reconstructed from the sequence of events), and the basic *mechanism* of technological intervention (determined from the constraints and requirements), respectively. The intervention mechanism "alerting" to prevent accidental injuries", conceived as the optimization of an auxiliary cause "Ca" (toddler supervision, see Table 1) to effect primary cause “C1” (access to dangerous locations, also in Table 1), is an example of this form of reasoning.

Conceptual Modelling: Here, the constraints and requirements identified in empirical modelling are transformed into functions, and further into the principle solution (Pahl & Baitz, 1996), to describe the behavior, structure, purpose, and embodiment of the prototype (Hunt, Price, & Lee, 1993), using a variety of representations, including, geometric, schematic, and physical representations of the product, see Fig. 1 for examples from case A, and chapter 5 (Mwangi, 2017), for representations (e.g., system architecture, database design, diagrams) specific to case B. We do not detail the models (space constraints), and point to Eckert & Hillerbrand (2022) instead.

Figure 1

a) Schematic diagram (workflow)   b) Geometric model (dimensioning)   c) Physical prototype

We find that the episodes, albeit described separately, influence each other within the practice of socio-technical design. For instance, in case A the informal, relational understanding of the cause (access to dangerous locations) and the associated technological action state (buzzing/alerting), resulted in influencing the nature and extent of empirical investigation conducted (see D in Table 1), and consequently, the types of constraints identified (e.g., range, efficiency, safety, see 3A in Table 1). In case B, however, it was the empirical investigation that resulted in the broadening of a list of requirements determined during informal modelling (see b in Table 1). Together, these examples suggest an interconnectedness between the two modelling stages (as is also prevalent in hypothetical reasoning within the social sciences, see Basso, Lisciandra, & Marchionni, 2017). With respect to conceptual modelling, we consider the interconnection between the combined outputs to be considerably tighter, as reflected in the following excerpt on the work-flow of the device, derived from the prototype pitch prepared by the students in case A:*“The Bluetooth Low Energy (BLE) tag…to be placed on the toddler is activated near the ESP 32, allowing its address to be captured. The BLE tag…continuously emits signals…[which] the ESP 32 module will monitor, and [subsequently] transmit [the output] to the WiFi module. In the event that the signal strength surpasses the specified threshold, an immediate alarm is sounded, and parents notified through an app installed on their mobiles.” (Participant A).* As part of the mechanism described here, different components of the system (e.g., BLE beacon, BLE tag, WiFi module, server, and mobile device) are configured and integrated to mimic seemingly natural, human *behaviors* and processes enacted during toddler supervision: monitoring the infant and raising alarm to initiate intervention. Here, the model functions as a *functional-analog model* of the surrogate (since ideal) situation (Nersessian, 1999), reflecting its alignment with the outputs of the preceding modelling stages. Further, for drawing inferences about the nature of cognitive processes, addressing the following questions is of relevance: *what is being modelled? How is it being modelled?*, and *to what end?* Concerning the first question, we observe that it is the behaviors and processes that are being modelled incrementally (e.g, sequence of events → structure of causal action → behavior of technological system). As for the second, we find the models' construction to entail a progressive, analogical comparison between source and target domains (here situations: non-ideal, real-world v/s ideal). Finally, our analysis shows that these models are constructed in service of specific epistemic aims (e.g.,hypothesis generation and testing about how to bring about a desired phenomenon). We thus characterize the cognitive processes underlying this form of design as simulative and analogical (Nersessian 2009), and therefore, generative (Rost & Knuutilla, 2022).

4 IMPLICATIONS & CONCLUSION

Overall, our analysis reveals that designing for complex socio-technical challenges requires the generation, interconnection, and transformation of sub-representations of phenomena. On our account, this modelling activity simulates the mechanism of technological intervention, needed to effect a social phenomenon, through a "coupling" of human and technological subsystems (Date & Chandrasekharan, 2016), to account for the multi-agented and spatially distributed nature of a real-world problem situation. In our view, the ability of the constructed models to simulate the *dynamics* of human-technological interaction(s) *to shape* social phenomena, is what renders them as active representations of their target systems (real or surrogate), capable of "loading" and "enacting" aspects of social reality.

Based on these findings, we recommend an epistemically-informed, and fully-integrated approach to teaching HSS through learner-driven, real world, and interdisciplinary projects, in undergraduate and graduate engineering. Consistent with prior literature (e.g., Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007) we find limited problem exploration, scoping, and information gathering on the part of learners, as demonstrated in the informal modelling stage in case A, caused by a general lack of awareness of the methods, to affect prototype design. For instance, in the same case, we consider modelling the intervention mechanism after a surrogate target situation (i.e., inferring safety behaviors from unsafe conditions), to have resulted in lack of attention to other crucial factors (e.g., guardians' preference for technological solutions within the Indian context, the toddlers' role in self-preservation etc.), which could have opened avenues for alternative, creative, and contextually appropriate designs (e.g., games to enhance toddlers' self regulatory behaviors). A focus on integration of key epistemic skills: finding patterns within a social phenomenon, understanding "evidence" of a cause within complex socio-technical systems, and visualizing the identified worldly phenomena as an engineer/ing scientist, early on in the project based course, through guided readings, topic-relevant case discussions etc., could help mitigate these challenges.

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Table 1. Similarities and differences in cognitive modelling of the artefact design across cases A and B

Steps of the Design Process for complex problem-solving	Data Description		Insights based on Comparative Analysis	Insight Clusters
	Case A (Empirical Data)	Case B (Secondary Data)	(Level I Inferences)	(Level II Inferences)
1. Task Determination (Translating a real world problem into a design problem)	**1A.Description of real world problem:** accidental injuries and/or mortality *[E1]* in toddlers within households due to access to dangerous locations *[C1]*. **2A.Description of design problem:** To design an alert-based toddler safety system *[G]* **to prevent accidental injuring and mortality** *[UDS—DS]* in indoor environments. Note. E = Effect C = Cause G = Goals U/DS = (Un/)Desired State	**1B.Description of real world problem:** rampant infant abduction *[E2]* across Kenyan office-spaces due to constraints on formal infant monitoring and supervision *[C]*. **2B.Description of design problem:** To design an integrated and scalable infant monitoring system *[G]* **to protect infants from abduction** *[UDS—DS]* in office-based day-care centres.	***Similarities:*** A.1A &1B are informal, causal models that explain E_1 & E_2 respectively. B.2A & 2B are hypothetical models that frame technological intervention possibilities. C. Predicted technological actions in 2A & 2B (prevention and protection) frame the conception of safety (as absence of harm/threat respectively,). ***Differences:*** a) The technological intervention is based on an understanding of unsafe situations (i.e., through the contrast condition).	i) Based on similarity/(ies): *Translation of causal models into hypothetical models results in Informal Model$_{DS}$ (IM$_{DS}$)* Inference based on difference(s): *IM$_{DS}$ can be conceived using deductive or inductive reasoning processes.*
2. Situation Analysis (Empiricizing the conception of safety)	**3A.Process Description: physical** requirements were identified, and mechanism for technological intervention **verified**, through **secondary and primary** research (e.g., lit. surveys, informal interactions with guardians) on hazardous characteristics of home environments, and user opinions of existing technological solutions.	**3B.Process Description: security, reliability, usability, control, and goodness of fit** requirements were identified, and mechanism for technological intervention **improvised**, through **primary and secondary** research on user requirements, available infrastructure, and *predicted functioning* of day care centre.	***Similarities:*** D. Only those characteristics of the target system that inform the mechanism of technological intervention in 2A & 2B are investigated. ***Differences:*** b) In case B unlike A, device attributes needed to facilitate *diverse* preventive actions of *multiple* purposive actors (day care staff, system operator, working parents) are integrated into the artefact design requirements (details in case B description in the data analysis section).	ii) Based on overall comparison: *IM$_{DS}$ shapes the development of Empirical Model$_{DS}$* (EM$_{DS}$) Inference based on difference(s): *Abstraction could function in service of simplification or integration.*
3. Conceptual and Prototypal	**4A.Principle Solution:** toddler safety system, equipped with an ESP-32 microcontroller and a BLE Beacon, to	**4B.Principle Solution:** wireless, RFID-based infant monitoring system that detects and alerts the	***Similarities:*** E. Functions are derived from existing forms that	iii) Overall comparison: *EM$_{DS}$ shapes the*

Designing	detect and alert guardians of toddlers' proximity to dangerous indoor locations.	parents, and those responsible for the infants' safety within the workplace.	embody those functions. ***Differences:*** c) In case A, the behaviour of the artefact maps directly to the task it needs to perform.	*concretization of artefact design.*

REFERENCES

Atman, Cynthia, J., Robin S. Adams, Monica E. Cardella, Jennifer Turns, Susan Mosborg, and Jason Saleem. 2007. "Engineering Design Processes: A Comparison of Students and Expert Practitioners." *Journal of Engineering Education96 (October): 359-379. https://doi.org/10.1002/j.2168-9830.2007.tb00945.x*

Basso, Alessandra, Chiara Lisciandra, and Caterina Marchionni. "Hypothetical Models in Social Science." In *Springer eBooks*, 413–33, 2017. https://doi.org/10.1007/978-3-319-30526-4_19.

Boon, Mieke. (2023). *Proceedings of the Annual Conference of the European Society for Engineering Education, Conceptual Modelling As An Overarching Research Skill In Engineering Education,* September 11-14, 2023. Dublin: *European Society for Engineering Education.* https://doi.org/10.21427/ZDX4-VV41

Boon, Mieke. 2009. "Understanding in the Engineering Sciences: Interpretive Structures." In *Scientific Understanding: Philosophical Perspectives*, edited by Henk W. de Regt, Sabina Leonelli, and Kai Eigner, 249–70. University of Pittsburgh Press. https://doi.org/10.2307/j.ctt9qh59s.16.

Clarke, Adele E. 2005. *Situational analysis: Grounded theory after the postmodern turn.* Sage Publications, Inc. *https://doi.org/10.4135/9781412985833*

Date, Geetanjali., and Sanjay, Chandrasekharan. "The Socio-Technical Connection is Plastic, but Only When Design Starts from Need Formulation." Paper presented at *2016 ASEE Annual Conference, New Orleans, LA, 2016.* https://lsr.hbcse.tifr.res.in/docs/Papers_pdf/Conference/2016/GD-SC_ASEEPaper_2016.pdf

Dogan, Fehmi, and Nancy Nersessian J. 2005. *Proceedings of the Annual Meeting of the Cognitive Science Society: Design Problem Solving with Conceptual Diagrams*, July 21-23, 2005. Italy: Cognitive Science Society

Eckert, Claudia, and Rafaela Hillerbrand. 2022. "Models in Engineering Design as Decision-Making Aids". *Engineering Studies14, no.2: 134-157.* https://doi.org/10.1080/19378629.2022.2129061

Hunt, John E., Mark H. Lee., and Chris, J. Price. 1993. "Applications of Qualitative Model-Based Reasoning." *Control Engineering Practice1, no.2: 253-266. https://doi.org/10.1016/0967-0661(93)91615-4*

Johnson, Kathryn, Jenifer, Blacklock, Stephanie, Claussen, Jon, Leydens, Barbara, Moskal, Janet, Tsai, and Natalie, Plata (2022). *Proceedings of the ASEE Annual Conference and Exposition: The Development of Socio-Technical Thinking in Engineering Undergraduates*, June 26-29, 2022. Minneapolis: American Society for Engineering Education. https://strategy.asee.org/42025

Mohr B. Lawrence. 1982. *Explaining Organisational Behavior.* San Francisco: Jossey-Bass.

Mwangi, Caroline M. 2017. "Wireless Baby Tracking System to curb Child Kidnapping. Master's Thesis, Strathmore University, http://suplus.strathmore.edu/handle/11071/5658

Nersessian, Nancy J. 2009. "The Cognitive Basis of Model-Based Reasoning in Science." In *The Cognitive Basis of Science*, edited by Peter Carruthers, Stephen Stich and Michael Siegal, 133-153. Cambridge: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511613517.008

Nersessian, Nancy, J. 1999. "Model-Based Reasoning in Conceptual Change." In *Model-Based Reasoning in Scientific Discovery*, edited by Lorenzo Magnani, Nancy Nersessian, J., and Paul Thagard, 5-22. Boston, MA: Springer

https://doi.org/10.1007/978-1-4615-4813-3_1
Pahl G and Wolfgang Beitz. 1996. *Engineering Design : A Systematic Approach*. London: Springer.
Rittel, Horst, W.J., and Melvin, M., Webber. 1973. "Dilemmas in a General Theory of Planning." *Policy Sciences4, no.2* (June): 155-169. http://www.jstor.org/stable/4531523?origin=JSTOR-pdf

Rost, Marvin, and Tarja Knuutila. 2022. "Models as Epistemic Artifacts for Scientific Reasoning Science Education Research." *Education Sciences12, no.2* (April): 1-20. https://doi.org/10.3390/
Timmermans, Stefan, and Iddo Tavory. 2022. Data Analysis in Qualitative Research: Theorizing with Abductive Analysis. Chicago: University of Chicago Press.

DON'T JUST THINK, PONDER: METACOGNITIVE SKILLS AMONG ENGINEERING STUDENTS WITH AND WITHOUT WORK PLACEMENTS

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Conference Key Areas: *2. Educating the whole engineer: teaching through and for knowing, thinking, feeling, and doing. 9. Continuing education and life-long learning in engineering*
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ABSTRACT

In today's world engineers need to be equipped with a range of different skills and experiences to succeed. There needs to be a combination of strong levels of meta-cognition and self-awareness. Nineteen final year mechanical engineering students who completed an industry placement and 20 students who did not took a metacognitive Self-Reflection and Insight Scale (SRIS) survey to test their levels of self-reflection and self-awareness. The two groups' results found higher metacognitive skills in the work placement group in all three areas tested: self-reflection, need for self-reflection (self-awareness) and insight. The study suggests that these metacognitive levels could be increased from taking a work placement year Recommendations are offered on how universities can improve the course curriculum to benefit work placement students and non-work placement students.

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INTRODUCTION

1.1 Background

In today's competitive job market, companies are increasingly seeking graduates who possess a blend of technical expertise and strong interpersonal skills (WEF 2020). While proficiency in technical knowledge remains essential for engineering roles, employers place a significant emphasis on attributes such as self-awareness, analytical abilities, critical thinking, and work experience. Self-awareness refers to the ability to recognize and understand your own thoughts, feelings, and behaviours. The ability to understand your strengths and weakness as well as knowing your limitations (Eurich, 2018). A key factor to improving self-awareness is through self-reflection, which, with practice, can lead to a deeper understanding of yourself and identifying your strengths and weaknesses (Grant et al. 2002). Many top CEOs exhibit exceptional self-awareness marked by fully comprehending their distinctive work styles and adeptly delegating tasks to employees who excel in areas where they may be less proficient (Resick et al. 2022). Therefore, there is a pattern of success with self-awareness that stems from self-reflection.

Extensive research conducted on the psychology of metacognitive function and self-awareness and their relevance in personal and professional development is well established (Dawson 2008). However, there is a notable absence of research on how self-awareness can enhance employability, despite several studies on graduate employment strategies (Morgan & O'Gordon 2011; Kinash et al. 2016; Su 2014). Similarly, there is a lack of literature focusing on how students' self-awareness evolves with industry experience. Addressing these gaps could provide valuable to the career development of students. This could lead to improvements in students' employability and career prospects as they secure employment more rapidly after graduation.

1.2 Metacognitive Function and Relevance to Employment

Moore and Parker (2013) carried out an analysis using pre-existing data on the importance of teaching critical thinking and problem solving in education. They summarized the importance for practical applications in the real world arguing that these cognitive skills and metacognition are closely related and are vital for students when navigating complex challenges. These challenges could occur in both academic and employment scenarios.

Critical thinking and problem solving are key skills looked for by employers (QS 2021; WEF 2020). These are often assessed through interview questions that demonstrate skills in strategic thinking and planning, for example using the STAR response format (Situation-Task-Action-Result). They demonstrate critical thinking by responding quickly to address questions and showcase time management by adhering to specified response times.

Critical thinking is a transferable skill and can be applied to various situations and fields making it an asset in employment. It allows a person to approach a problem with a structured and analytical solution. Graduates with strong critical thinking and problem-solving abilities are better equipped to handle workplace challenges and can contribute more effectively to their own organisations (Moore & Parker 2013). Therefore, developing metacognitive skills should not be overlooked as a pre-requisite to developing these highly sought skills like critical thinking.

1.3 Research Aim and Objectives

This study will investigate whether there is a difference in metacognitive skills and self-awareness between mechanical engineering students that have undertaken a work placement year and those who have not. A metacognitive survey designed and validated by Grant et al. 2002 will be used to assess three metacognitive areas: self-reflection, need for self-reflection (self-awareness) and insight that can be taken from self-reflection. From this report a summary of recommendations will be put forward to aid in developing the employability of mechanical engineering students in the programme. The objectives were:

1. To carry out a survey on final year mechanical engineering students that have completed an industry work placement year and those that have not.
2. To carry out a comparative analysis of the data between the two groups comparing work placement and non-work placement students.
3. To conclude recommendations for the engineering department for further curriculum development

2 METHODOLOGY

2.1 Survey

This study was carried out by using the Self Reflection and Insight Scale (SRIS) questionnaire that was designed by Grant et al. (2002). The questions were designed to identify three aspects of metacognition: engagement in self- reflection, need for self-reflection and insight. The targeted inclusion criteria for this study focused on final year students enrolled in Mechanical Engineering and Design Engineering undergraduate courses at the author's university.

The survey contained 22 questions in total with the first question differentiating students with and without placement year experience and the second question applicable to the placement students on their job title during their placement. The third question asked for consent. The last 20 questions were the SRIS survey questions, which employed a grading scale ranging from 1-6, where 1 indicated strong disagreement and 6 indicated strong agreement with the statement.

Before proceeding with the survey, the participating students were asked to read the Participant Information Sheet and ask to give consent. Responses were anonymously collected. The Participants were made aware that they had the right to not participate at any point during the survey up until they press submit. The study was approved by Aston University's Engineering and Physical Sciences Ethics Committee.

2.2 Data Collection and Statistical Testing

The survey was distributed electronically via Microsoft Forms and data collected were anonymised. Mann Whitney U test was performed on each question to assess if there was any difference between the scores. The results were also displayed onto bar graphs comparing work placement student's vs non work placement students.

3 RESULTS AND DISCUSSION

3.1 Survey Outcomes

A total of 40 students participated in the Self Reflection and Insight Scale (SRIS) survey, where 20 students had taken a placement year and 20 students had not. One of the results from the placement side was disregarded as they had completed the survey in 11 seconds. The duration of this submission contrasted with the average time taken to complete the survey, which was 4:25 minutes and therefore was unlikely to have been a true reflection of the participant's experience. After this submission was excluded from the data, there were 19 students who had taken a work placement year and 20 students who had not.

4 WORK PLACEMENT STUDENTS VS NON- WORK PLACEMENT STUDENTS

The work placement participants were working in a wide range of roles including manufacturing and packaging, quality testing, mechanical engineering, and financial services.

During the data collection phase of this study, qualitative insights were gathered through conversations held while surveys were distributed, and participants were briefed. It became apparent that several non-work placement students did not take a work placement year by choice, and some didn't go as they didn't get offered a placement when they applied. Several students did not apply for placements a sighted reasons due to not wanting a placement, the desire to graduate earlier or wanting to pursue a Master's degree after graduation. However, all students who applied but were unable to secure placements stated that they stopped applying around December time unlike the successful placement students who continued to apply and often received offers around March. This raises the question of why the non-placement students had prematurely stopped applying. Is there an underlying perseverance trait from the placement students that meant they didn't lose confidence too soon? Perhaps these students didn't have enough knowledge, expectation, and guidance as to the typical time frame required for getting a placement and how many applications were needed. Noting that students start applying during year 2 starting from September, the start of the UK academic calendar, with the expectation that they begin placements the following summer in year 3.

4.1 Metacognition Skill: Engagement in Self Reflection

Questions 1 to 6 of the SRIS survey evaluates "engagement in self-reflection", showing no significant difference in this aspect of metacognition between the placement versus non-placement group except in one question. The statement: "I often think about the way of feel about things," shows significant difference with the work placement group agreeing more strongly (figure 1). It is important to note that the work placement group rated higher levels of engagement in self-reflection for all other statements, even if they were not significant between the groups.

The questions respond to engaging in thinking about thoughts (Q1), spending time self-reflecting (Q2), examining their feelings (Q3), thinking about cause of behaviour (Q4), examining other thoughts (Q5), and examining their feelings (Q6). What would be interesting is to schedule interviews with some students and evaluate how they spent their time evaluating or if they thought emotional reflection was beneficial or not. It is noted that the non-placement students were less engaged with emotional reflection (Q3 and Q6), a sense of how one feels. Perhaps non-placement students are less aware of the benefits of emotional reflection.

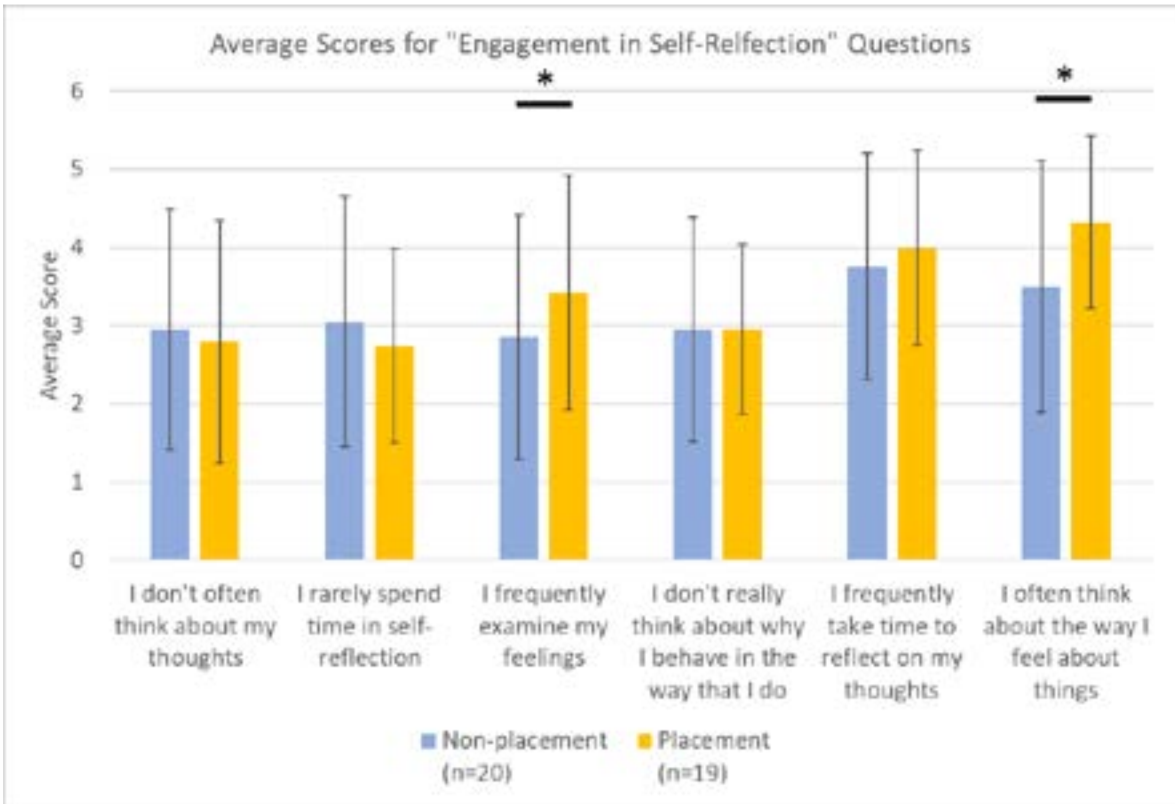

*Figure 1: Average Scores (+/- SD) for the "Engagement in Self-Reflection" questions showing no significant difference between placement versus non-placement students. * Significant difference, p<0.05.*

4.2 Metacognition Skill: Need for Self-Reflection

Questions 7-12 of the SRIS survey evaluates the "need for self-reflection" as shown in figure 2 with a notable increase in average scores among the placement students except for Q7 statement "I am not really interested in analysing my behaviour", where a lower response indicates an interest in analysing behaviour – a metacognitive trait. Therefore, on average, work placement students demonstrated a higher need for self-reflection compared to their non-placement peers. All the questions in this section of the survey showed significant differences in results with placement students performing better in every question, except Q7 where it was not statistically different.

The remaining questions respond to engaging in evaluating the things done by the student (Q8), examining thoughts (Q9), understanding feelings (Q10), the need to understand how their mind works (Q11) and understand how thoughts arise (Q12). Placement students often receive feedback and get challenged with their university knowledge at work, this common practice can push students to analyse themselves more often to improve. It is safe to say that the placement students think it is important to evaluate the things they do as they scored remarkably higher than non-placement students (Q8). It is possible that after partaking in self-evaluation at work and understanding how quickly they developed from this the placement students recognise the benefits of self-reflection.

*Figure 2: Average scores (+/- SD) for the "Need for Self-Reflection" questions showing significantly higher responses in students that completed a placement versus students that had not. * Significant difference, p<0.05.*

A key question for the placement students, is whether the skills of self-reflection and self-awareness is what led them to secure the job in the first place or whether these traits were developed through the work placement. It is very possible that the students that secured a placement were naturally predisposed with higher metacognitive levels to perform better in securing these placements either through experience, a better understanding of the interview process or even personality types. Examining this and whether the university experience does build these skills would be interesting to look at.

4.3 Metacognition Skill: Insight

Questions 13-20 of the SRIS survey evaluates "insight" as shown in figure 3 with varied responses showing no clear distinction between the two groups. The work placement group have a slightly better insight into their thoughts and emotions compared to the non-placement group, however only Q14 and Q20 were significantly different. The score for Q16 "I'm often aware that I'm having a feeling, but I often don't quite know what it is" was almost identical between the groups. This question relates to emotional regulation, with neither group showing any differences.

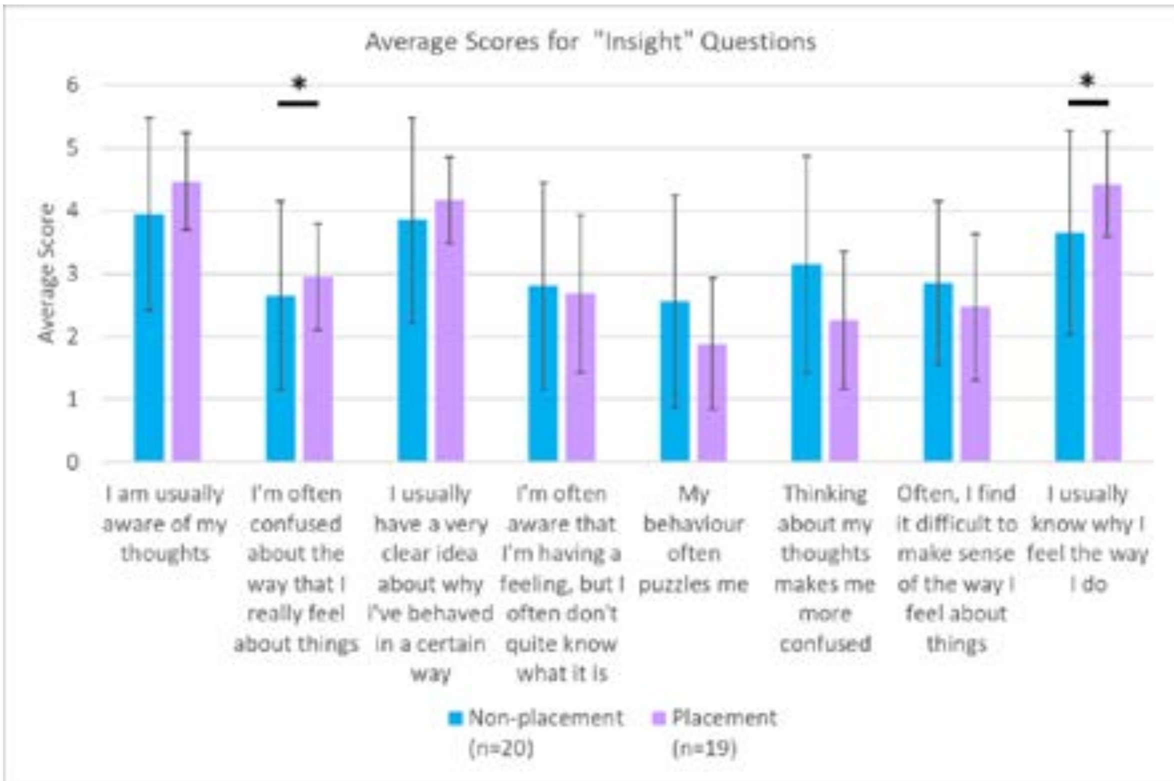

*Figure 3: Average (+/- SD) scores for the "Insight" questions with only the last question showing significant difference in average responses. * Significant difference, p<0.05.*

Emotional regulation is the ability to effectively manage and modulate one's emotions in response to internal and external stimuli (Sanchis et al. 2020). It is interesting that both groups of students scored similarly in this "Insight" section of the survey, showing no clear difference between groups. Exploring the link between work placement experience and developing emotional regulation would be interesting and offer a new understanding into the impact of developing professional skills in the workplace. However, this area is beyond this study and would need to be explored further.

Question 20 "I usually know why I feel the way I do" and question 18 "Thinking about my thoughts makes me more confused" the placement students performed better. Although both groups are usually aware of what feelings they are having (Q19) the placement students are better at understanding why they feel those feelings (Q20, significant). The non-placement students are not as good at making sense of their thoughts and get more confused the more they think about them. These two results argue that a placement year may have some benefits for emotional regulation and the constant behaviour analysis in a workplace supports this finding. It seems logical that an environment where you are being challenged and taught by others on new tasks would be a training ground for emotional regulation and improving communication skills.

The exposure to real-life work experiences gained through a work placement might have contributed to the better metacognitive scores among the work placement group. On the other hand, students who secure placements may have specific personality traits or characteristics that make them pre-disposed to have higher metacognitive skills. However, a longitudinal study is needed to explore this further, particularly exploring metacognitive development at university in comparison to a work placement.

The need for developing lifelong learning and learning strategies has not been missed in engineering curriculums, however, more awareness of how to develop underlying metacognitive skills is needed to provide effective recommendations for programme development. Engineering industries are calling for these non-technical skills, with a recent World Economic Forum reporting “active learning and learning strategies” as a top three skill needed in the advanced manufacturing industry (WEF 2020).

There are several limitations in this study. Firstly, the group sizes for this study were small (n=20 and n=19) and should be expanded in future studies. Secondly, a longitudinal study is needed to also allow a comparison of metacognitive development in the initial years at university while students engage in academic studies and metacognitive development before and after a work placement. Thirdly, a look at other engineering disciplines would also be advantageous, allowing a cross-sectional look across disciplines, which would provide better oversight across the engineering profession. Finally, employer views would be interesting to analyse to see any correlations between students and employer perceptions. However, despite these limitations, the study provides valuable preliminary insights into this field that would benefit engineering educators.

5 SUMMARY

The aim for this project was to determine if mechanical engineering students at a UK university demonstrated different metacognitive skills between students that had completed a work placement compared to students that had not. The study aimed to assess the two groups metacognitive levels through a validated survey assessing three areas of metacognition: their engagement in self-reflection, the need for self-reflection and insight. The results revealed a heavy slant towards work placement students engaging in more in self-reflection and showed a greater awareness of the need for it. Placement students performed better overall with several significant findings, most notably in the awareness of the need for self-reflection. Placement students generally spent more time reflecting on thoughts, feelings, and behaviours in their roles. The results also indicated that placement students drew more insight from their reflection. In a workplace where colleagues challenge and guide interns through new tasks the results suggests that such an environment is highly conducive to developing self-reflection and self-awareness.

While placement students performed better in this study further research needs to be done to understand cause and effect. This will help drive research-informed curriculum development and pedagogical reform towards training highly skilled and employable engineering graduates.

REFERENCES

Aliu, J., D. Aghimien, C. Aigbavboa, A. Ebekozien, A. E. Oke, S. A. Adekunle, O. Akinradewo, and O. Akinshipe (2024). *Engineering, construction, and architectural management* 31,6: 2248 – 2263.

Eurich, T. “What self-awareness is (and how to cultivate it),” *Harvard Business Review*, January 4, 2018, https://hbr.org/2018/01/what-self-awareness-really-is-and-how-to-cultivate-it.

Dawson, T.L. (2008). “Metacognition and learning in adulthood.” Prepared in response to tasking from ODNI/CHCO/IC Leadership Development Office, Developmental Testing Service, LLC Northampton, MA.

Flavell, J. H. (1979). “Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry.” *American Psychologist* 34, 10: 906–911. https://doi.org/10.1037/0003-066X.34.10.906.

Fleming, S. M., and R.J. Dolan (2012). “The Neural Basis of Metacognitive Ability.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 367, 1594: 1338-1349. https://doi.org/10.1098/rstb.2011.0417.

Grant, A. M., J. Franklin and, P. Langford (2002). “The Self Reflection and Insight Scale: A New Measure of Private Self-Consciousness.” *Social Behaviour and Personality* 30,8: 821-836. https://doi.org/10.2224/sbp.2002.30.8.821.

Kinash, S., L. Crane, M.-M. Judd, and C. Knight (2016). “Discrepant Stakeholder Perspectives on Graduate Employability Strategies.” *Higher Education Research & Development* 35,5: 951–67. https://doi.org/10.1080/07294360.2016.1139555.

Moore, B. N., and R. Parker (2013). Teaching critical thinking and problem solving. Elsevier.

Morgan, M., and P. O’Gorman. "Enhancing the employability skills of undergraduate engineering students." *Innovations* (2011): 239-248.

QS Higher Education Report (2018). “The Global Skills Gap in the 21st Century”. Accessed 12 June 2024. https://www.qs.com/portfolio-items/the-global-skills-gap-in-the-21st-century/.

Resick, C. J., S. Nadkarni, J. Chu, J. Chen, W.-C. Lien, J.A. Margolis, and P. Shao (2022), “I Did It My Way: CEO Core Self-Evaluations and the Environmental Contingencies on Firm Risk-Taking Strategies.” *Journal of Management Studies Special Issue: Heuristics and Biases of Top Managers* 60,5: 1236-1272. https://doi.org/10.1111/joms.12872.

Sanchis-Sanchis, A., M.D. Grau, A.-R. Moliner, and C.P. Morales-Murillo (2020). “Effects of Age and Gender in Emotion Regulation of Children and Adolescents.” *Frontiers in Psychology* 11:946. https://doi.org/10.3389/fpsyg.2020.00946.

Su, Y. (2014). Self-directed, genuine graduate attributes: The person-based approach. *Higher Education Research & Development,* 33, 6: 1208–1220. http://doi.org/10.1080/07294360.2014.911255.

WEF Future of Jobs. October 2020 report. Geneva, Switzerland: World Economic Forum 2020. Accessed June 11, 2024. https://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf.

RESILIENCE IN CONTEXT: A COMPARATIVE STUDY OF ENGINEERING STUDENTS IN THE UNITED KINGDOM AND SOUTH AFRICA (RESEARCH)

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Conference Key Areas: *Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing; Engineering skills, professional skills, and transversal skills*
Keywords: *Academic resilience, cross-cultural comparison, engineering education, South Africa, United Kingdom*

ABSTRACT

This qualitative study investigates the academic resilience of engineering students within the distinct cultural, social, and institutional landscapes of the United Kingdom and South Africa. Engaging with 36 participants through semi-structured interviews, the research aimed to discern the elements fostering academic resilience and gauge students' preparedness for professional life. Two overarching themes were identified: similarities and differences in resilience experiences in these two contexts. Under similarities, individual resilience traits such as hard work, determination, and growth mindset emerged prominently, alongside the shared challenges of academic pressures and the transition to university life. The importance of support systems, including the role of peers, faculty, and university resources, was acknowledged across both contexts. Differences highlighted distinct institutional and cultural influences on resilience: South Africa grappled with resource constraints, technological gaps, and historical educational disparities, while the UK experience revealed more detailed insights into the role of institutional support and introspective

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resilience. By contributing to the discourse on engineering education and student success, this research underscores the imperative for engineering programmes to focus on nurturing resilient, future-ready responsible engineers, and emphasises the value of cross-cultural insights and cooperation in fostering inclusive and supportive environments that respond to the unique needs of students in different educational contexts.

1 INTRODUCTION

Engineering education (EE) plays a crucial role in shaping the future of our societies, as engineers are at the forefront of addressing global challenges and driving technological advancements. However, the journey to becoming an engineer is often fraught with obstacles, requiring students to develop and maintain a strong sense of resilience. This work aims to explore how resilience is understood and fostered in two distinct educational contexts: the United Kingdom (UK) and South Africa (SA).

Resilience, defined as the ability to overcome adversity and adapt to challenging circumstances, is a key factor in determining student success and well-being (Mwangi and Watt 2021). Academically resilient students are those "who sustain high levels of achievement motivation and performance despite the presence of stressful events and conditions that place them at risk of doing poorly in school and ultimately dropping out of school" (Alva 1991, 19). In the context of EE, students face a myriad of challenges, including rigorous coursework, high academic expectations, and the need to develop a wide range of technical and interpersonal skills (Cajander, Daniels, and McDermott 2012; Llorens-Molina et al. 2022). Understanding factors that contribute to academic resilience and identifying effective strategies to support its development is essential for promoting student success and well-being.

Recent research has explored resilience in engineering education from various angles. A systematic literature review by Winkens and Leicht-Scholten (2023) found that resilience in EE is connected to both engineering students' personal attributes and to university systems. For students, resilience was linked to persistence, adaptability, learning from failures, coping with stress, and being a desired competence (Winkens and Leicht-Scholten, 2023). Resilience has also been described as the ability to manage or recover from stress (Huerta et al., 2021) and the term 'academic resilience' has been used to examine students' responses to academic challenges (Hunsu, Carnell, and Sochacka, 2021; Martin and Marsh, 2006).

Moreover, studies have associated resilience with self-regulation (Concannon et al., 2019) and self-efficacy (Anthony et al., 2016; Concannon et al., 2019) in engineering students. Resilience has also been investigated in relation to equity, diversity, and inclusion, focusing on specific groups like mature students (McGivney, 2007; Servant-Miklos, Dewar, and Bøgelund, 2021), women (Khilji and Pumroy, 2019), African American and Latino students (Samuelson and Litzlerb, 2016), and black women (Ross, Huff, and Godwin, 2021). Long and Mejia (2016) even present resilience as an asset, arguing that society often overlooks the resilience of minorities while stereotyping them as low-income and poorly educated.

The UK and SA provide unique contexts for examining academic resilience within EE. Whilst both countries have a strong tradition of EE, they also present distinct challenges and opportunities for students. In the UK, as part of the Global North, the

EE system is characterised by well-established infrastructure, a high level of industrial integration, and advanced research facilities (Engineering Council 2014; Polit and Beck 2010). In contrast, SA, situated in the Global South, faces unique challenges such as resource limitations, a need for educational transformation, and the imperative to align EE with rapid economic and social changes (Fisher and Naidoo 2020).

In the UK, the impact of Brexit on the EE sector and the experiences of international students and staff is a pertinent issue (UCL Centre for Engineering Education, n.d.). In SA, the need to increase diversity and representation in the engineering field, particularly among women and underrepresented groups, is a pressing concern (Direito, Chance, and Malik 2019). While the UK also faces challenges in diversifying EE (according to HESA, in 2021/2022 ~80% of engineering students in the UK were male and ~63% were classed as 'home'), it notably differs in its reliance on international students for revenue (PwC, 2024), a trend less pronounced in SA.

By fostering cross-cultural dialogue and collaboration, this paper aims to contribute to the ongoing efforts to create inclusive, supportive, and transformative EE environments that nurture academic resilience and success.

2 METHODOLOGY

2.1 Research approach and design

This study employed a qualitative research design, situated within an interpretivist paradigm, to explore the resilience of engineering students in the UK and SA (Denzin and Lincoln 2003; Kivunja and Kuyini 2017). The interpretivist approach allowed for a deep understanding of participants' subjective experiences and the meanings they attached to their resilience in their respective educational contexts (Oakley 1998).

2.2 Participants and sample

Purposive sampling was used to recruit 36 participants, their characteristics shown in Table 1, with 13 engineering students from Nelson Mandela University in SA and 23 from Swansea University in the UK. The former is a comprehensive university in SA, the latter being a public research university located in Wales, UK.

In both cases, students were studying a broad range of engineering disciplines.

The mean age of participants in both the UK and SA is notably consistent, averaging 23.5 years. This similarity in age distribution underscores a commonality in the student demographics between the two distinct geographical and educational contexts.

Table 1: Participant Information

	SA	UK
	Population	
Student population (Institution)	28, 000	22, 000 (HESA, 2022)
Home students	~95 %	81% (HESA, 2022)

Engineering students		15% (HESA, 2022)
	Sample	
Sample size	13	23
Gender identity (M/F)	10/3	17/6
Age range	21-28	18-39
Level of study	All Bachelors (final year)	2 Foundation Year (pre-Bachelor) 5 First year 5 Second year 2 Third year 9 Masters
Home/International	9/4	9/14

2.3 Data generation

Semi-structured interviews were selected as the primary data generation method, as they provided the opportunity to explore participants' experiences, thoughts, and feelings in depth while maintaining a focus on the research questions (Guba and Lincoln 1994). An interview protocol was developed, which included open-ended questions and prompts to guide the discussions (Jacob and Furgerson 2012). The questions focused on participants' educational experiences, their understanding of resilience, examples of times they demonstrated or developed resilience, and their views on the importance of resilience in education and the workplace. In both contexts, interviews were conducted either face-to-face or via video conferencing, guided by the participants' preferences and availability. Each interview spanned from 20 minutes to one hour. With the participants' consent, all interviews were audio-recorded and transcribed verbatim for data analysis.

2.4 Data analysis

Reflexive thematic analysis, as outlined by Braun and Clarke (2019, 2021) and Byrne (2021), was employed to analyse the transcribed data, underscoring the researchers' active role in identifying and interpreting meaning patterns within the datasets. This analysis adhered to Braun and Clarke's six-phase process: familiarisation with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report (Braun and Clarke 2019). Analysis was conducted independently for the datasets from each context, then integrated to compare the resilience experiences of engineering students in both contexts. Reflexive practices were maintained throughout the analysis to recognise the researchers' subjectivity in data interpretation (Braun and Clarke, 2019). To validate the findings, strategies such as member checking—inviting participants to comment on the initial themes—and peer debriefing—discussing the analysis and findings with colleagues for additional insights and to challenge biases—were implemented (Baumbusch 2010; Noble and Smith 2015).

2.5 Ethical considerations

To ensure the integrity and ethical conduct of this research, appropriate measures were taken in both the UK and SA. In the UK, ethical approval was obtained from Swansea University, aligning with institutional guidelines and standards for research involving human participants. In SA, the Research Ethics Committee: Human (REC-H) at Nelson Mandela University granted institutional ethical clearance before the research began. Informed consent was secured from all participants, and ethical standards were consistently upheld throughout data generation in both countries, thus maintaining the integrity of the research processes.

2.6 Limitations of the study

This comparative case study on the academic resilience of engineering students in SA and the UK offers valuable insights but has limitations. Conducted at only two universities, its findings might not extend to other institutions (Polit and Beck 2010). The small sample sizes limit the breadth of student experiences captured (Boddy 2016; Vasileiou et al. 2018). Reliance on self-reported data from interviews may introduce biases (Althubaiti 2016; Rosenman, Tennekoon, and Hill 2011). Finally, its cross-sectional design provides a snapshot rather than a longitudinal view of academic resilience (Caruana et al. 2015; Farrington 1991).

3 FINDINGS AND DISCUSSION

This section describes the results of the thematic analysis results, uncovering the nuanced experiences of engineering students in the UK and SA. It reveals both shared and distinct aspects of their resilience journeys, shaped by their unique educational and socio-cultural environments. Through examining individual resilience traits, coping mechanisms, and support systems, alongside cultural and institutional influences, we unpack the complexities of their experiences.

3.1 Similarities

In the exploration of similarities, we observe common threads in the resilience narratives of engineering students from both the UK and SA. Despite their geographical and cultural differences, these students share key resilience traits and face comparable challenges. This section highlights these shared experiences, emphasising universal aspects of academic resilience in EE. Excerpts are numbered to allow the reader to identify quotes from the same participant.

Individual resilience traits: Students in both contexts emphasised the importance of personal characteristics such as hard work, determination, and a growth mindset in fostering resilience. For example, a UK participant remarked, "*I approached this more as an opportunity to learn… because I'm not treating this as someone else's mistake. I rather try to take it as my own and see if actually there's something wron*g" (UK#23), underscoring the significance of self-reflection and personal growth. Another UK student shared, "*the idea that instead of focusing on the fact that last time when I did a lot of work, it didn't go so well, like its instead trying to build on what I did for the last assignment*" (UK#6), highlighting the importance of building on past experiences to improve future outcomes. Similarly, a SA student stated, "*I am a person who does* *not give up so easily, and when I tell myself that I need to fight, besides passion because at some point it's not all about passion, but it's about achieving what you want*" (SA#4), illustrating the significance of perseverance and goal attainment.

Coping with challenges: Engineering students in the UK and SA faced similar challenges, including the transition from high school to university, balancing academic demands with personal responsibilities, and navigating the coronavirus (COVID-19) pandemic. One UK student highlighted the distractions and temptations encountered when starting university: "*now you can do whatever you want to… so like that's also kind of one that pushes my resilience because now I have to keep my morals... there's no reason for you to get up early or anything*" (UK#1). This reflects the personal responsibility and self-discipline required at this educational stage. Similarly, an SA student shared, "*Interacting with people was a bit challenging to me, and even speaking or asking lecturers was a big challenge to me*" (SA#4), indicating the social and communicative hurdles faced in the university environment.

Support networks: In both the UK and SA, the significance of supportive networks including lecturers, tutors, and peers was universally recognised for providing essential guidance and encouragement. The influence of these networks extended to shaping students' sense of belonging and, consequently, their resilience. Engaging educators were seen as having the potential to "*inspire you to be a bit more resilient*" (UK#19) and to "*initiate the curiosity in someone, like the desire to learn*" (UK#12), making clear "*why you have to learn this*" (UK#12) to motivate students in a manner that supported resilience. Lecturers were appreciated for "*trying their best to give me as much as they can, and they even make themselves available*" (UK#9), enhancing student motivation and accountability. The motivational advantage of group settings was highlighted by a UK participant: "*when you're in a group you've got the motivation of working with people around you, whereas alone you don't have that so it makes it harder*" (UK#13). Within SA, the value of peer relationships, as well as the support from tutors and lecturers, was strongly emphasised, with students articulating the vital assistance they received from these relationships during their academic journey. SA#10 described a more informal peer support by saying that "*having a friend from South Africa that helped you with the English enough to transition with the language … built confidence*." This sentiment was echoed by another SA student who mentioned, "*Lecturers give you, like, personal contacts, email. Talk to me whenever we have a problem with this, just communication*" (SA#1), illustrating the critical role of accessible and interactive support systems in fostering resilience among engineering students.

Gender dynamics: The conversation around gender dynamics in EE revealed additional layers of complexity. Female students face unique challenges, including gender discrimination and heightened pressures to prove themselves in a predominantly male sector. For example, the UK data touched upon these gender-specific resilience demands, as a student recounted, "*horror stories from like woman being groped and stuff… I think that requires a lot of resilience. Also, I wouldn't want to work in like a super macho cultural workplace. I couldn't come to work like I know I couldn't handle it. It's too much. That would require a lot of resilience*" (UK#8). In SA, the sentiment resonates, with a student expressing, "*When you go into the engineering field as a lady, already people think that it's a male-dominated field. So, you go in with like a two mind of working as much as harder as them so you would end up maybe working like two times extra*" (SA#4). This underlines the critical intersection of gender and resilience, highlighting the necessity to address and comprehend these dynamics within the EE sphere, across both SA and the UK.

3.2 Differences

This section describes how varying cultural, social, and institutional factors uniquely shape participants' resilience journeys and abilities to navigate and overcome the specific challenges they face. For example, the UK findings offered more detailed insights into the role of institutional support in fostering resilience. A UK participant noted a "*myriad of things*" (UK#2) that were offered in terms of support with another saying, "*I have the full support I need*" (UK#11). Others listed the types of facilities they had access to with one saying the "*support team is really, really helpful to the students. They are on call to take measures to ensure students are at their best and also the psychological support from the students' support at university and also mentors, especially my project guide is really good to help me be more resilient towards situations*" (UK#14), with another explaining that "*suppose if you are facing struggling you can go to the Students Union and discuss with them. If you are some struggling in economies. You can get economic support, if you are struggling in your wellbeing or something there is some group where you can just pop in and just discuss with them. So, like there are more resources*" (UK#7). This indicates that responsive and supportive institutional practices are essential in enhancing resilience among UK engineering students. In contrast, in the SA context, institutional support was not as prominently or favourably discussed. A South African student expressed, "*I haven't necessarily used any support from the varsity system*" (SA#6), indicating a potential gap or underutilisation of institutional support mechanisms in enhancing student resilience.

Differences in support may be a result of the general marketisation of higher education within the UK (Brown, 2015) which has meant that the ability of the higher education institutions to charge increased fees became dependent upon their ability to demonstrate 'excellence' as part of the Teaching Excellence Framework (Department for Education, 2015) and thus an increased focus on metrics such as student satisfaction which is measured via the national student satisfaction survey (NSS). With this in mind, it is interesting to note that the majority of participants who spoke favourably of support within the UK context were international students and often compared the situation to their experience within their home country, with one saying "*general support is a lot more positive…I found, like professors here are lot more friendly than they are back in, my hometown or my country*" (UK#2). Much of these discussions were based around hierarchy and status and the fact that lecturers were more accessible in the UK "*because back there in my country… what I see in my university is that you can't sit next to the lecturer and talk about different subjects, because the lecturer is something up high, and you can't even get in touch…But here there are too many staff everyone. I think everyone tries to help you*" (5). In comparison, home students in the UK tended to be more critical of the support provided by university, thus highlighting the way in which experience and expectations shape resilience, this being articulated by one student who said "*to be honest its [resilience] very rare in the Western world… Very, very rare. Because, for example, the only way you can really get resilience, like I was saying is going through tough times or going through hardships of some sort, and the thing here is life I've seen is generally too easy*" (UK#1).

4 SUMMARY AND ACKNOWLEDGEMENTS

This study examined the academic resilience of engineering students in the UK and SA, uncovering nuanced experiences shaped by individual traits, cultural backgrounds, and institutional environments. While students in both regions face common academic pressures and life balance challenges, those in SA additionally navigate resource constraints, technological disparities, and the enduring effects of historical inequalities (Mapaling, Webb, and du Plooy 2022). Despite these hurdles, students from both countries exhibit significant resilience, harnessing personal strengths, supportive networks, and university resources to manage their challenges.

The findings emphasise the necessity for engineering programmes in both countries to bolster academic resilience through tailored support, inclusive curricula, and the creation of nurturing educational environments (Mapaling 2024). Such strategies are vital for developing a cadre of engineers who are not only academically adept but also socially responsible and prepared to tackle global challenges (Engineers Without Borders UK n.d.).

In conclusion, this study not only highlights the resilient nature of engineering students in diverse settings but also underscores the pivotal role of individual, communal, and institutional support in fostering academic success (Mapaling, Webb, and du Plooy 2021). It advocates for global collaboration in EE to equip students as future innovators and leaders. Future research should explore the efficacy of specific resilience-enhancing interventions, sampling multiple universities, recruiting larger and more diverse participant groups, incorporating additional data sources beyond. self-report, and adopting longitudinal designs to examine the long-term effects of resilience on the academic and professional journeys of engineering students.

REFERENCES

Althubaiti, A. 2016. "Information Bias in Health Research: Definition, Pitfalls, and Adjustment Methods." *Journal of Multidisciplinary Healthcare* no. 9 (May): 211-217. https://doi.org/10.2147/JMDH.S104807

Alva, S. A. 1991. "Academic Invulnerability among Mexican-American Students: The Importance of Protective and Resources and Appraisals." *Hispanic Journal of Behavioral Sciences* 13: 18–34.

Anthony, Anika B., Howard Greene, Paul E. Post, Andrew Parkhurst and Xi Zhan. 2016. "Preparing University Students to Lead K-12 Engineering Outreach Programmes: A Design Experiment." *European Journal of Engineering Education* 41 (6): 623-637.

Baumbusch, J. 2010. "Semi-Structured Interviewing in Practice-Close Research." *Journal for Specialists in Pediatric Nursing* 15 (3): 255-258. https://doi.org/10.1111/j.1744-6155.2010.00243.x.

Braun, V., and V. Clarke. 2019. "Reflecting on Reflexive Thematic Analysis." *Qualitative Research in Sport, Exercise and Health* 11 (4): 589-597. https://doi.org/10.1080/2159676X.2019.1628806.

Braun, V., and V. Clarke. 2021. *Thematic Analysis: A Practical Guide*. London: Sage.

Brown, R. “The Marketisation of Higher Education: Issues and Ironies,” *New Vistas (University of West London)*, vol. 1, no. 1, pp. 4–9, 2015.

Boddy, C. R. 2016. “Sample Size for Qualitative Research.” *Qualitative Market Research* 19 (4): 426-432. https://doi.org/10.1108/QMR-06-2016-0053

Byrne, D. 2021. “A Worked Example of Braun and Clarke’s Approach to Reflexive Thematic Analysis.” *Quality & Quantity* 56 (June): 1-22. https://doi.org/10.1007/s11135-021-01182-y.

Cajander, Å., M. Daniels, and R. McDermott. “Soft Skill Development along the Education Path Evaluating Expectations on and Perceptions of Student Competencies in Software Engineering Education.” In *2012 Frontiers in Education Conference Proceedings*, *Seattle, 2012*, pp. 1-6. IEEE.

Caruana, E. J., M. Roman, J. Hernández-Sánchez, and P. Solli. 2015. “Longitudinal studies.” *Journal of Thoracic Disease* 7 (11): E537-E540. https://doi.org/10.3978/j.issn.2072-1439.2015.10.63

Concannon, James, P., Susan B. Serota, Megan R. Fitzpatrick, and Patrick L. Brown. 2019. “How Interests, Self-efficacy, and Self-regulation Impacted Six Undergraduate Pre-engineering Students’ Persistence.” *European Journal of Engineering Education* 44 (4): 484-503.

Denzin, N. K., and Y. S. Lincoln. 2003. *The Landscape of Qualitative Research: Theories and Issues*. Thousand Oaks, CA: Sage.

Department for Education. “Teaching Excellence and Student Outcomes Framework Specification,” 2017. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/658490/Teaching_Excellence_and_Student_Outcomes_Framework_Specification.pdf. [Accessed Jan. 29, 2022].

Direito, I., S. Chance, and M. Malik. 2019. “The Study of Grit in Engineering Education Research: A Systematic Literature Review.” *European Journal of Engineering Education* 45(2): 161-185. https://doi.org/10.1080/03043797.2019.1688256.

Engineering Council. 2014. *The Accreditation of Higher Education Programmes*. 3rd ed. London: Engineering Council.

Engineers Without Borders UK. n.d. “Engineering for People Design Challenge.” Engineers Without Borders UK. Accessed April 6, 2024. https://www.ewb-uk.org/engineering-for-people-design-challenge/.

Farrington, D. P. 1991. “Longitudinal Research Strategies: Advantages, Problems, and Prospects.” *Journal of the American Academy of Child & Adolescent Psychiatry* 30 (3): 369-374. https://doi.org/10.1097/00004583-199105000-00003

Fisher, D., and L. Naidoo. 2020. “*Exploring the Factors that influence the Career Choices of Women in Engineering: A South African case study*.” Journal of Engineering Education 109 (4): 760-775. https://doi.org/10.1002/jee.20351.

Guba, E. G., and Y. S. Lincoln. 1994. “Competing Paradigms in Qualitative Research.” In *Handbook of Qualitative Research*, edited by N. K. Denzin and Y. S. Lincoln, 105–117. Thousand Oaks, CA: Sage Publications.

HESA. 2023. What do HE students study? Accessed March 27, 2024. https://www.hesa.ac.uk/data-and-analysis/students/what-study.

Hunsu, Nathaniel J., Carnell, Peter H., & Sochacka, Nicola W. 2021. “Resilience theory and research in engineering education: what good can it do?.” *European Journal of Engineering Education* 46 (6): 1026-1042.

IECURRICULA. n.d. “Bringing Life to our Engineering Curricula.” Accessed April 5, 2024. https://iecurricula.co.za.

Jacob, S. A., and S. P. Furgerson. 2012. “Writing Interview Protocols and Conducting Interviews: Tips for Students New to the Field of Qualitative Research.” *The Qualitative Report* 17 (42): 1-10. https://doi.org/10.46743/2160-3715/2012.1718.

Khilji, Shaista, E. and Kelly Harper Pumroy. 2019. “We are Strong and we are Resilient: Career Experiences of Women Engineers.” *Gender, Work and Organization* 26: 1032– 1052.

Kivunja, C., and A. B. Kuyini. 2017. “Understanding and Applying Research Paradigms in Educational Contexts.” *International Journal of Higher Education* 6 (5): 26-41. https://doi.org/10.5430/ijhe.v6n5p26.

Llorens-Molina, J. A., F. Cardona, J. Llorens De Jaime, and M. J. Lerma-García. "The Academic Poster as a Resource to Enhance Cross-Curricular Competences in Higher Education." In *EDULEARN22 Proceedings*, *Spain, 2022*, pp. 1-9. IATED.

Long, L. L. and Mejia, J. A. 2016. “Conversations about Diversity: Institutional Barriers for Underrepresented Engineering Students.” *Journal of Engineering Education* 105 (2): 211 – 218.

Mapaling, C. 2024. *Studying engineering is tough: 6 insights to help university students succeed.* The Conversation. https://theconversation.com/studying-engineering-is-tough-6-insights-to-help-university-students-succeed-219260

Mapaling, C., Webb, P., & du Plooy, B. 2021. “’Everyone Plays a Key Role’: Students, Lecturers and Support Staff in South Africa talk about the Academic Resilience of Engineering Students.” *Proceedings of the 14th annual International Conference of Education, Research and Innovation*: 7201- 7207.

Mapaling, C., Webb, P., & du Plooy, B. 2022. “‘I Would Help the Lecturer with Marking’: Entrepreneurial Education Insights on Academic Resilience from the Perspectives of Engineering Students in South Africa.” In J. Halberstadt, J. Greyling, A. A. de Bronstein & S. Bisset (Eds.), *Transforming entrepreneurship education: Interdisciplinary insights on innovative methods and formats*. Springer Nature.

Martin, Andrew J., and Herbert W. Marsh. 2006. “Academic resilience and its psychological and educational correlates: A construct validity approach.” *Psychology in the Schools* 43 (3): 267–281.

McGivney, Veronica. 2007. “Understanding Persistence in Adult Learning.” Open Learning: *The Journal of Open, Distance and e-Learning* 19 (1): 33–46.

Mwangi, C. A. S., and D. Watt, D. 2021. “Exploring the Relationship between Resilience and Student Success among Engineering Students in South Africa.” *Cogent Psychology* 8 (1): 1-15. https://doi.org/10.1080/23311908.2021.1893256.

Noble, H., and J. Smith. 2015. "Issues of Validity and Reliability in Qualitative Research." *Evidence-Based Nursing* 18 (2): 34-35. http://dx.doi.org/10.1136/eb-2015-102054.

Oakley, Ann. 1998. "Gender, Methodology and People's Ways of Knowing: Some Problems with Feminism and the Paradigm Debate in Social Science." *Sociology* 32 (4): 707-731. https://doi.org/10.1177/0038038598032004005.

Polit, D. F., and C. T. Beck. 2010. "Generalization in Quantitative and Qualitative Research: Myths and Strategies." *International Journal of Nursing Studies* 47 (11): 1451-1458. https://doi.org/10.1016/j.ijnurstu.2010.06.004

PwC. 2024. "UK Higher Education Sustainability Report." Accessed April 8. 2024. https://www.pwc.co.uk/government-public-sector/education/documents/higher-education-financial-sustainability-report.pdf

Rosenman, R., V. Tennekoon, and L. G. Hill. 2011. "Measuring Bias in Self-reported Data." *International Journal of Behavioural and Healthcare Research* 2 (4): 320-332. https://doi.org/10.1504/IJBHR.2011.043414

Ross, M. S., Huff, J. L., and Godwin, A. (2021). "Resilient Engineering Identity Development Critical to Prolong Engagement of Black Women in Engineering." *Journal of Engineering Education* 110 (1): 92-113.

Samuelson, Cate C., and Elizabeth Litzler. 2016. "Community Cultural Wealth: An Assets-based Approach to Persistence of Engineering Students of Color." *Journal of Engineering Education* 105 (1): 93– 117.

Servant-Miklos, Virginie F. C., Eleanor F. A. Dewar, and Pia Bøgelund. 2021. "'I started this, and I will end this': a phenomenological investigation of blue collar men undertaking engineering education as mature students." *European Journal of Engineering Education* 46 (2): 287-301.

UCL Centre for Engineering Education. n.d. "Brexit Impact on UK's Engineering Education Sector: Exploring EU Students and Staff Experiences." Accessed April 5, 2024. https://www.ucl.ac.uk/centre-for-engineering-education/research/brexit-impact-uks-engineering-education-sector-exploring-eu-students-and-staff-experiences.

Winkens Ann-Kristin, and Carmen Leicht-Scholten. 2023. "Does engineering education research address resilience and if so, how? – a systematic literature review." *European Journal of Engineering Education* 48 (2): 221-239.

Vasileiou, K., J. Barnett, S. Thorpe, and T. Young. 2018. "Characterising and justifying Sample Size Sufficiency in Interview-based Studies: Systematic Analysis of Qualitative Health Research over a 15-year Period." *BMC Medical Research Methodology* 18 (1): 1-18. https://doi.org/10.1186/s12874-018-0594-7

Are technical knowledge sacrificed with the integration of transferable skills into the engineering curriculum? – an evaluation of one-week intensive project-based learning in biochemical and biomedical engineering

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ABSTRACT

Problem-solving and collaborative skills are crucial transferable skills for professional practice in engineering, as acknowledged by universities, employers, and accreditation bodies. However, there are engineering teachers who maintain a dichotomous perspective on the balance between transferable skills and academic knowledge, prioritizing the latter. Consequently, they are reluctant to integrate these

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skills into the curriculum at the expense of technical knowledge. Project-based learning (PjBL) has demonstrated potential in fostering both academic knowledge and transferable skills (Nguyen et al. 2020). However, existing research primarily focuses on students' perceptions on their learning outcomes (Guo et al. 2020). This study addresses this gap within the context of a first-year PjBL activity for biochemical and biomedical engineering students in a UK university by evaluating students' learning outcomes using both direct and indirect assessment methods. Findings from the study suggest that the PjBL activity can cultivate both technical knowledge and transferable skills. These results may help dispel misconceptions among engineering teachers that transferable skills can only be developed at the expense of technical knowledge. Interestingly, this study also found that engineering students perceived the development of critical problem-solving skills, but not collaborative skills from the PjBL activity. This observation warrants further investigation to determine the factors that influence students' perceptions of skill development in PjBL activities.

1 INTRODUCTION

Problem-solving and collaborative skills have been widely recognized by universities, employers and accreditation bodies as important transferable skills (Chan and Luk 2021) for professional practice in engineering (Passow and Passow 2017). Despite increasing efforts made by universities to introduce or integrate these competencies into the engineering curriculum, employers continue to express their dissatisfaction with engineering graduates, complaining about the gap between their expectations and the competencies an engineer graduate should possess. At the same time, engineering teachers were found to hold dichotomous perspective regarding the balance between transferable skills and academic knowledge in engineering, with some teachers seeing transferable skills to be secondary and continue to emphasize the importance of academic knowledge for engineers (Chan and Luk 2022). To put it simply, they do not want to help students to develop these competencies at the expense of technical knowledge and skills. They also find integrating the teaching of these competencies into their already dense course curriculum time-consuming and resource-intensive (Krause 2014; Chan et al. 2017).

Project-based learning (PjBL) has shown promise in developing both academic knowledge and transferable skills (Nguyen et al. 2020), increasing students' motivation (Wijnia et al 2024) and career aspirations in STEM disciplines (Beier et al 2019). However, studies on its impacts have largely focused on the perceptions of students (Guo et al. 2020). This study does not only provide an example of a one-week intensive project-based learning activity that is integrated into the engineering curriculum in an UK university, but also reports on findings from an evaluation of engineering students' learning outcomes through the use of both direct and indirect assessment. During the week, students were exposed to engineering design principles and theoretical knowledge related to assigned projects, as well as product development process, project management and teamwork skills. As previous studies mainly looked at undergraduates' perceived learning outcomes from their project-based learning experiences, there is a lack of empirical evidence on academic outcome indicators (i.e. technical knowledge gain) which provide more direct evidence of student learning. This study addresses this gap in the literature in the context of a first year PjBL activity for biochemical and biomedical engineering students by measuring their perceived transferable skills development with a validated instrument, which also include a direct measure of their technical knowledge. It aims to examine the research question: What are the learning gains in technical knowledge, problem-solving skills, and collaborative skills experienced by biochemical and biomedical engineering students as a result of a one-week intensive project-based learning activity?

2 LITERATURE REVIEW

2.1 Project-based Learning in Engineering

Project-based Learning (PjBL) offers engineering students the chance to apply their knowledge in practical situations (Mitchell and Rogers, 2020). According to Palmer and Hall (2011), this approach engages students in solving problems that lead to the creation of an artifact, which can be a model, an application, etc. Typically, students work in teams, and the projects can be multidisciplinary, requiring collaboration over an extended period of time.

2.2 Impact of Project-based Learning on Student Learning in Engineering

There is a general agreement in the literature about the benefits of project-based learning to students' development of technical knowledge and transferable skills. For example. Rodríguez et al. (2015) found that space engineering students who participated in PjBL activities felt more confident about their technical subject knowledge compared to students who did not. In a study conducted by Alves and colleagues (2017) in Portugal, it was found that industrial engineering students who participated in PjBL self-reported enhanced teamwork skills, leadership skills, communication skills, adaptability and sense of responsibility and self-reflective skills.

However, studies (e.g. Palmer and Hall 2011; Hall, Palmer and Bennett 2012; Alves et al. 2017) have largely focused on student perception. Majority of these studies have adopted self-reported questionnaires, with few using direct measures, such written tests or multiple-choice questions (Guo et al. 2020).

3 RESEARCH CONTEXT

This study took place in an Engineering Faculty in a UK university that has been implementing project-based learning (PjBL) activities across the first two years of undergraduate engineering programmes (Mitchell et al. 2021). Survey data was collected during the one-week scenarios that are central to the undergraduate engineering programmes.

In the biochemical scenario, students had to work in teams of four to five as part of a consultancy company that aims to tackle problems relating to the quality of ice cream production. By understanding the science behind ice cream (e.g. its multiphasic nature and the impact of certain ingredients such as emulsifiers) along with the manufacturing process, students were able to redesign the manufacturing process and provide advice on raw materials and additives to better enhance the quality of the end product. Students also had to provide a cost analysis and present their research and new process design to the client (staff). To further assist them, students visited an ice cream manufacturing site and were able to tour the facility, observe and participate in ice cream production and ask questions to the facility director to aid them in their own research. In the Biomedical scenario, students had to work in a team of three to develop a useful healthcare application which can identify objects.

4 METHODOLOGY

4.1 Participants

A total of 106 engineering undergraduates in a UK university participated in the Pre-Scenario Survey and 111 students participated in the Post-Scenario survey. After removing incomplete responses, the final student sample of the Pre-Scenario Survey consists of 104 biochemical and biomedical engineering undergraduate students, while the final student sample of the Post-Scenario survey consists of 80 biochemical and biomedical engineering undergraduate students. All the participants are first year undergraduate students, between 18 and 26 years old.

4.2 Instrument

The survey instrument consists of 2 sections. The first section consists of a technical knowledge test developed by the module leader. Here is an example of one test question taken from the test for Biomedical engineering students:

In a Matlab app, which function is executed first after the app has started? Answer Options: (a) startupFcn, (b) main, (c) function, (d) ButtonPushed.

The second section contained two scale (10 items), presented in Table 1, measuring students' perceived competency in problem-solving and collaborative skills, adapted from a validated Student Holistic Competency developed by Chan and Luk (2021). Each of the 10 items was rated on a 5-point Likert scale ranging from 1 (not competent) to 5 (very competent). Students were also required to provide demographic information including their gender, age, year of study, programme of study at the end of the questionnaire.

The 10 items soft skills questionnaire was piloted on 88 students from electrical and electronic engineering. Exploratory factor analysis was conducted on the 10 items to assess construct validity of the instrument. Presented in Table 1, factor analysis yielded two factors based on the eigenvalue greater than 1 criterion (Kaiser 1974). The two factors accounted for 55.98% of the total variance. Factor 1 consisted of seven items related to critical thinking and problem-solving skills. This factor was labelled as 'Critical problem-solving skills'. Factor 2 contained three items referring to the ability with work collaboratively with others as a team. This factor was named as 'Collaborative skills'.

Table 1. Exploratory Factor Analyses of the Transferable Skills Items

	1	2
Critical Problem-solving Skills		
Questioning values, practices and opinions	**0.43**	

Reflecting on and challenging one’s values, perceptions and actions	**0.53**	
Taking your own position or viewpoint	**0.47**	
Taking a holistic overview of complex problems	**0.61**	
Applying different problem-solving frameworks to complex problems	**0.71**	
Collectively developing viable solutions to solving complex problems	**0.84**	
Analysing complex problems	**0.94**	
Collaborative Skills		
Learning from others		**0.77**
Understanding and respecting the needs, perspectives and actions of others		**0.91**
Handling conflicts in a group		**0.58**

4.3 Procedures

A purposive sampling approach (Johnson and Christensen 2014) was undertaken, such that students were approached by the researcher on the first and last day of the scenario project, which is held in the second term of Year 1. The students were given approximately 15 minutes to complete the questionnaire.

4.4 Data Analysis

Data analysis was undertaken using SPSS 24.0 and R. Before conducting independent samples t-test to investigate differences between students’ technical knowledge and perceived soft skills development before and after the scenario, confirmatory factor analysis was conducted on the Pre-Scenario survey data to confirm the internal structure of the transferable skills questionnaire. This step is undertaken to ensure that survey is valid for biochemical and biomedical engineering students as well. Based on the criteria suggested by Hu and Bentler (1999), the results show an acceptable fit of the ten items to the two-factor structure for the questionnaire, which is indicated by a Comparative Fit Index (CFI) above 0.90, a Root Mean Squared Error of Approximation (RMSEA) below 0.08, and a Standardized Root Mean Squared Residual (SRMR) below 0.08. The item-factor loadings were all significantly different from zero ($p<.05$), with values ranging from 0.52 to 0.77, as reported in Table 2. The Cronbach alpha coefficient (see Table 3) for the two scales ranged from 0.77 to 0.89, suggesting that the questionnaire is reliable.

Table 2. Confirmatory Factor Analyses of the Transferable Skills Items

	1	2
Critical Problem-solving Skills		
Questioning values, practices and opinions	**0.71**	
Reflecting on and challenging one’s values, perceptions and actions	**0.74**	

Taking your own position or viewpoint	**0.57**	
Taking a holistic overview of complex problems	**0.56**	
Applying different problem-solving frameworks to complex problems	**0.59**	
Collectively developing viable solutions to solving complex problems	**0.63**	
Analysing complex problems	**0.52**	
Collaborative Skills		
Learning from others		**0.58**
Understanding and respecting the needs, perspectives and actions of others		**0.77**
Handling conflicts in a group		**0.66**

Table 3. Reliability and Validity Evidence at Scale Level

	No. of items	*n*	*M*	*SD*	Cronbach's Alpha	Eigenvalue	% of Variance
Critical Problem-solving Skills	7	100	3.54	0.67	0.89	4.23	60.38
Collaborative Skills	3	100	3.82	0.76	0.77	2.08	69.33

5 RESULTS

Table 4 and 5 presents the means, standard deviations, and t-values for the two scales, as well as Cohen d as a measure of the effect size.

Comparison of biomedical and biochemical engineering students' perceived competency in transferable skills through the use of independent samples t-test revealed no substantive differences between students' perceived competency in collaborative skills before and after the scenario project. This finding suggests that the students perceive themselves as competent in collaborative skills, and do not see the scenario project as an opportunity to further develop their collaborative skills.

However, there is a significant difference between their perceived competency in critical problem-solving skills before ($M_{Biomed}=3.48$, $SD_{Biomed}=0.74$; $M_{Biochem}=3.63$, $SD_{Biochem}=0.54$) and after ($M_{Biomed}=3.93$, $SD_{Biomed}=0.63$; $M_{Biochem}=4.04$, $SD_{Biochem}=0.56$) the scenario project. The calculated effect size is medium ($d_{Biomed}=-.66$; $d_{Biochem}=-0.75$). The independent samples t-test also indicated that there is a significant difference between their technical knowledge before ($M_{Biomed}=2.60$, $SD_{Biomed}=1.15$; $M_{Biochem}=4.82$, $SD_{Biochem}=1.32$) and after ($M_{Biomed}=3.95$, $SD_{Biomed}=1.30$; $M_{Biochem}=5.55$, $SD_{Biochem}=0.69$) the scenario project. The calculated effect size is large ($d_{Biomed}=1.09$) for biomedical students and medium ($d_{Biochem}=-0.64$) for biochemical students. The findings suggest that students perceive an improvement in both critical problem-solving skills and technical knowledge after completing the scenario project.

Table 4. Comparison between Biomedical students before and after the PjBL activity

Biomedical Students	Pre/Post	*M*	*SD*	*n*	*t*	*df*	Sig.	Cohen *d*
Technical Knowledge	Pre	2.60	1.15	58	-6.03	120	0.000	-1.09
	Post	3.95	1.30	64				
Critical Problem-solving Skills	Pre	3.48	0.74	61	-3.56	116	0.001	-0.66
	Post	3.93	0.63	57				
Collaborative Skills	Pre	3.75	0.87	61	-2.13	116	0.035	-0.39
	Post	4.08	0.77	57				

Table 5. Comparison between Biochemical students before and after PjBL activity

Biochemical Students	Pre/Post	*M*	*SD*	*n*	*t*	*df*	Sig.	Cohen *d*
Technical Knowledge	Pre	4.82	1.32	39	-2.32	57	0.024	-0.64
	Post	5.55	0.69	20				
Critical Problem-solving Skills	Pre	3.63	0.54	39	-2.59	54	0.012	-0.75
	Post	4.04	0.56	17				
Collaborative Skills	Pre	3.93	0.56	39	-0.65	54	0.522	-
	Post	4.04	0.60	17				

6 DISCUSSION

The findings of this study suggests that PjBL can foster the development of both technical knowledge and transferable skills, especially when the activities are designed with both aspects in mind. These results can help dispel the misconception among engineering teachers that transferable skills can only be developed at the expense of technical knowledge. Building on the finding in Rodríguez et al.’s (2015) study, findings from this study suggest that PjBL does not only help to increase engineering students’ self-confidence in their technical knowledge, but also improve their technical knowledge.

An interesting finding from this study is that engineering students perceived the development of critical problem-solving skills, but not collaborative skills.

One possible explanation is that collaborative skills were heavily emphasized during the Engineering Challenges module, which occurs in the first term of their undergraduate studies. Consequently, students might view the second-term Scenario module as an opportunity to apply, rather than develop, these skills. The findings from this study contrast with those of Alves and colleagues (2017), who found that engineering students perceived an increase in teamwork skills from their PjBL experiences. However, comparison is difficult because the students in Alves et al.'s study were Masters-level students who worked in teams to propose solutions for an ill-defined problem, which was not described in detail in their paper.

Another potential explanation is that transferable skills, such as collaborative skills, require time and multiple opportunities for practice or application to develop fully. In other words, students need to apply these skills in various contexts before perceiving their development. For critical problem-solving skills, students may have had numerous opportunities to apply them in other modules and prior to their university studies, leading them to feel they are progressing in this area. In contrast, teamwork might be a relatively new concept for them compared to problem-solving. They may have only begun practicing these skills during the first term of their university studies, and thus, require more time to feel comfortable demonstrating their collaborative abilities and perceiving their development.

To gain further insights, follow-up interviews need to be conducted with the students. This will help explore the reasons behind their perceptions of skill development, and allow for a more in-depth understanding of the factors influencing these perceptions. Future research can also involve collecting feedback from alumni on whether their learning and skill development through PjBL is helpful in preparing them for the workplace.

REFERENCES

Alves, Anabela C., Celina P. Leão, Francisco Moreira, and Senhorinha Teixeira. "Project-Based Learning and Its Effects on Freshmen Social Skills in an Engineering Program." In *Human Capital and Competences in Project Management*, edited by Otero-Mateo Manuel and Pastor-Fernandez Andres, Ch. 2. Rijeka: IntechOpen, 2017.

Beier, Margaret E., Michelle H. Kim, Ann Saterbak, Veronica Leautaud, Sandra Bishnoi, and Jaqueline M. Gilberto. "The Effect of Authentic Project-Based Learning on Attitudes and Career Aspirations in Stem." 56, no. 1 (2019): 3-23. https://doi.org/10.1002/tea.21465.

Chan, Cecilia K. Y., and Lillian Y. Y. Luk. "Development and Validation of an Instrument Measuring Undergraduate Students' Perceived Holistic Competencies." *Assessment & Evaluation in Higher Education* 46, no. 3 (2021): 467-82. https://doi.org/10.1080/02602938.2020.1784392.

Chan, Cecilia K. Y., and Lillian Y. Y. Luk. "Academics' Beliefs Towards Holistic Competency Development and Assessment: A Case Study in Engineering Education." *Studies in Educational Evaluation* 72 (2022): 101102. https://doi.org/10.1016/j.stueduc.2021.101102.

Chan, Cecilia Ka Yuk, and Lillian Yun Yung Luk. "Development and Validation of an Instrument Measuring Undergraduate Students' Perceived Holistic Competencies." *Assessment & Evaluation in Higher Education* 46, no. 3 (2021): 467-82. https://doi.org/10.1080/02602938.2020.1784392.

Chan, Cecilia Ka Yuk , Emily T. Y. Fong, Lillian Yun Yung Luk, and Robbie Ho. "A Review of Literature on Challenges in the Development and Implementation of Generic Competencies in Higher Education Curriculum." *International Journal of Educational Development* 57 (2017): 1-10. https://doi.org/10.1016/j.ijedudev.2017.08.010.

Guo, Pengyue, Nadira Saab, Lysanne S. Post, and Wilfried Admiraal. "A Review of Project-Based Learning in Higher Education: Student Outcomes and Measures." *International Journal of Educational Research* 102 (2020): 101586. https://doi.org/10.1016/j.ijer.2020.101586.

Hall, Wayne, Stuart Palmer, and Mitchell Bennett. "A Longitudinal Evaluation of a Project-Based Learning Initiative in an Engineering Undergraduate Programme." *European Journal of Engineering Education* 37, no. 2 (2012): 155-65. https://doi.org/10.1080/03043797.2012.674489

Johnson, R. Burke, and Larry Christensen. *Educational Research: Quantitative, Qualitative, and Mixed Approaches.* 5th ed. Thousand Oaks, California: SAGE, 2014.

Kaiser, Henry F. "An Index of Factorial Simplicity." *Psychometrika* 39, no. 1 (1974): 31-36. https://doi.org/10.1007/bf02291575.

Krause, Kerri-Lee D. "Challenging Perspectives on Learning and Teaching in the Disciplines: The Academic Voice." *Studies in Higher Education* 39, no. 1 (2014): 2-19. https://doi.org/10.1080/03075079.2012.690730.

Mitchell, John E., and Lynne Rogers. "Staff Perceptions of Implementing Project-Based Learning in Engineering Education." *European Journal of Engineering Education* 45, no. 3 (2020): 349-62. https://doi.org/10.1080/03043797.2019.1641471.

Mitchell, John E., Abel Nyamapfene, Kate Roach, and Emanuela Tilley. "Faculty Wide Curriculum Reform: The Integrated Engineering Programme." *European Journal of Engineering Education* 46, no. 1 (2021): 48-66. https://doi.org/10.1080/03043797.2019.1593324.

Nguyen, Ha, Lily Wu, Christian Fischer, Gregory Washington, and Mark Warschauer. "Increasing Success in College: Examining the Impact of a Project-Based Introductory Engineering Course." 109, no. 3 (2020): 384-401. https://doi.org/https://doi.org/10.1002/jee.20319.

Palmer, Stuart, and Wayne Hall. "An Evaluation of a Project-Based Learning Initiative in Engineering Education." *European Journal of Engineering Education* 36, no. 4 (2011): 357-65. https://doi.org/10.1080/03043797.2011.593095.

Passow, Honor J., and Christian H. Passow. "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review." *Journal of Engineering Education* 106, no. 3 (2017): 475-526. https://doi.org/10.1002/jee.20171.

Rodríguez, Jacobo, Ana Laverón-Simavilla, Juan M. del Cura, José M. Ezquerro, Victoria Lapuerta, and Marta Cordero-Gracia. "Project Based Learning Experiences in the Space Engineering Education at Technical University of Madrid." *Advances in Space Research* 56, no. 7 (2015): 1319-30. https://doi.org/10.1016/j.asr.2015.07.003.

Wijnia, Lisette, Gera Noordzij, Lidia R. Arends, Remigius M. J. P. Rikers, and Sofie M. M. Loyens. "The Effects of Problem-Based, Project-Based, and Case-Based Learning on Students' Motivation: A Meta-Analysis." *Educational Psychology Review* 36, no. 1 (2024): 29. https://doi.org/10.1007/s10648-024-09864-3.

CAREER PATH INFLUENCES: A THEMATIC ANALYSIS AMONG PRACTICING ENGINEERS AND FORMER ASPIRANTS

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ABSTRACT

The study conducted by Lee *et al.* (2019) delves into the impact of exposure to STEM learning on the participation and retention of women in engineering studies. Building upon this research, this study explores the intricate relationship between individuals' formative educational experiences and their career pathways, investigating the factors that shape these decisions. Utilising online focus groups, the research engages two distinct participant groups: practicing engineers and individuals who diverted from pursuing a career in engineering. Thematic analysis

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was employed to decipher the data, revealing multifaceted challenges such as confidence barriers, gender dynamics, and mismatches between academic theory and industry demands. The study underscores the significance of holistic support systems, practical learning experiences, and critical thinking skill development to empower students and better prepare them for the complexities of the engineering profession. It advocates for inclusivity, diversity, and hands-on learning initiatives within engineering education, emphasising the importance of bridging the gap between academia and industry. By prioritising the development of critical thinking skills and fostering a culture of support and collaboration, we can ensure graduates are adequately equipped to tackle engineering challenges effectively, thus enhancing both educational experiences and the advancement of the engineering field.

1 INTRODUCTION

Engineering education serves as the cornerstone of technological advancement and innovation across diverse industries. The cultivation of skilled engineers is pivotal for addressing complex societal challenges and driving economic growth. However, despite concerted efforts to recruit and retain talented individuals in the field, challenges persist in comprehensively understanding the multifaceted experiences and decision-making factors within engineering education and careers. Scholarly research such as that by Cheryan *et al.* (2017), Buckley *et al.* (2019), Ishikawa and Newcombe (2021) and Lane and Sorby (2022) underscores the importance of elucidating these dynamics to optimise educational practices, inform policy initiatives, and foster a supportive environment conducive to the success of aspiring engineers. Recent studies have highlighted various factors influencing the decision to pursue engineering as a field of study. For instance, research conducted by Tyler-Wood *et al.* (2018) explores human constructivist learning and how it influences students' attitudes, interest and performance in STEM (Science, Technology, Engineering and Mathematics) education and their later career choices, emphasising the importance of active engagement and learning in modern education. Furthermore, findings from a longitudinal study by (Cheryan et al. 2017) underscore the impact of stereotypes and societal perceptions on the underrepresentation of certain demographic groups, emphasising the need for targeted interventions to promote diversity and inclusivity within the engineering profession.

While existing literature provides insights into specific aspects of engineering education, there remains a gap in comprehensively exploring the educational experiences of practicing engineers and those diverging from engineering careers. Understanding these experiences is crucial for addressing barriers, enhancing support mechanisms, and fostering inclusivity. This study addresses this gap through a thematic exploration of formative educational experiences in engineering, using qualitative methods such as online focus groups with two distinct participant groups: practicing engineers and individuals pursuing non-engineering careers. By examining their narratives, this research aims to uncover the challenges, successes, decision-making processes, and socio-cultural influences in their educational and professional journeys. Exploring spatial thinking in engineering education and careers is significant due to its profound impact on practice. Spatial thinking, involving understanding and manipulating spatial relationships, is fundamental in visualizing systems, designing structures, and solving spatial problems (McNea et al., 2023). This study investigates how individuals perceive and apply spatial thinking throughout their educational and professional paths in engineering, aiming to underscore its importance and identify areas for improvement.

To summarise, this research seeks to shed light on three critical questions. Firstly, we aim to explore the challenges and opportunities encountered by engineering aspirants during their academic journey, and how these experiences influence their career decision-making processes within the field of engineering (RQ1). Secondly, by examining the insights garnered from this study, we seek to inform the development of strategies and initiatives aimed at enhancing diversity, inclusivity, and support mechanisms within engineering education and professional practice (RQ2). Lastly, we aim to investigate how individuals perceive the evolution and application of spatial thinking throughout their journey in engineering education and career, unveiling the efficacy and importance of spatial thinking education and training initiatives in the engineering domain (RQ3). Through addressing these research questions, this study aims to contribute to a deeper understanding of the challenges and opportunities within the engineering pipeline and to provide evidence-based recommendations for fostering a more inclusive and equitable environment within the engineering profession.

2 METHODOLOGY

Recognising the complexity and diverse nature of individuals' journeys in the engineering profession, qualitative methods are chosen to capture the richness of participants' narratives, perspectives, and insights. The research methodology encompasses the following key components:

- **Formulation of Research Questions**: The research questions were carefully formulated to address specific topics relevant to the study's objectives. They were designed to be focused, feasible, and aligned with the study's scope and purpose, as detailed in Section 1.
- **Participant Recruitment**: As a preliminary study, participants were selectively chosen to ensure diverse representation relevant to the research goals. Eligibility included practicing engineers or those who had considered engineering careers, convenience sampling was used with small participant numbers due to this being the pilot phase of the study. Upon meeting criteria, participants were assigned time slots for online focus groups. Transparent communication channels were established throughout recruitment to address inquiries promptly, ensuring informed consent.
- **Ethical Considerations** were crucial in every stage. Participants provided informed consent before data collection, understanding the study's purpose, procedures, risks, benefits, and their rights. Confidentiality and anonymity were strictly preserved to protect participants' privacy and sensitive information. Identifiable data were pseudonymised during analysis to maintain confidentiality.
- **Data Collection**: Arrangements were made with all participants for synchronous online discussions (focus groups) using Microsoft Teams. Prior to the sessions, they were briefed on the objectives of the focus groups and provided with necessary instructions for participating in the online environment. Throughout the sessions, the principal investigator facilitated discussions, steering the

conversation toward predetermined topics or questions aligned with the research objectives;

1. Can you share what influenced your decision (not) to pursue a career in engineering? How did these expectations align with your actual experiences or career trajectories?
2. Reflecting on your educational journey in engineering education, can you share specific moments or aspects that surprised you, made your experience enjoyable, or influenced your overall recommendation for others considering a path in engineering?
3. How do you believe the engineering education system could be enhanced to better prepare individuals for the challenges they may face in their careers? What advice would you offer to someone currently navigating their path in engineering or considering a different career direction?
4. Can you talk to me about your experiences with spatial thinking / learning throughout your education and career?

All sessions were recorded with consent, allowing for a comprehensive capture of verbal exchanges, non-verbal cues, and group dynamics. Following the completion of each focus group, recordings were transcribed verbatim, ensuring an accurate representation of participant dialogue. The transcriptions were then subjected to thorough quality checks to maintain fidelity to the original recordings.

- The **Data Analysis** process employed in this study was a theoretical thematic analysis as described by Braun and Clarke (2006 and 2012) aimed at uncovering the diverse and multifaceted narratives embedded within participants' experiences in engineering education and careers. It consists of six steps:
  1. Data Familiarisation
  2. Initial Coding
  3. Code Development and Organisation
  4. Iterative Refinement
  5. Theme Elaboration and Definition
  6. Interpretation and Synthesis

3 RESULTS

Table 1 presents the themes that emerged from the focus groups listed by the theme’s appearance in transcriptions. These findings encapsulate insights from both active engineers *(n=7)* and individuals who previously considered pursuing engineering *(n=3)*. Formulated meanings from each focus group were arranged into clusters which resulted in six themes: “challenges”, “confidence”, “social dynamics & influence”, “personal factors”, “opportunities & surprises” and “skills & competencies”.

Table 1: Frequency Distribution of Themes across all 3 Online Focus Groups

THEME	FREQUENCY & VALID PERCENTAGES*					
	All Participants (n=10)		Practicing Engineers (n=7)		Engineering Contemplators (n=3)	
Challenges	50	(12%)	43	(13%)	7	(5%)
Confidence	70	(16%)	27	(8%)	43	(32%)
Social Dynamics & Influence	71	(16%)	44	(14%)	27	(20%)
Personal Factors	97	(22%)	72	(23%)	25	(19%)
Opportunities & Surprises	54	(12%)	47	(15%)	7	(5%)
Skills & Competencies	93	(21%)	87	(27%)	26	(19%)
Total:	435	(100%)	320	(100%)	135	(100%)

3.1 Emerging Themes

While a relatively small sample size, in the combined results (n=10), 'Personal Factors' emerge as a significant influence, with both positive and negative aspects. This theme encompasses various codes like "personal background," "interests," "lifestyle choices," and "expectations versus reality." Among practicing engineers (n=7), 'Skills and Competencies' such as "work experience," "cross-experience collaboration," "critical thinking," and "spatial thinking" are highlighted as primary influencers on their educational journeys. These factors often steer individuals toward unexpected career paths. For former aspiring engineers (n=3), 'Confidence' emerges as the key influencer, with factors like "imposter syndrome," "self-belief," "fear of failure," and "undermining" playing significant roles in their decisions. These insights underline the complex relationship between personal confidence and career aspirations.

3.2 Challenges

The results of the analysis provide a comprehensive understanding of the challenges individuals encounter throughout their career trajectories. Despite proactive efforts, participants faced limitations in job opportunities, suggesting potential mismatches between skills and market demands. Communication hurdles, including difficulties in professional presentations and articulating needs without conflict, emerged as significant obstacles. Additionally, participants expressed dissatisfaction with the theoretical nature of their education, particularly in engineering, longing for more practical, hands-on experiences. Feelings of self-doubt and a lack of confidence were prevalent, influenced by academic performance, gender dynamics, and peer comparison. External influences, such as societal expectations, also played significant roles in shaping career decisions. Furthermore, participants identified challenges within the educational system, notably in navigating administrative processes like the Irish Central Applications Office (CAO), adding complexity to career planning. These findings highlight the multifaceted nature of career challenges and underscore the importance of holistic support systems to address them effectively, empowering individuals in their professional journeys.

3.3 Confidence

Participants expressed a variety of experiences and perspectives, illustrating both positive and negative effects on their educational journeys. On one hand, confidence was identified as a catalyst for enhanced engagement and enjoyment in engineering coursework. Participants described how gaining a deeper understanding of concepts or receiving support positively impacted their confidence levels, leading to greater satisfaction with their studies and aspirations for future careers. Overcoming initial apprehensions, particularly regarding the rigorous mathematical aspects of engineering, contributed to a sense of personal growth and empowerment among participants. Moreover, embracing mistakes as integral to the learning process and fostering belief in oneself were identified as crucial factors in cultivating confidence and resilience within the academic setting. Conversely, the discussions also revealed the presence of social dynamics, particularly concerning gender, that could negatively influence confidence levels among certain participants. Female students, in particular, recounted experiences of feeling outnumbered, overlooked, or underestimated in predominantly male environments, highlighting the challenges of navigating gendered spaces within engineering education. Instances of "mansplaining" and unsolicited advice further underscored the need for greater awareness and inclusivity to mitigate gender biases and promote a supportive learning environment for all students. Furthermore, participants shared personal struggles with self-doubt and fears, particularly related to mathematics, a cornerstone of engineering curricula.

"It was the fear of failing … that fear put me down the route I am as well (non-engineer)" (female)

Intimidation by perceived difficulty and pressure to excel in mathematical coursework were identified as significant barriers to confidence and academic persistence. These narratives underscored the importance of addressing psychological barriers and fostering a culture that embraces failure as a natural part of the learning process, thereby promoting confidence and academic success. While confidence can fuel engagement and personal development, it's imperative to tackle systemic barriers and cultivate inclusive environments to foster confidence and empower every student to excel in engineering fields.

3.4 Social Dynamics and Influence

Role models, particularly those within families, profoundly influenced participants' educational paths. Often family members with engineering backgrounds, these figures not only inspired but also shaped career aspirations. Their guidance from a young age instilled a passion for engineering, impacting decisions to pursue this field. This influence extended beyond individuals, inspiring peers and colleagues to follow similar paths. Teamwork emerged as fundamental in engineering education. Collaborative efforts cultivated interpersonal skills, problem-solving abilities, and collective responsibility. Group projects mimicked real-world workplaces, emphasising effective communication and interdisciplinary cooperation. Diverse team backgrounds enriched problem-solving, though challenges like communication barriers were acknowledged, highlighting the need for ongoing interpersonal skill development alongside technical competencies. Support systems were crucial in nurturing individuals' growth. Peer interactions provided motivation and camaraderie, spurring excellence in studies and projects. Mentorship programs and practical experiences, like internships, offered guidance from seasoned professionals, enhancing learning and skill development. Moreover, individuals influenced each other, shaping experiences and decisions through peer interactions and collaborative efforts, fostering a sense of community and propelling collective growth towards shared goals and success.

3.5 Personal Factors

The exploration of participants' experiences in engineering education uncovered a notable contrast between initial expectations and actual realities. Many were surprised to find themselves drawn to aspects of engineering they hadn't initially anticipated, such as software development or research, while others noted a disconnect between academic theory and real-world engineering demands. Additionally, participants emphasised the significance of teamwork, problem-solving, and practical skills throughout their educational journey. These findings underscore the necessity for a curriculum that harmonises theoretical knowledge with hands-on experience to better equip students for the multifaceted challenges of the engineering profession. Lifestyle decisions emerged as pivotal factors shaping educational pathways in engineering. Participants cited personal considerations like family responsibilities, career aspirations, and shifting values as influential in their decision-making processes. Some pursued engineering education to advance their careers or foster personal growth, while others altered their paths to align with evolving priorities.

"It was primarily driven through a lifestyle decision. You know, young baby on the way". (male)

This highlights the intricate interplay between individual circumstances and educational choices within the engineering realm. The analysis of participants' personal backgrounds revealed diverse routes into engineering education, shaped by prior qualifications or experiences in related fields such as teaching or software development. Participants also discussed the influence of upbringing, ranging from farming backgrounds to legal professions, underscoring the diverse influences shaping individuals' interests and motivations in pursuing engineering. Overall, these findings emphasise the multifaceted nature of personal backgrounds in shaping educational experiences and career trajectories within the field of engineering.

3.6 Opportunities and Surprises

Participants highlighted how positive experiences, particularly from secondary school projects like Formula One in Schools, sparked their interest in engineering disciplines. Internships were pivotal in shaping career paths and providing practical application of knowledge. Collaborative teamwork enhanced problem-solving skills. The flexibility of educational programs, exemplified by internship opportunities, influenced students' decisions to pursue engineering studies. Opportunities were crucial in instilling confidence and fostering growth, advocating for early exposure to practical learning experiences. Surprising elements, such as unexpected career paths and challenges in transitioning between undergraduate and postgraduate studies, underscored the importance of adaptability. Participants expressed astonishment at the emphasis on teamwork and the level of detail in specialised programs. Moreover, the absence of continuity between school-based initiatives and higher education highlighted the need for greater integration of hands-on initiatives throughout the educational pipeline to sustain interest in engineering disciplines from school to college.

3.7 Skills and Competencies

Participants offered varied perspectives, with some praising the invaluable role of internships in shaping their academic journey and career trajectory, while others stressed the importance of practical learning in real-world engineering contexts. Despite positive attitudes toward work experience, concerns were raised about the disparity between academic studies and practical learning in engineering education. Participants suggested integrating hands-on experiences into curricula to align better with industry standards.

"The problem-solving skills, critical thinking that you will use on a day-to-day basis are probably the lesser focused topics" (male)

Cross-experience collaboration was highlighted as vital, emphasising the value of diverse perspectives and problem-solving approaches. Recommendations included enhancing collaboration between educational institutions and industry partners to cultivate critical thinking skills. Participants underscored the need to prioritise critical thinking in engineering education and recommended incorporating more diverse courses to prepare graduates for real-world challenges. Overall, there was a consensus on the importance of balancing practical experience with critical thinking skills in engineering education to adequately prepare students for professional complexities. In light of the diverse perspectives on spatial thinking in engineering education, there is a pressing need to prioritise critical thinking and problem-solving skills to adequately prepare graduates for the complexities of the profession. While spatial thinking plays a crucial role in engineering tasks, it is just one aspect of the multifaceted challenges engineers encounter. By emphasising critical thinking and problem-solving, engineering education can equip students with the ability to approach problems holistically, analyse situations from multiple angles, and devise innovative solutions. This broader skill set not only enhances their capacity to navigate spatial challenges but also equips them to tackle the intricate socio-technical problems prevalent in today's engineering landscape. Moreover, fostering critical thinking cultivates a mindset of continuous learning and adaptability, essential for engineers to thrive in an ever-evolving technological environment. Thus, by integrating spatial thinking within a framework of robust critical thinking and problem-solving skills, engineering education can better prepare graduates to tackle the diverse and dynamic demands of the profession effectively.

4 DISCUSSION

This study aimed to explore the educational experiences within engineering education and careers, with a focus on uncovering challenges, triumphs, decision-making processes, and the role of spatial thinking in participants' journeys. Through online focus groups engaging practicing engineers and individuals who diverted from pursuing engineering careers, valuable insights were gained into the multifaceted nature of experiences within the field. In this discussion, we will analyse and interpret the findings considering existing literature, addressing key themes such as "Personal Factors", "Confidence" and "Skills & Competencies". Firstly, the narratives of practicing engineers shed light on the practical aspects, dynamics, and factors contributing to success within the engineering field. Their experiences underscore the importance of practical learning, interdisciplinary collaboration, and ongoing skill development in navigating the complexities of engineering careers. Additionally, insights into the experiences of individuals who diverted from engineering careers offer valuable perspectives on the diverse reasons and decision-making processes guiding them away from their initial aspirations. By examining both groups' narratives, we can gain a comprehensive understanding of the challenges and opportunities present within engineering education and career trajectories.

The notion of students experiencing a disconnect between their initial expectations and the realities of engineering education resonates with existing literature on the mismatch between academic preparation and industry demands (Brunhaver et al. 2018; Trevelyan 2019). Research suggests that students often have idealised perceptions of engineering careers, and the actual experiences may differ significantly, leading to challenges in academic and professional adaptation (Eliot and Turns 2011; Morelock 2017). The emphasis on teamwork, problem-solving, and practical skills aligns with the literature advocating for hands-on, experiential learning approaches in engineering education (Sorby *et al.* 2018; Van den Beemt *et al*. 2020; Bower *et al*. 2022; Maker *et al*. 2023). Studies have shown that integrating practical experiences into the curriculum enhances students' abilities to apply theoretical knowledge to real-world challenges and fosters a deeper understanding of engineering concepts (Ring et al. 2017; Lobovikov-Katz 2019; Dare *et al.* 2021; Le *et al.* 2023; Nipyrakis *et al.* 2023).

The findings regarding the positive impact of confidence on academic engagement and enjoyment in engineering coursework align with existing literature on self-efficacy theory (Bandura 1997). Research suggests that students with higher levels of confidence are more likely to persevere through challenges, actively engage in learning activities, and experience greater satisfaction with their academic experiences (Cheryan *et al*. 2017; Gagnier *et. al* 2022; Miola *et al.* 2023). The identification of overcoming apprehensions about the mathematical aspects of engineering as contributing to personal growth resonates with literature on mathematical anxiety and its impact on STEM education (Close and Shiel 2009; Shiel and Kelleher 2017; Delage et al. 2022). Studies have shown that students who experience mathematical anxiety may exhibit avoidance behaviours and reduced performance in engineering disciplines, highlighting the importance of addressing these barriers to promote academic success (Sorby *et. al* 2018; Daker *et al*. 2021). The discussion on gender dynamics and their influence on confidence levels among female students reflects broader research on gender disparities in STEM fields (Stoet and Geary 2018). Literature suggests that women in male-dominated environments may experience stereotype threat, imposter syndrome, and microaggressions, which can negatively impact their confidence and sense of belonging in STEM disciplines (Cheryan et al. 2017). The discussion underscores the need for inclusive environments to mitigate gender biases and promote confidence among all students, which aligns with literature on diversity and inclusion in engineering education (Scott 2020; García-Holgado *et al.* 2021; Verdugo-Castro *et al.* 2022) Research emphasises the importance of creating supportive learning environments that value diversity, equity, and inclusion to enhance engagement, retention, and success in STEM disciplines (O'Leary et al. 2020).

It is noteworthy that participants in the study struggled to provide a clear definition of spatial thinking. This observation aligns with existing literature that acknowledges the complexity and multidimensionality of spatial thinking, which encompasses various cognitive processes such as mental rotation, visualisation, and spatial reasoning (Newcombe and Shipley 2015; McNea et al. 2023). While participants may not have articulated a precise definition of spatial thinking, their experiences and insights shed light on its importance in engineering education. This aligns with literature emphasising the significance of spatial thinking abilities in engineering tasks, including the visualisation and manipulation of complex structures, analysis of spatial relationships, and design of innovative solutions (Sorby 2009; Gagnier *et al*. 2017). Moreover, the data highlights the necessity for a holistic approach to problem-solving in engineering education. This aligns with literature advocating for integrative and interdisciplinary approaches, recognising that addressing engineering challenges requires students to consider multiple factors, perspectives, and constraints (Hegarty 2018). Critical thinking skills are essential for students to analyse problems from various angles and develop effective solutions.

This emphasises the role of critical thinking in fostering a mindset of continuous learning and adaptability, essential for engineers to thrive in an ever-evolving technological environment. This aligns with literature highlighting the importance of lifelong learning and professional development in engineering practice (Power and Maclean 2013). Engineering graduates must be equipped with the skills to adapt to rapid technological advancements and evolving industry trends. The integration of spatial thinking within a framework of robust critical thinking and problem-solving skills is paramount for adequately preparing graduates to tackle the multifaceted demands of the profession (Gagnier *et al.* 2022). By prioritising these skills and adopting interdisciplinary approaches, educational institutions can ensure that engineering graduates possess the analytical acumen and problem-solving capabilities necessary to succeed in today's rapidly evolving technological landscape.

5 CONCLUSION

In conclusion, the study provides valuable insights into the challenges, experiences, and opportunities encountered by individuals in engineering education and career paths. It emphasises the importance of holistic support systems, inclusivity, and practical learning experiences in empowering students to succeed in the engineering profession. By addressing systemic barriers, fostering confidence, and promoting critical thinking skills, educational institutions and stakeholders can better prepare graduates to navigate the diverse and dynamic demands of the engineering landscape.

It is essential to continue advocating for inclusivity, diversity, and hands-on learning initiatives within engineering education. By prioritising the development of critical thinking skills, fostering a culture of support and collaboration, and bridging the gap between academia and industry, we can ensure that graduates are equipped to tackle the challenges and complexities of the engineering profession effectively. This comprehensive approach will not only enhance the educational experiences of students but also contribute to the advancement of the engineering field as a whole.

REFERENCES

Bandura, Albert. 1997. *Self-Efficacy: The Exercise of Control*. Worth Publishers.

Bower, Corinne A., Laura Zimmermann, Brian N. Verdine, Calla Pritulsky, Roberta Michnick Golinkoff, and Kathy Hirsh-Pasek. 2022. ‘Enhancing Spatial Skills of Preschoolers from Under-Resourced Backgrounds: A Comparison of Digital App vs.

Concrete Materials'. *Developmental Science* 25 (1): e13148. https://doi.org/10.1111/desc.13148.

Braun, Virginia, and Victoria Clarke. 2006. 'Using Thematic Analysis in Psychology'. *Qualitative Research in Psychology* 3 (2): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Braun and Clarke. 2012. 'Thematic Analysis.' In *APA Handbook of Research Methods in Psychology, Vol 2: Research Designs: Quantitative, Qualitative, Neuropsychological, and Biological.*, edited by Harris Cooper, Paul M. Camic, Debra L. Long, A. T. Panter, David Rindskopf, and Kenneth J. Sher, 57–71. Washington: American Psychological Association. https://doi.org/10.1037/13620-004.

Brunhaver, Samantha R., Russell F. Korte, Stephen R. Barley, and Sheri D. Sheppard. 2018. 'Bridging the Gaps between Engineering Education and Practice'. In *US Engineering in a Global Economy*, 129–63. University of Chicago Press. https://www.nber.org/books-and-chapters/us-engineering-global-economy/bridging-gaps-between-engineering-education-and-practice.

Buckley, Jeffrey, Niall Seery, and Donal Canty. 2019. 'Spatial Cognition in Engineering Education: Developing a Spatial Ability Framework to Support the Translation of Theory into Practice'. *European Journal of Engineering Education* 44 (1–2): 164–78. https://doi.org/10.1080/03043797.2017.1327944.

Cheryan, Sapna, Sianna A. Ziegler, Amanda K. Montoya, and Lily Jiang. 2017. 'Why Are Some STEM Fields More Gender Balanced Than Others?' *Psychological Bulletin* 143 (1): 1–35. https://doi.org/10.1037/bul0000052.

Close, Sean, and Gerry Shiel. 2009. 'Gender and PISA Mathematics: Irish Results in Context'. *European Educational Research Journal* 8 (1): 20–33. https://doi.org/10.2304/eerj.2009.8.1.20.

Daker, Richard J., Sylvia U. Gattas, H. Moriah Sokolowski, Adam E. Green, and Ian M. Lyons. 2021. 'First-Year Students' Math Anxiety Predicts STEM Avoidance and Underperformance throughout University, Independently of Math Ability'. *Npj Science of Learning* 6 (1): 1–13. https://doi.org/10.1038/s41539-021-00095-7.

Dare, Emily Anna, Khomson Keratithamkul, Benny Mart Hiwatig, and Feng Li. 2021. 'Beyond Content: The Role of STEM Disciplines, Real-World Problems, 21st Century Skills, and STEM Careers within Science Teachers' Conceptions of Integrated STEM Education'. *Education Sciences* 11 (11): 737. https://doi.org/10.3390/educsci11110737.

Delage, Veronic, Genevieve Trudel, Fraulein Retanal, and Erin A. Maloney. 2022. 'Spatial Anxiety and Spatial Ability: Mediators of Gender Differences in Math Anxiety'. *Journal of Experimental Psychology-General* 151 (4): 921–33. https://doi.org/10.1037/xge0000884.

Eliot, Matt, and Jennifer Turns. 2011. 'Constructing Professional Portfolios: Sense-Making and Professional Identity Development for Engineering Undergraduates'. *Journal of Engineering Education* 100 (4): 630–54. https://doi.org/10.1002/j.2168-9830.2011.tb00030.x.

Gagnier, Kristin M., Kinnari Atit, Carol J. Ormand, and Thomas F. Shipley. 2017. ‘Comprehending 3D Diagrams: Sketching to Support Spatial Reasoning’. *Topics in Cognitive Science* 9 (4): 883–901. https://doi.org/10.1111/tops.12233.

Gagnier, Kristin Michod, Steven J. Holochwost, and Kelly R. Fisher. 2022. ‘Spatial Thinking in Science, Technology, Engineering, and Mathematics: Elementary Teachers’ Beliefs, Perceptions, and Self-Efficacy’. *Journal of Research in Science Teaching* 59 (1): 95–126. https://doi.org/10.1002/tea.21722.

García-Holgado, Alicia, Sonia Verdugo-Castro, Angeles Dominguez, Itzel Hernández-Armenta, Francisco J García-Peñalvo, Andrea Vázquez-Ingelmo, and M Cruz Sánchez-Gómez. 2021. ‘The Experience of Women Students in Engineering and Mathematics Careers: A Focus Group Study’. In *2021 IEEE Global Engineering Education Conference (EDUCON)*, 50–56. https://doi.org/10.1109/EDUCON46332.2021.9454079.

Hegarty, Mary. 2018. ‘Ability and Sex Differences in Spatial Thinking: What Does the Mental Rotation Test Really Measure?’ *Psychonomic Bulletin & Review* 25 (3): 1212–19. https://doi.org/10.3758/s13423-017-1347-z.

Ishikawa, Toru, and Nora S. Newcombe. 2021. ‘Why Spatial Is Special in Education, Learning, and Everyday Activities’. *Cognitive Research: Principles and Implications* 6 (1): 20. https://doi.org/10.1186/s41235-021-00274-5.

Lane, Diarmaid, and Sheryl Sorby. 2022. ‘Bridging the Gap: Blending Spatial Skills Instruction into a Technology Teacher Preparation Programme’. *International Journal of Technology and Design Education* 32 (4): 2195–2215. https://doi.org/10.1007/s10798-021-09691-5.

Le, Hong Chung, Van Hanh Nguyen, and Tien Long Nguyen. 2023. ‘Integrated STEM Approaches and Associated Outcomes of K-12 Student Learning: A Systematic Review’. *Education Sciences* 13 (3): 297. https://doi.org/10.3390/educsci13030297.

Lee, Yujin, Robert M. Capraro, and Ali Bicer. 2019. ‘Gender Difference on Spatial Visualization by College Students’ Major Types as STEM and Non-STEM: A Meta-Analysis’. *International Journal of Mathematical Education in Science and Technology* 50 (8): 1241–55. https://doi.org/10.1080/0020739X.2019.1640398.

Lobovikov-Katz, Anna. 2019. ‘Methodology for Spatial-Visual Literacy (MSVL) in Heritage Education: Application to Teacher Training and Interdisciplinary Perspectives’. *REVISTA ELECTRONICA INTERUNIVERSITARIA DE FORMACION DEL PROFESORADO* 22 (1): 41–55. https://doi.org/10.6018/reifop.22.1.358671.

Maker, C. June, Randy Pease, and A. Kadir Bahar. 2023. ‘Profiles of Exceptionally Talented Students in Science, Technology, Engineering, and Mathematics (STEM): An Exploration Using Q Factor Analysis’. *ROEPER REVIEW-A JOURNAL ON GIFTED EDUCATION*, December. https://doi.org/10.1080/02783193.2023.2285045.

McNea, Meryn, Reena Cole, David Tanner, and Diarmaid Lane. 2023. ‘Problematising and Framing Spatial Research in Engineering Education’. Presented at the SEFI 2023 Engineering Education for Sustainability.

Miola, Laura, Chiara Meneghetti, Veronica Muffato, and Francesca Pazzaglia. 2023. ‘Orientation Behavior in Men and Women: The Relationship between Gender

Stereotype, Growth Mindset, and Spatial Self-Efficacy'. *Journal of Environmental Psychology* 86 (March):101952. https://doi.org/10.1016/j.jenvp.2022.101952.

Morelock, John R. 2017. 'A Systematic Literature Review of Engineering Identity: Definitions, Factors, and Interventions Affecting Development, and Means of Measurement'. *European Journal of Engineering Education* 42 (6): 1240–62. https://doi.org/10.1080/03043797.2017.1287664.

Newcombe, Nora, and Thomas Shipley. 2015. 'Thinking About Spatial Thinking: New Typology, New Assessments', November. https://doi.org/10.1007/978-94-017-9297-4_10.

Nipyrakis, Argyris, Chara Bitsaki, and Lucy Avraamidou. 2023. *STEM Digitalis Project: Recommendations for Policymakers*. https://doi.org/10.13140/RG.2.2.11022.37442.

O'Leary, Erin Sanders, Casey Shapiro, Shannon Toma, Hannah Whang Sayson, Marc Levis-Fitzgerald, Tracy Johnson, and Victoria L. Sork. 2020. 'Creating Inclusive Classrooms by Engaging STEM Faculty in Culturally Responsive Teaching Workshops'. *International Journal of STEM Education* 7 (1): 32. https://doi.org/10.1186/s40594-020-00230-7.

Power, Colin Nelson, and Rupert Maclean. 2013. 'Lifelong Learning: Meaning, Challenges, and Opportunities'. In *Skills Development for Inclusive and Sustainable Growth in Developing Asia-Pacific*, edited by Rupert Maclean, Shanti Jagannathan, and Jouko Sarvi, 29–42. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-5937-4_2.

Ring, Elizabeth A., Emily A. Dare, Elizabeth A. Crotty, and Gillian H. Roehrig. 2017. 'The Evolution of Teacher Conceptions of STEM Education Throughout an Intensive Professional Development Experience'. *Journal of Science Teacher Education* 28 (5): 444–67. https://doi.org/10.1080/1046560X.2017.1356671.

Scott, Colin. 2020. 'Managing and Regulating Commitments to Equality, Diversity and Inclusion in Higher Education'. *Irish Educational Studies* 39 (2): 175–91. https://doi.org/10.1080/03323315.2020.1754879.

Shiel, Gerry, and Cathy Kelleher. 2017. *An Evaluation of the Impact of Project Maths on the Performance of Students in Junior Cycle Mathematics.*

Sorby, Sheryl A. 2009. 'Educational Research in Developing 3-D Spatial Skills for Engineering Students'. *International Journal of Science Education* 31 (3): 459–80. https://doi.org/10.1080/09500690802595839.

Sorby, Sheryl, Norma Veurink, and Scott Streiner. 2018. 'Does Spatial Skills Instruction Improve STEM Outcomes? The Answer Is "Yes"'. *Learning and Individual Differences* 67 (October):209–22. https://doi.org/10.1016/j.lindif.2018.09.001.

Stoet, Gijsbert, and David C. Geary. 2018. 'The Gender-Equality Paradox in Science, Technology, Engineering, and Mathematics Education'. 2018. https://journals.sagepub.com/doi/full/10.1177/0956797617741719?journalCode=pssa.

Trevelyan, James. 2019. 'Transitioning to Engineering Practice'. *European Journal of Engineering Education* 44 (6): 821–37. https://doi.org/10.1080/03043797.2019.1681631.

Tyler-Wood, Tandra, Karen Johnson, and Deborah Cockerham. 2018. ‘Factors Influencing Student STEM Career Choices: Gender Differences’. *Journal of Research in STEM Education* 4 (2): 179–92. https://doi.org/10.51355/jstem.2018.44.

Van den Beemt, Antoine, Miles MacLeod, Jan Van der Veen, Anne Van de Ven, Sophie van Baalen, Renate Klaassen, and Mieke Boon. 2020. ‘Interdisciplinary Engineering Education: A Review of Vision, Teaching, and Support’. *Journal of Engineering Education* 109 (3): 508–55. https://doi.org/10.1002/jee.20347.

Verdugo-Castro, Sonia, Alicia García-Holgado, and Mª Cruz Sánchez-Gómez. 2022. ‘The Gender Gap in Higher STEM Studies: A Systematic Literature Review’. *Heliyon* 8 (8): e10300. https://doi.org/10.1016/j.heliyon.2022.e10300.

"What I Meant to Say Was...": Unravelling the Knots of Competent Communication in Engineering Research Teams

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ABSTRACT

The escalating complexity of global challenges demands a collaborative approach in scientific research that leverages diverse expertise, cultural backgrounds, and disciplines. This paper investigates communication barriers within multicultural engineering education research teams, emphasizing competent communication in fostering effective collaboration and innovation. Using Thompson's Collective

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Communication Competence (CCC) Model, this study explores engineering students' experiences in a multicultural engineering education research project, aiming to identify specific challenges that hinder competent communication and propose actionable strategies for improvement. Through qualitative interviews and content analysis, the research highlights challenges in comprehensibility, team bonding, and navigating diverse disciplinary languages and cultural norms. The findings advocate for proactive measures such as early training in common language establishment, trust-building activities, and engaged reflexivity to enhance communication dynamics within multicultural research teams.

1 INTRODUCTION

Today's world faces significant environmental and societal challenges, including climate change, population growth, disasters, and equity disparities. To tackle these challenges effectively, groundbreaking scientific and technological research among individuals with varied expertise and cultural backgrounds is essential (Aldert 2019; Leevers, H 2020). Diversity of knowledge, skills, and cultural backgrounds is crucial, as it brings fresh insights and perspectives and enhances problem-solving capabilities needed to address complex challenges (Aldert 2019; Chubin, May, and Babco 2005; Euro-CASE 2020). Cultural diversity, sometimes referred to as multiculturalism, is "a system of beliefs and behaviors that recognizes and respects the presence of all diverse groups in an organization or society, acknowledges and values their socio-cultural differences, and encourages and enables their continued contribution within an inclusive cultural context which empowers all within the organization or society" (Rosado 2006). Thus, effective communication is vital in culturally diverse engineering research environments to ensure successful collaboration and knowledge exchange (Varhelahti and Turnquist 2021). This paper aims to identify factors hindering competent communication among engineering students in multicultural research project settings and proposes strategies to promote improved communication. By promoting competent communication and recognizing individual differences, engineering environments can thrive and effectively tackle complex societal and environmental challenges.

1.1 Background and Theoretical Framing

Engineering education must develop technically and professionally competent graduates to meet the ever-changing demands of engineering practice. This necessitates curriculum reform incorporating early exposure through hands-on, practical activities that reflect real engineering practices (Crawley et al. 2014). Engineering research projects provide an excellent avenue for such exposure, equipping students with essential competencies and leading to notable outcomes such as career readiness, disciplinary knowledge, and an understanding of how engineering practice functions (Seymour et al. 2004).

Supported by funding bodies like NSF and Horizon 2020 Europe (Castelpietra et al. 2020; NSF 2008), these engineering research projects involve culturally diverse teams with varied skills and expertise crucial for enhancing creativity and advancing science (Leung et al. 2008). However, this multiculturalism introduces complex communication challenges crucial to a team's success and cohesion (Varhelahti and Turnquist 2021). Cultural differences, language barriers, varying communication styles and tools, and differences in professional roles or power dynamics can lead to miscommunication and misunderstandings (Liu et al. 2021; Varhelahti and Turnquist 2021). Such challenges threaten the efficiency and effectiveness of research collaborations and risk undermining trust among team members, potentially affecting the quality of work (Walther and Sochacka 2014) and resulting in decreased performance and project failure (Marlow, Lacerenza, and Salas 2017).

Addressing these communication challenges requires a nuanced understanding of the factors influencing information exchange and comprehension within multicultural research teams. Given cultural diversity's essential role in shaping how individuals communicate and understand shared information, developing competent communication skills is crucial (Ravesteijn, Graaff, and Kroesen 2006). These skills are essential for research members to learn and carry forward into their future careers in both academic and industrial settings (Lappalainen 2009). By fostering an environment that promotes effective communication practices, multicultural engineering research teams can leverage their diversity to overcome communication challenges and enhance collaboration (Mohanty 2018).

Competent communication within a multicultural engineering research group can be defined as interactions that effectively achieve objectives in a manner suitable to the context in which they occur (Spitzberg 1988). Employing frameworks such as Thompson's Collective Communication Competence (CCC) Model to guide competent communication practices can be beneficial. Thompson’s CCC model, built originally on an ethnographic study of an interdisciplinary academic research team, stems from the understanding that interactions among group members are intertwined, necessitating appropriateness and effectiveness (Thompson 2009). This model identifies processes fundamental to and that hinder CCC, such as task talk, reflexive communication, backstage communication, spending time together, building trust, demonstrating practice, discussing language differences, and shared laughter (Thompson 2009).

This study, utilizing Thompson's model within a multicultural engineering research setting, focuses on illuminating students' experiences with competent communication, especially during the formative stages of a project, as it can provide valuable insights for improving their engagement in multicultural engineering settings. Specifically, this research focuses on the formative stage of a multicultural engineering education research project called ‘Critical Conversation.’ This team is engaged in NSF-funded research aimed at empowering Black PhD students in engineering programs to act agentic in the face of systemic and racial biases. The team consists of three engineering education faculty mentors and five engineering students, all culturally diverse and possessing at least one underrepresented identity in engineering (e.g., Black and Latine’). This study aims to identify communication challenges that may hinder or limit interactions among team members by examining the communication dynamics within this engineering education research project. The goal is to help guide engineering education research teams seeking to effectively kickstart their projects from the outset.

Research Question: What specific communication challenges do engineering students encounter when collaborating in multicultural engineering education research teams, and how do these challenges impact the team's ability to communicate competently?

2 METHODOLOGY

2.1 Context and Participants

This study is part of a broader research project investigating the agency of Black graduate students in engineering at a highly research-intensive public institution in the United States. The research project team comprises three culturally diverse subgroups collaborating to achieve the project's objectives. Each subgroup is led by the principal investigator (PI) or one of two co-investigators – each from a different department. The PIs are two self-identified Black women and one Latine' woman. Additionally, five research students are working alongside the investigators to contribute to the successful completion of the project. This study focuses on the research students involved in the project, and the authors of this paper are members of the research project. Table 1 details the demographic information of the research students involved in the study.

Table 1: Demographic Information of Research Students

Research Student's Pseudonym	Self-identified Gender	Race/Ethnicity	Discipline	Academic Level
Hassan	Man	Asian/Pakistan	Engineering Education	Ph.D.
Kim	Woman	White/Columbian	Engineering Education	Ph.D.
Kiki	Woman	Asian/not identified	Computer Science	Master's
David	Man	Hispanic/not Identified	Electrical Engineering	Undergraduate
Bima*	Woman	Black/ Nigerian	Civil Engineering	Ph.D.

*Bima is the pseudonym of the first author conducting the research. Her demographic info is listed; however, this study does not include her interview data.

2.2 Data Collection

The data for this study was collected through qualitative interviews using a protocol designed based on the Team Effectiveness Questionnaire by the London Leadership Academy and the CIMER Mentorship Model (Law 2020; Pfund et al. 2021). Initially, semi-structured interviews were conducted to understand how an interdisciplinary, multicultural, and multidisciplinary team can effectively initiate collaboration from the project's start and identify what elements influenced this process. The preliminary findings highlighted communicating competently as a significant challenge for the research students. Consequently, follow-up semi-structured interviews were conducted to dive deeper into the engineering research students' challenge with communicating competently. The follow-up protocol was structured using the critical incident technique (Flanagan 1954; D. Simmons and Martin 2010) to identify and analyze specific communication challenges the students face, clarify meanings, and facilitate exploration of impactful incidents to improve practices and contribute to theoretical knowledge. The interviews were recorded, transcribed, and coded.

2.3 Data Analysis

The qualitative nature of the data led to using content analysis to examine the recorded and transcribed interview data (Weber 1990). This analysis involved two distinct coding processes: a deductive code employing Thompson's Collective Communication Competency Model as a conceptual framework and an inductive coding approach allowing for emergent codes from the interview data (Saldaña 2016). To generate the study findings, the first author familiarized herself with the dataset and then coded using the CCC framework. Following this, the first author ensured the validity of the findings by engaging in peer debriefing with the second author and members of her subgroup research lab. This debriefing involved scrutinizing the coding procedure and triangulating the data with other sources (i.e., memos, the first author's diary entry, and the first interview) (Creswell and Miller 2000). Once an interrater agreement was reached, the first and second authors collectively categorized the codes to answer the research questions (McHugh 2012). This approach ensured a thorough analysis of the qualitative data, allowing for interpretation within the social and cultural context and providing a deeper understanding of communication relevant to the research objectives.

3 RESULTS

3.1 Tables

Analyzing the data through the CCC model made it apparent that the research students encountered challenges in comprehensibility, team bonding, and skills gap insight while collaborating within the multicultural academic research team. These challenges resulted in deficits in the team's integrative task discourse, integrative team harmony, and engaged reflexivity. Table 2 is a structured presentation of the analytical process and findings.

Table 2: Content Analysis: Defined Categories, Codes, and Sample Quotes

Category (Impact on Team)	**Description**	**Communication Process Codes**	**Exemplar Quote**
Integrative Task Discourse	integrates task-focused conversations with the mindful negotiation of language differences, thereby facilitating a more cohesive and productive team dynamic	Task Talk Discussions of language differences	One project investigator sent us an e-mail requesting that research participants be contacted. However, it was not clearly mentioned which students should send the e-mail. (Kiki) I worked with [my advisor] on [research topic], and then there were two other areas [other research topics], which were very new to me. So, those are challenging for me to understand. (Hassan)

Integrative Team Harmony	holistically integrates spending meaningful time together, fostering trust (both swift and deep), and encouraging open, informal communication	Spending time together Practicing trust Backstage communication	The best way to collaborate is first by being friends. You can't have random strangers work together because they don't know how even to start the conversation and work together because they don't know each other well [...]then it's weird just communicating. (David) If I'm very near to someone, if I'm going to ask something from that person, there might be some points at which the other person or even myself will not answer those specific questions. So, you must remove those boundaries. You have to give the other person more clarity about your intentions. (Hassan) I feel like it's just a lot of behind-the-scenes things which sometimes can be hard for me to catch up with […] I sometimes feel like the communication can be a little spotty. (Kim)
Engaged Reflexivity	underscores the importance of both being wholly present in collaborative efforts and maintaining an ongoing, reflective dialogue that	Reflective talk	I'm an undergrad, and compared to (other teammates), they have a little more experience and knowledge of the project […] But for me, I just try to build the best effort I can and show them the best work I can provide. (David)

	encourages mutual trust, shared understanding, and collective growth within teams	Demonstrating presence	Qualitative analysis is something new for me right now, and at some point, I know that in the future, when we do the analysis portion, it will be a challenging part for me as well. (Hassan)

Integrative Task Discourse (ITD) relates to the dual focus required in interdisciplinary teams: concentrating on the project's tasks and objectives while acknowledging and addressing the linguistic and conceptual differences inherent in diverse academic fields. By promoting an approach that values clarity in task-related communication and sensitivity to disciplinary languages, teams can achieve a more effective and inclusive CCC, enabling them to navigate the complexities of interdisciplinary research more smoothly. Task talk is crucial to achieving ITD. However, students encountered challenges in understanding the roles delegated to them through written documents guiding the project, leading to disrupted project timelines, misaligned expectations with project investigators, feelings of being out of the loop, and unfamiliarity with the project's status. These challenges may have stemmed from the fact that the research team was in their first year or early stages of their careers, and the students were likely unfamiliar not only with the research process but also with the nuances of the products generated by the three different disciplinary strands of the project.

Moreover, addressing language differences and establishing a common language among teams in multicultural academic research settings can be highly beneficial. Students in the study struggled to comprehend the disciplinary jargon and acronyms common to the other sub-groups and the linguistic and pronunciation variances across the team, thus affecting their ability to comprehend the information they received.

Integrative Team Harmony (ITH) highlights the multifaceted approach to building a cohesive team, where each member feels valued and understood, trust is woven into the fabric of the team's interactions, and informal communication channels are recognized as vital for the team's emotional and social cohesion. This integrated approach ensures that teams are effective in accomplishing their tasks and enriched by the shared human experience, fostering a sense of unity and collective purpose. Communication processes such as spending time together are invaluable for fostering better ITH. However, students in the study faced challenges in effectively communicating with one another, stemming from infrequent team interactions and limited time to bond. Thus, their ability to interact, build trust, cultivate shared understanding, and foster clear communication, which promotes team harmony rather than a sense of estrangement, was stymied. Students also identified trust-building, which supports team harmony, as a barrier to team interactions. Practicing trust-building helps team members overcome perceived boundaries in relationships and fosters interpersonal bonding. Additionally, backstage communication, a form of informal verbal communication, also facilitates harmony. Students recognized the benefits of backstage communication, such as one-on-one meetings with advisors and informal discussions with team members, for understanding projects and overcoming challenges. However, the students also acknowledge that such communication, especially involving discussions about project changes with specific individuals outside general team conversations, led to miscommunication and confusion regarding tasks and project developments. Additionally, the fact that all teams were not only in different disciplines but also located in different buildings posed an additional challenge.

Engaged Reflexivity (ER) emphasizes the outward actions of being present and participative and the inward reflection that enables individuals to contribute more meaningfully and cohesively to their teams. It is about creating a culture where team members are encouraged to be fully there, both physically and mentally, while also being mindful of how their contributions, behaviors, and interactions influence the collective output and team spirit. ER suggests a dynamic interplay between being present and being thoughtful, ensuring that team collaboration is vibrant and considerate, and students can successfully engage reflexivity by integrating communication processes such as reflexive talk and demonstrating presence. According to Thompson's CCC model, reflexive talk is vital in students' ability to observe, reflect upon, and ultimately effect changes within a multicultural academic research setting. The self-awareness from students' reflective talk can significantly impact their ability to demonstrate their presence and effectively communicate within the group. Students showed they were team players by supporting each other and sharing presentation responsibilities. However, their awareness of personal differences, lack of experience, and doubts about their skills posed a challenge and created perceived barriers in their interactions, leading to uncertainty about how their contributions would be received during team meetings. Therefore, understanding diversity can foster confidence and trust in group settings.

4 SUMMARY AND ACKNOWLEDGEMENTS

4.1 Summary

Using Thompson's CCC model, this study aimed to identify specific communication challenges engineering students encountered when collaborating in multicultural engineering education research teams and how these challenges impact the team's ability to communicate competently. Consistent with Thompson's CCC study, this research highlights the necessity for trust-building time, explicit conversations around disciplinary research concepts and languages, and the inclusion of social activities to strengthen research team communicative interaction (Thompson 2009). A nuanced addition to Thompson's CCC study is the need for skill training and critical conversations around the research team ethos, as many of the students' challenges stemmed from their skill gaps and unfamiliarity with the team's research process, expectations, and culture.

Engineering employers prioritize technically and professionally skilled graduates, which calls for engineering education to incorporate training instrumental for students' skill development (Simmons, McCall, and Clegorne 2020). Communication skills are essential to engineering practices because nearly all engineering activities rely on communication. Therefore, there is a need to shift from viewing communication merely as information sharing to recognizing it as a means to establish and nurture relationships (Trevelyan 2009). Engineering education research teams are encouraged to utilize models such as CIMER and CDIO (Conceive, Design, Implement, Operate), focusing on knowledge-building and facilitating professional skill development through active and experiential learning (Crawley et al. 2014; Janet, Amanda, and Amber 2020). Direct student engagement in learning contributes to lifelong learning skills and a stronger sense of responsibility (Seymour et al. 2004).

The findings of this study also call for engineering educators engaged in multicultural and interdisciplinary research to collectively uncover the hidden curriculum behind the cultural norms and expectations around communication, project, and task-related activities within their research settings. This will ensure students' alignment and enhanced comprehension for task execution (Villanueva Alarcón 2022). Competent communication is a holistic process involving both educators and students (Rosado 2006). Therefore, engineering students are encouraged to proactively seek clarification to build familiarity with the research setting and team's ethos (Ravesteijn, Graaff, and Kroesen 2006). Engineering research teams should prioritize active listening, constructive critique, and continuous learning within the team for successful engagements and collaboration, free of internal resistance and fear (Ravesteijn, Graaff, and Kroesen 2006). Based on the findings of this study, the Principal Investigators of this research project have collectively established a more defined research ethos, detailing the research process, team communication methods, frequent in-team interactions, and skill development training to help all team members communicate competently and collaborate effectively to achieve the research goals.

4.2 Limitations and Future Directions

The research findings primarily reflect students' perspectives in a multicultural engineering education research project. Future research could broaden its scope by investigating the viewpoints of the principal investigators to gain insights into the factors that may promote competent communication and cultural and disciplinary differences within research environments. The findings of this study may not be broadly transferable. This research was conducted within a research-intensive public institution in the United States; hence, future research may replicate this study in a different region and/or institution type to uncover other challenges preventing students from communicating competently within a multicultural setting.

4.3 Acknowledgement

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REFERENCES

Aldert, Kamp. 2019. "Science and Technology Education for 21st Century Europe." *Discussion Paper S&T Education for 21st Century Europe*, December. https://doi.org/10.5281/ZENODO.3582544.

Castelpietra, G., A. Nicotra, L. Pischiutta, M. R. Gutierrez-Colosía, J. M. Haro, and L. Salvador-Carulla. 2020. "The New Horizon Europe Programme 2021–2028: Should the Gap between the Burden of Mental Disorders and the Funding of Mental Health Research Be Filled?” *The European Journal of Psychiatry* 34 (1): 44–46. https://doi.org/10.1016/j.ejpsy.2019.12.001.

Chubin, Daryl E., Gary S. May, and Eleanor L. Babco. 2005. “Diversifying the Engineering Workforce.” *Journal of Engineering Education* 94 (1): 73–86. https://doi.org/10.1002/j.2168-9830.2005.tb00830.x.

Crawley, Edward F., Johan Malmqvist, Sören Östlund, Doris R. Brodeur, and Kristina Edström. 2014. *Rethinking Engineering Education: The CDIO Approach*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-05561-9.

Creswell, John W., and Dana L. Miller. 2000. “Determining Validity in Qualitative Inquiry.” *Theory Into Practice* 39 (3): 124–30. https://doi.org/10.1207/s15430421tip3903_2.

Euro-CASE. 2020. *Euro-CASE ENGINEERING EDUCATION PLATFORM-Discourses on the Future of Engineering Education in Europe.* Grand Palais des Champs-Élysées | Porte C Avenue Franklin D. Roosevelt 75008 Paris, France: The European Council of Academies of Applied Sciences, Technologies and Engineering (Euro-CASE). https://www.euro-case.org/wpcontent/uploads/Eurocase/Publications/PDF/EuroCASE_Engineering_Education_Platform-2021.04.pdf.

Flanagan, John C. 1954. “The Critical Incident Technique.” *Psychological Bulletin* VOL. 51, (No. 4).

Janet, L. Branchaw, R. Butz Amanda, and Smith Amber. 2020. “Entering Research 2nd Edition | Janet L. Branchaw | Macmillan Learning.” 2020. https://store.macmillanlearning.com/us/product/Entering-Research/p/1319263682.

Lappalainen, Pia. 2009. “Communication as Part of the Engineering Skills Set.” *European Journal of Engineering Education* 34 (2): 123–29. https://doi.org/10.1080/03043790902752038.

Law, Jaime M. 2020. “A Comparison of Team Effectiveness and Perception of Team Success in Academic and Athletic Teams.” Oregon State University. 2020.

Leevers, H. 2020. “Comment: Driving Diversity in Engineering Has Never Been More Important.” The Engineer. June 19, 2020. https://www.theengineer.co.uk/content/opinion/comment-driving-diversity-in-engineering-has-never-been-more-important/.

Leung, Angela Ka-yee, Wiliam Maddux, Adam Galinsky, and Chi Yue Chiu. 2008. “Multicultural Experience Enhances Creativity: The When and How.” *The American Psychologist* 63 (April):169–81. https://doi.org/10.1037/0003-066X.63.3.169.

Liu, Pingyang, Audrey Lyndon, Jane L. Holl, Julie Johnson, Karl Y. Bilimoria, and Anne M. Stey. 2021. “Barriers and Facilitators to Interdisciplinary Communication during Consultations: A Qualitative Study.” *BMJ Open* 11 (9): e046111. https://doi.org/10.1136/bmjopen-2020-046111.

Marlow, Shannon L., Christina N. Lacerenza, and Eduardo Salas. 2017. “Communication in Virtual Teams: A Conceptual Framework and Research Agenda.” *Human Resource Management Review*, Virtual Teams in Organizations, 27 (4): 575–89. https://doi.org/10.1016/j.hrmr.2016.12.005.

McHugh, Marry L. 2012. “Interrater Reliability: The Kappa Statistic.” *Biochemia Medica*, 276–82. https://doi.org/10.11613/BM.2012.031.

Mohanty, Ashish. 2018. “THE IMPACT OF COMMUNICATION AND GROUP DYNAMICS ON TEAMWORK EFFECTIVENESS: THE CASE OF SERVICE SECTOR ORGANISATIONS” 17 (4).

NSF. 2008. “Interdisciplinary Research.” *Report to Congress on Interdisciplinary Research at the National Science Foundation*, NSB-08-80, , August, 1–9.

Pfund, Christine, Janet L. Branchaw, Melissa McDaniels, Angela Byars-Winston, Steven P. Lee, and Bruce Birren. 2021. “Reassess–Realign–Reimagine: A Guide for Mentors Pivoting to Remote Research Mentoring.” Edited by Derek Braun. *CBE—Life Sciences Education* 20 (1): es2. https://doi.org/10.1187/cbe.20-07-0147.

Ravesteijn, Wim, Erik De Graaff, and Otto Kroesen. 2006. “Engineering the Future: The Social Necessity of Communicative Engineers.” *European Journal of Engineering Education* 31 (1): 63–71. https://doi.org/10.1080/03043790500429005.

Rosado, Caleb. 2006. “What Do We Mean By ‘Managing Diversity’?” *N Sumati Reddy, Editor. Workforce Diversity, Vol. 3: Concepts and Cases. Hyderabad, India: ICAFAI University*, January.

Saldaña, Johnny. 2016. *The Coding Manual for Qualitative Researchers*. 3E [Third edition]. Los Angeles ; London: SAGE.

Seymour, Elaine, Anne-Barrie Hunter, Sandra L. Laursen, and Tracee DeAntoni. 2004. “Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study.” *Science Education* 88 (4): 493–534. https://doi.org/10.1002/sce.10131.

Simmons, Denise, and Julie Martin. 2010. “Use Of The Critical Incident Technique For Qualitative Research In Engineering Education: An Example From A Grounded Theory Study.” In . https://doi.org/10.18260/1-2--15712.

Simmons, Denise R., Cassandra McCall, and Nicholas A. Clegorne. 2020. “Leadership Competencies for Construction Professionals as Identified by Construction Industry Executives.” *Journal of Construction Engineering and Management* 146 (9): 04020109. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001903.

Spitzberg, Brian H. 1988. “Communication Competence: Measures of Perceived Effectiveness.” In *A Handbook for the Study of Human Communication: Methods and Instruments for Observing, Measuring, and Assessing Communication Processes*, 67–105. Communication and Information Science. Westport, CT, US: Ablex Publishing.

Thompson, Jessica Leigh. 2009. “Building Collective Communication Competence in Interdisciplinary Research Teams.” *Journal of Applied Communication Research* 37 (3): 278–97. https://doi.org/10.1080/00909880903025911.

Trevelyan, James. 2009. “Engineering Education Requires a Better Model of Engineering Practice.” *2009 Research in Engineering Education Symposium, REES 2009*, January.

Varhelahti, Mervi, and Tiia Turnquist. 2021. “Diversity and Communication in Virtual Project Teams.” *IEEE Transactions on Professional Communication* 64 (2): 201–14. https://doi.org/10.1109/TPC.2021.3064404.

Villanueva Alarcon, Idalis. 2022. “Ethical Practices and Tips for Improving Engineering Faculty-Student Research Relationships.” In *2022 IEEE Frontiers in Education Conference (FIE)*, 1–8. Uppsala, Sweden: IEEE. https://doi.org/10.1109/FIE56618.2022.9962431.

Walther, Joachim, and Nicola Sochacka. 2014. “Qualifying Qualitative Research Quality (The Q^3 Project): An Interactive Discourse around Research Quality in Interpretive Approaches to Engineering Education Research.” In *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, 1–4. Madrid, Spain: IEEE. https://doi.org/10.1109/FIE.2014.7043988.

Weber, Robert Philip. 1990. “BASIC CONTENT ANALYSIS.” *Newbury Park, CA: Sage Publications.*, Quantitative Applications in the Social Sciences,

A STUDY INTO ENGINEERING STUDENTS' SENSE OF BELONGING AT UNIVERSITY

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ABSTRACT

Recently there has been a diversification of student profiles across the UK at all taught levels. The student fee freeze for home students, increasing fees for overseas students and other financial considerations have led to many universities announcing that they are considering increasing their student intake, which will undoubtedly impact modes of delivery and our student body representation, which implicates the need for a new approach to instilling a sense of belonging and a review of university provisions and support mechanisms (all of which have been shown to impact student performance). UCL Engineering has seen a sharp increase in student numbers (>40% in 3 years), with a large portion comprising of international students. The sector is often cited as one that actively promotes social mobility, however the Engineering UK briefing *Social Mobility in Engineering* (2018) argues that there is further work required due to performance outcomes of different student cohorts. This study investigates the contributing factors towards creating a good holistic student experience for both home and international students with the aim of developing and adapting current university provisions. A combination of surveys, focus groups and interviews were used to capture the student voice. The main outcomes of the survey will be presented in this paper. Overall, the results indicate that the extent of university integration is impacted by factors related to living arrangements, student societies and perceptions of the university's efforts to address EDI-related issues.

1 INTRODUCTION

The landscape of higher education in the UK has increasingly diversified in recent years. According to the latest government report *International students in UK higher education* (Bolton et al., 2023), a record high of 24% (679,970) of the total student population in British universities has an overseas background in 2021/2022 with about 18% from the EU and the remaining from elsewhere. China, India, and Nigeria are the top three countries in terms of the number of students studying in British universities. China accounts for the largest proportion, with 151,690 students, followed by India with 126,535 students. The number of Nigerian students has more than doubled, increasing from 14,270 in the 2020-2021 academic year to 32,945 in 2021-2022. The new report also highlights that the proportion of EU students has decreased by 21.4%, while the number of non-EU students has grown by 23.8% (Bolton et al., 2023; Universities UK, 2024).

With a mix of home and international students navigating their academic journeys in the UK, understanding the unique challenges faced by each cohort is vital for institutions aiming to provide inclusive and supportive environments. This section aims to explore challenges experienced by students from home and international backgrounds. It will cover perspectives on student experience, well-being, and cultural challenges, including visa application difficulties, as well as language differences that are particularly related to international students.

A large and growing body of literature has investigated the obstacles encountered by international students and what factors might affect their sense of belongings. Hoffman et al.'s (2002) mixed methods study concluded that five factors affect students' sense of belonging: peer support, faculty support, classroom comfort, isolation, and empathetic faculty. More recently, Cena et al. (2021) examined the experiences of 16 international students at Queen's University Belfast (QUB) in

Northern Ireland, focusing on their sense of belonging and the challenges they face both academically and socially. Through semi-structured interviews, researchers identified four domains impacting their feelings of belonging: educational differences, on-campus social interactions, influences from the home society, and the wider off-campus environment.

Ramachandran (2011) has identified eight common challenges, which are financial issues, academic issues, English proficiency, social and cultural issues, university administrative procedures, issues of transnational student, bilateral state relationship and its effect and information and support systems. Along the same lines, Khodabandelou et al. (2015) interviewed 21 Iranian postgraduate students in Malaysian universities, identifying four challenges: financial matters, visa, culture and insurance. It should be noted that some of the challenges might also apply for home students, such as financial issues, academic issues (Office for Student, 2022). However, these challenges can affect international student sense of belonging even more profoundly. For instance, social and cultural issues and the anxiety of being far from their home country can be significant (Taylor and Ali, 2017). Additionally, lack of participation and engagement due to English proficiency have also been identified (Cammish, 2002; Carroll, 2007; Trenkic and Warmington, 2019). Even when students are able to adapt to the new environment quickly and have met language requirements, they might have difficulties in understanding different variants of English (Pho, 2019).

There is a large volume of published studies describing the significant role of support mechanism with regards to increase student wellbeing and experiences in universities. Stress is not uncommon among university students, particularly since the outbreak of COVID, there has been an increase concern for student wellbeing considering factors related financial pressure, worry for academic performance, university experience, social isolation, and career prospects (Son *et al.*, 2020; Appleby *et al.*, 2022). Engineering students, in particular, face additional challenges due to their demanding curriculum, heavy workload and low retention rates (Chadha *et al.*, 2021; Jensen and Cross, 2021). Yet the literature specific to the experience and support mechanism of engineering programme students is relatively limited.

Chadha *et* al., (2021) has conducted a mixed methods research study exploring student experiences of support mechanisms to enhance wellbeing on an engineering programme in the UK. A variety of supporting scheme has emerged and put into practice in British universities setting to enhance engineering student wellbeing, such as peer mentoring, wellbeing officers, tutorial support system (personal tutor). However, with many types of assistance available, it is difficult to assess their impact. Concerns from students include a lack of clear links and coherent organization in these initiatives. Additionally, although peer to peer support has gained popularity among British universities in recent years and it has been suggested to have positive impact on student integration (Collings, Swanson and Watkins, 2014), a clear scope of responsibilities of the role is essential to make sure the system runs smoothly. Moreover, tutorial support system has received positive feedback, but the lack of training and specificity of the personal tutoring role, staff hiring freezes and increases in student numbers is leading to less regular contact with students and eventual student detachment. As several students state: “I would not go to my personal tutor for anything”, and “I feel detached from it and that I can’t really make any change” (Chadha *et* al., 2021, p. 642).

Many British universities and organizations have taken actions to help students. According to the Department for Education (2023), Office for Student (OfS) has distribution 276 million of government funding to help students. The University of York which announced that £150 would be given to student households who are finding it difficult to pay their bills as part of a £6 million package to support students most in need (Department for Education, 2023; University of York, 2022). The University of Southampton which has made a total of £1.1 million in the current academic year available to students to cover emergency costs (Department for Education, 2023). Turning the focus back to the capital city, Queen Mary University of London which has a bursary scheme automatically provided to any domestic undergraduate from a family whose annual taxable income is below £20,000 (Department for Education, 2023; Russel Group, 2022). Similarly, UCL has announced the following financial support to students since September 2022. There is a permanent £500 increase to the UCL Undergraduate Bursary, supporting students with an annual household income of £42,875 or less (UCL, 2022). Additional funding for students in financial need can be accessed from the Financial Assistance Fund and the Sarah Douglas Hardship Fund, enabling us to support more students dealing with unexpected financial pressure. However, it should be noted that a number of these funding opportunities are only open to home students.

2 METHODOLOGY

The results discussed in this paper focus on the data gathered from the survey, although data was also collected from focus groups and interviews which will be analysed in the future. The survey was disseminated to the entire faculty (undergraduate and postgraduate taught >1500) and was completed by 87 students (~5% of the cohort). The survey mainly uses a combination of Likert scale and free text questions, with a mix of obligatory and non-obligatory responses. The survey comprised of 36 total questions split into 6 sections: Section 1: Demographics, Section 2: Sense of Belonging, Section 3: Course Experience, Section 4: Student Values, Section 5: EDI at University, Section 6: Open-Ended Questions. This research has been approved by the UCL Research Ethics Committee.

3 RESULTS

For the purposes of this paper, we have provided a brief overview of all of the sections of the survey but honed in specifically on the overall sense of belonging, the evolution of their mental health during their time in the engineering department, their perspectives on EDI issues and involvement in extracurricular activities as these categories provided a diverse set of responses across different personal characteristics.

3.1. Sense of belonging

A summary of section 1 shows that there were an equal number of home and international (overseas) student participation (44% each) and 12% International EU with a near enough equal split of male: female respondents. 30% of respondents were noted as having a disability. Approx. 60% of respondents were of Asian background, 30% Caucasian, 10% Black, mixed, Arab or other.

Section 2 of the online survey focused on the feelings of belonging, comfort and connectedness that students developed during their time at university. Figure 1 shows the distribution of all answers received, on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) for various Likert scale questions.

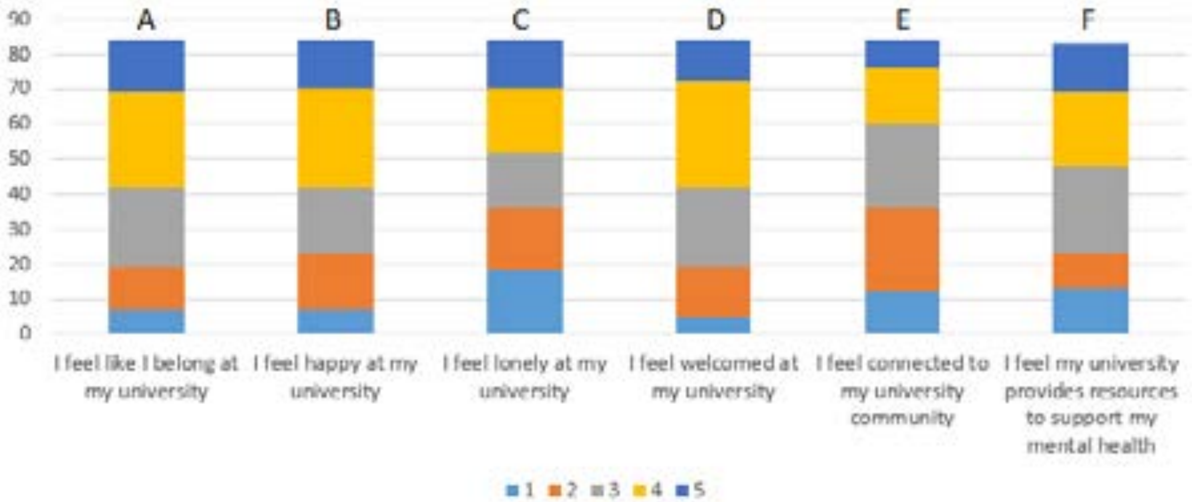

Figure 1: Students perception of their sense of belonging, happiness, loneliness, welcome, connectedness and resource availability at university

The overall averages of the answers for the 6 categories (A-F) of questions shown in Figure 1 were 3.37, 3.31, 2.9, 3.36, 2.81 and 3.16 respectively. It is interesting to note that whilst students appear to have developed a feeling of belonging and feel welcome at the university, they also feel lonely and sometimes disconnected from it (categories that scored the lowest averages). We further disaggregated these results to observe whether there were any deviations from the averages occur when looking at various categories of students. We only report on those where the sample was larger than 5 students and where a deviation was noticed.

Table 1 shows the average answers given by students, based on their fee status, where Home refers to home fee payers, Intl-EU represents international students from the European Union and Intl-OS represents overseas students or international students from outside of the European Union. The number of students in each category is shown in the first column. The bottom line shows the overall average for comparison.

Table 1: Averages of answers to questions in Figure 1, based on fee status.

Fee status	A	B	C	D	E	F
Home (35)	3.26	3.2	2.77	3.14	2.74	2.94
Intl-EU (12)	3.83	3.67	3.17	3.83	3.08	3.58
Intl-OS (37)	3.32	3.3	2.95	3.41	2.78	3.14
Overall (84)	3.37	3.31	2.9	3.36	2.81	3.16

Table 2 shows the average answers given by students, based on their accommodation type. The number of students in each category is shown in the first column. The bottom line shows the overall average for comparison. As can be seen, students living with their families are generally less connected to the university and feel the loneliest, whilst students in private shared flats have the scored the strongest.

Table 2: Averages of answers to questions in Figure 1, based on living arrangements.

Accommodation setup	A	B	C	D	E	F
With family (17)	2.88	2.88	3.12	2.88	2.41	2.82
Student accommodation (25)	3.44	3.32	2.76	3.64	2.88	3.12
Private shared flat (28)	3.79	3.68	2.89	3.36	3.04	3.14
Private single flat (14)	3	3.07	2.93	3.43	2.71	3.43
Overall (84)	3.37	3.31	2.9	3.36	2.81	3.16

When focusing on ethnicity, lower scores were given by Arab students, indicating that they feel less integrated at university. No significant deviations from the overall averages were observed for other ethnicities or based on gender identity, sexual orientation, age, or level of study.

3.2. Mental health evolution

Another important factor in assessing the student experience, is the evolution of their mental health while at university. Overall, 34% respondents state that their mental health has improved during their studies, 44% that it has worsened and 32% that there has been no change (last column in the chart of Figure 2) and for various categories of students, where a deviation from the overall numbers is present. As can be seen in Figure 2, students with disabilities and those living with their families show a decline in mental health while at university.

The survey also directly addressed students' perspectives of whether their experience at UCL had improved, worsened or made no impact on their mental health. The figure below reflects the responses to this question, showing that the most popular answer was that student's felt that their mental health had worsened since coming to UCL. A significant proportion also reported that there had been no change in their mental health – which suggests that the relationship between mental health and a students' experience at the university was more complex than could be captured in a survey.

3.3. Extra-curricular activities

This section of the survey explored students' experiences with extra-curricular activities such as joining clubs, groups or organisations. The survey highlighted that over two thirds of the respondents engaged in extracurricular activities. The most popular reason that respondents did not join societies was due to lack of personal time or extracurricular activities occurring at unfeasible times for students. Other significant reasons for not joining clubs or societies included commuting students finding it difficult to justify the journey and transport costs, social anxiety & insecurities and no personal interest.

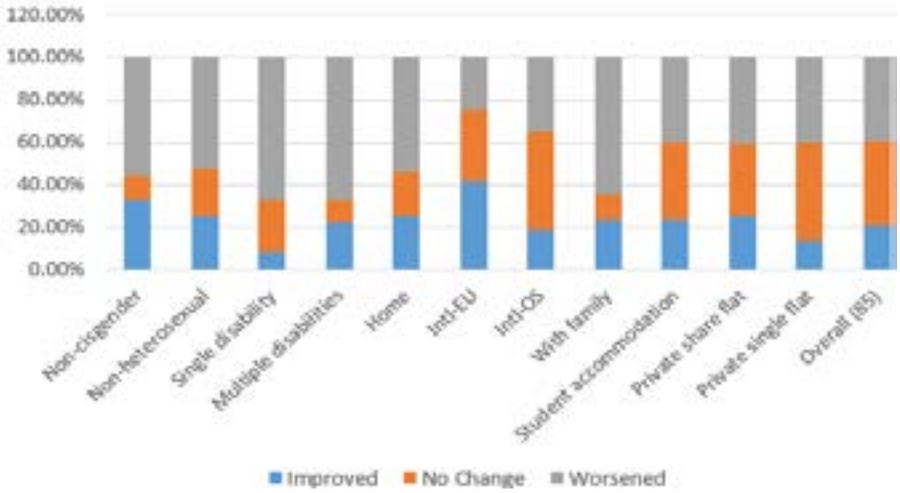

Figure 2: Evolution of mental health of different groups whilst at university

In section 6 one student stated:

*"I do not live on campus so **I do not feel it is worth commuting for an hour for club activities**. Most social activities are centred around alcohol, and **I work while studying so I do not have enough free time**"*

Others reflected that:

*"**work load is difficult to manage** alongside personal life"*

and

*"As a girl who lives far from school, **I felt very insecure**, so it was impossible for me to participate"*

3.4. Students' perceptions on how EDI is addressed

Section 5, Question 28, of the online survey focused on students' perceptions of the extent to which their institutions were prepared to listen to, and to address, issues pertaining to diversity, equity and inclusion. Table 3 shows the distribution of all answers (84 respondents) received, on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree).

Approximately 70% of the respondents (Likert scales 1,2, and 3) were either uncertain that they would know how to raise with their university an issue to do with diversity, equity and inclusion (68.96%), did not feel confident that an issue to do with diversity, equity and inclusion would be listened to by their university (68.66%) or did not feel confident that an issue to do with diversity, equity and inclusion would be addressed appropriately by their university (69.33%).

Table 3: Average scores for student perception on how EDI concerns are addressed

Likert Scale Question:	1	2	3	4	5
I would know how to raise an issue to do with diversity, equity and inclusion if I see any. (n=87)	11.49%	26.44%	31.03%	16.09%	14.94%

I feel confident that an issue to do with diversity, equity and inclusion would be listened to. (n=67)	14.93%	16.42%	37.31%	2.99%	28.36%
I feel confident that an issue to do with diversity, equity and inclusion would be addressed appropriately by my university. (n=75)	13.33%	18.67%	37.33%	8.00%	22.67%

4 SUMMARY AND ACKNOWLEDGEMENTS

Overall, the results show that there are a number of differences in challenges faced by international vs home students, and these can be further exacerbated by delving deeper into other characteristics related to gender, disability and ethnicity. The main outcomes show that the sense of belonging is felt the least by certain populations in the international student body, but also by home students (particularly those who live at home), reasons for which are explored in the next phase of the study.

The results also show that student experience may differ based on living arrangements. Home students are likely to live with family which may impact on their integration with university life given the central location of UCL. This is contrary to international students who will most likely live with fellow students closer to campus. The results also explored the impact on mental health, engagement with student societies and student perceptions on how inclusion concerns are handled by UCL, all further explored in the next phase. The next phase of this study delves further into the main outcomes of the survey through focus groups and interviews with cohorts of home students and international students to compare and contrast experiences and their perspectives on what support looks like for them. Questions we intend to ask during focus groups and interviews include how comfortable students feel within their department and on their course. Specifically, we want to know if they feel like they belong, and if so, why. Furthermore, we will explore what impacts their sense of belonging. Additionally, we will evaluate the current measures to improve students' sense of belonging and discuss how we can further enhance it.

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REFERENCES

Appleby, J. A. *et al.* (2022) 'Impact of the COVID-19 pandemic on the experience and mental health of university students studying in Canada and the UK: A cross-sectional study', *BMJ Open*, 12(1), pp. 1–13. doi: 10.1136/bmjopen-2021-050187.

Arday, J. (2018) 'Understanding mental health: What are the issues for black and ethnic minority students at University?', *Social Sciences*, 7(10). doi: 10.3390/socsci7100196.

Cena, E., Burns, S., Wilson, P., 2021. Sense of Belonging and the Intercultural and Academic Experiences Among International Students at a University in Northern

Ireland. Journal of International Students 11, 812–831. https://doi.org/10.32674/jis.v11i3.2541

Chadha, D. *et al.* (2021) 'Are the kids alright? Exploring students' experiences of support mechanisms to enhance wellbeing on an engineering programme in the UK', *European Journal of Engineering Education*, 46(5), pp. 662–677. doi: 10.1080/03043797.2020.1835828.

Collings, R., Swanson, V. and Watkins, R. (2014) 'The impact of peer mentoring on levels of student wellbeing, integration and retention: a controlled comparative evaluation of residential students in UK higher education', *Higher Education*, 68(6), pp. 927–942. doi: 10.1007/s10734-014-9752-y.

Department for Education (2023). Cost of living boost for students. [online] GOV.UK. Available at: https://www.gov.uk/government/news/cost-of-living-boost-for-students.

Hoffman, M., Richmond, J., Morrow, J., Salomone, K., 2002. Investigating "Sense of Belonging" in First-Year College Students. J Coll Stud Ret 4, 227–256. https://doi.org/10.2190/DRYC-CXQ9-JQ8V-HT4V

Jensen, K. J. and Cross, K. J. (2021) 'Engineering stress culture: Relationships among mental health, engineering identity, and sense of inclusion', *Journal of Engineering Education*, 110(2), pp. 371–392. doi: 10.1002/jee.20391.

Kelly, A. F. and Mulrooney, H. M. (2019) 'Student perceptions of belonging at university: a qualitative perspective.', *New Directions in the Teaching of Physical Sciences*, 14(14), pp. 1–11. doi: 10.29311/ndtps.v0i14.3238.

Odgen, K. and Waltmann, B. (2022) *Cost-of-living crisis to hit students harder than expected*, *IFS*. Available at: https://ifs.org.uk/news/cost-living-crisis-hit-students-harder-expected.

Office for Student (2022) *Universities take steps to address cost of living as poll highlights impact on students*, *Office for Student*. Available at: https://www.officeforstudents.org.uk/news-blog-and-events/press-and-media/universities-take-steps-to-address-cost-of-living-as-poll-highlights-impact-on-students/.

Rubin, M. and Wright, C. L. (2015) 'Age differences explain social class differences in students' friendship at university: implications for transition and retention', *Higher Education*, 70(3), pp. 427–439. doi: 10.1007/s10734-014-9844-8.

Russel Group (2022). Russell Group universities step up support for students in response to cost-of-living crisis. [online] The Russell Group. Available at: https://russellgroup.ac.uk/news/russell-group-universities-step-up-support-for-students-in-response-to-cost-of-living-crisis/.

Son, C. *et al.* (2020) 'Effects of COVID-19 on college students' mental health in the United States: Interview survey study', *Journal of Medical Internet Research*, 22(9), pp. 1–14. doi: 10.2196/21279.

Stoll, N. *et al.* (2022) 'Mental health and mental well-being of Black students at UK universities: a review and thematic synthesis', *BMJ open*, 12(2), p. e050720. doi: 10.1136/bmjopen-2021-050720.

UCL (2022). Support for students affected by the rising cost of living. [online] UCL News. Available at: https://www.ucl.ac.uk/news/2022/sep/support-students-affected-rising-cost-living

Universities UK (2024). International student recruitment data. [online] Universities UK. Available at: https://www.universitiesuk.ac.uk/international-student-recruitment-data.

University of York (2022). University announces energy grants to help York students. [online] University of York. Available at: https://www.york.ac.uk/news-and-events/news/2022/campus/fuel-energy-grants

Yale, A. T. (2019) 'The personal tutor–student relationship: student expectations and experiences of personal tutoring in higher education', *Journal of Further and Higher Education*, 43(4), pp. 533–544. doi: 10.1080/0309877X.2017.1377164.

Yale, A. T. (2020) 'Quality matters: an in-depth exploration of the student–personal tutor relationship in higher education from the student perspective', *Journal of Further and Higher Education*, 44(6), pp. 739–752. doi: 10.1080/0309877X.2019.1596235.

Preparing Future Engineers for Responsible Technology Development – Building Ethics Competences by Disciplinary and Academic Irritation

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ABSTRACT

In the discourse of technology assessment, future engineers are expected to contribute to inter- and transdisciplinary processes of responsible technology development. However, the role they are expected to play contradicts prevailing principles of engineering culture that engineering students internalize during their studies. To support them in developing competences for ethics integration in technology development, they need to be encouraged to question disciplinary attitudes and assumptions as well as to develop an appreciation for the diversity of perspectives. One approach to triggering such personality-effective processes is by irritating people's routines of reasoning and thinking. For this study, a new project course was developed with disciplinary and academic irritation as central didactic

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elements. Using a multi-method design, the first cohort's changes in appreciation for the diversity of perspectives. was investigated over one semester to test the approach's usefulness, making the start of a longer study with growing sample size. The first results discussed here are very promising and indeed invite further research.

1 USING DISCIPLINARY IRRITATION FOR ENGINEERING ETHICS EDUCATION

Technological innovation has the potential to steer human development in a more sustainable direction. At the same time, anthropogenic perturbations of the Earth's systems are themselves a direct consequence of technological innovation. Thus, engineering students need training in responsible technology development as part of their engineering ethics education. Since responsible technology development is necessarily inter- and transdisciplinary (Grunwald 2017), engineers need competences in knowledge integration (Repko and Szostak 2017; Klein 2012, Godemann 2008) which relies heavily on an appreciative attitude for a broad diversity of perspectives, as a prerequisite for developing competences for *interpersonal relations and collaboration* as well as for *interdisciplinary work* as described by Lozano et al. (2017). However, this request is at odds with present-day engineering culture (Faulkner 2015) and requires a shift in attitudes and assumptions. At the Berlin Ethics Lab of the TU Berlin, we wanted to know how engineering students can be encouraged to rethink their fundamental epistemic attitudes and assumptions in favor of appreciation for diversity of perspectives as an inter- and transdisciplinary-oriented mindset.

To initiate such personal learning processes (Combe and Gebhard 2009, 550f.), the didactic approach of *irritation* seems promising since irritation results from challenged attitudes and assumptions, which is seen as a necessary trigger for changing mindsets (Koller 2016). Such irritations occur through encounters with people who have different perspectives (ibid., Swierstra 2017) or through disruptions of routines where standard procedures fail and new solutions must be sought (Combe and Gebhard 2009, 552). To test the effects of irritation on engineering students' appreciation for diversity of perspectives, we developed a new project course based on the irritation paradigm. We collected data following a multi-method approach by carrying out 1. a qualitative data analysis of students' reflection papers, 2. an online survey on students' change in self-perception, and 3. a group discussion. In this paper, we provide the theoretical foundation upon which the research question was built in chapter 2. In chapter 3, we describe our methodological design before presenting our research findings in chapter 4 and concluding them in chapter 5.

2 HOW TO INITIATE COMPETENCE BUILDING FOR RESPONSIBLE TECHNOLOGY DEVELOPMENT IN ENGINEERING EDUCATION

The history of engineering shows that new technologies always have consequences for the way we live, both intended and unintended. This requires engineers to be particularly aware of the responsibility they bear for society. Since technologies' unintended negative effects are not primarily related to the engineering context but affect all areas within and outside of society, it is impossible for engineers alone to comprehensively assess such potential consequences. Therefore, widespread "microethical" (Martin, Conlon and Bowe 2021) approaches to ethical engineering education, which aim to make engineers aware of their individual responsibility in decision making, are too short-sighted. Instead, responsible technology development requires integrated technology assessment that includes a variety of disciplinary (interdisciplinarity) and even non-academic (transdisciplinarity) perspectives (Grunwald 2017).

Although from a production perspective, engineering has always been interdisciplinary, inter- and transdisciplinary collaboration for ethics integration in responsible technology development represents a fundamental shift in the role of engineers. Traditional engineering interdisciplinarity is aligned to the needs of engineering solutions. As a result, engineers are accustomed to processes, values, and a language of collaboration based on engineering reasoning and thinking. However, responsible technology development through technology assessment considers ethical values and societal impacts by integrating broader disciplinary and non-academic perspectives (*Fig. 1*). As a result, not only is the set of stakeholders much more diverse, but engineering reasoning and thinking is no longer the exclusive guiding framework. Instead, the engineering perspective is one position among many in a framework of responsible technology development.

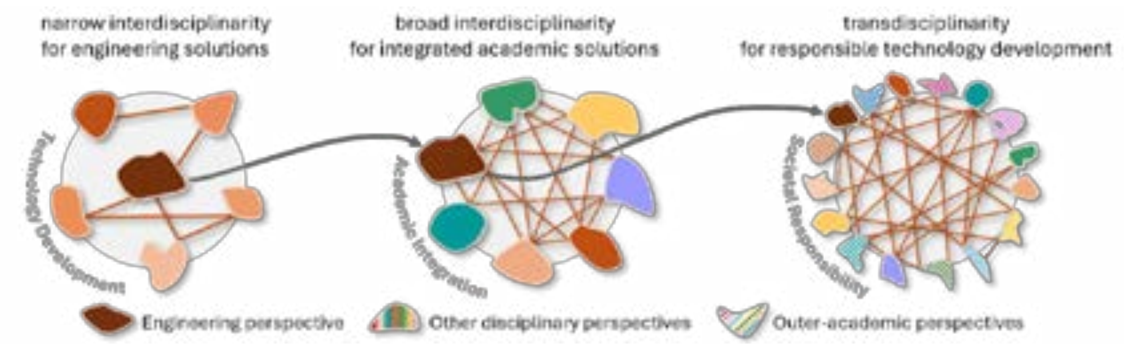

Fig. 1. Change of engineers' role for responsible technology development

This is nothing less than a break with the dominant engineering culture, which in its continuous reproduction refers almost exclusively to the technical dimensions of engineering, while neglecting its social and therefore also its ethical dimension (Faulkner 2015). This engineering culture is largely constructed through the socialization processes of education, defining a conceptual framework through which students will see and judge all experiences, actions and ideas. The effect of this socialization process can be seen e.g. in engineering students' significant decline in welfare orientation over the course of their studies as identified by Cech (2014).

Therefore, engineering ethics education faces the challenge of working against an established paradigm of reasoning and thinking. Thus, successful engineering ethics education might be less about ethics knowledge than about a cultural change of the conceptual framework that shapes the professional attitudes and assumptions of future engineers in favor of an appreciation for diversity of perspectives. This cannot be achieved alone by adding more formative learning of ethical content but calls for transformative learning which focuses on experiences that challenge students on a cognitive, conative, and emotional level (Mezirow 1998).

From a didactic perspective this enters the challenging realm of competence-oriented teaching. In contrast to mere knowledge, competences refer to an individual's network of knowledge and skills, as well as to socio-psychological elements such as attitudes and assumptions. Therefore, competences cannot be explicitly taught; the learner individually combines all these individual resources in such a way that he or she can consistently shape and manage situations in a specific context (Vitello, Greatorex and Shaw 2021). However, teachers can try to initiate personal learning processes in their students (Combe and Gebhard 2009, 550f.) which may affect their conceptual framework and thus allow for competence development. For this, it takes a learning environment in which students can experiment with combining their personal resources . In our case this would be an environment stimulating (re)combinations in favor of the competence for *change of perspective*.

Disciplinary and academic irritations, as we want to argue in the following, can be an important stimulus to initiate these processes in engineering students. According to the transformative understanding of education (Mezirow 2002), people only fundamentally adapt their views when they experience an irritation of their existing perspective, so that taken-for-granted ways of thinking are challenged (Koller 2016). Since irritation occurs through confrontation with other perspectives or disruptions of routines, it should be possible to deliberately stage moments of irritation in the classroom to expose learners to a "pressure to change" (ibid., 30). We have taken advantage of this possibility to initiate this kind of re-sorting with respect to diversity of perspectives by deliberately irritating the disciplinary and academic attitudes and assumptions of engineering students.

3 RESEARCH DESIGN FOR TESTING IRRITATION FOR CHANGING CONCEPTUAL FRAMEWORKS IN ENGINEERING STUDENTS

Inter- and transdisciplinary collaboration, as needed for responsible technology development, requires competence of *change of perspectives* (Barth et al. 2007, Brandstädter and Sonntag 2016) which is defined as the ability to place oneself into the perspective of another person without neglecting one's own (Repko and Szostak 2017). However, the willingness to consider other perspectives is based on the acceptance that knowledge is always fragmented (Parker 2010) and situated (Haraway 1988), meaning that all knowledge has been developed under particular historical, political, and disciplinary conditions that have given it its specific epistemic perspective. This results in the necessity of recognizing other bodies of knowledge and appreciating them as a supplement to one's own knowledge. Additionally, students need to understand that epistemological perspectives often are value-loaden and come with a normative stance engrained in the disciplinary culture. Thus, what engineering students need as a prerequisite for building competence for *change of perspective* is an *appreciation for diversity of perspectives* by recognizing their own epistemic and ethical values as well as those of others (Ammon et al. 2022) This requires that attitudes and assumptions of traditional engineering culture towards diversity of perspectives are challenged.

Thus, following the transformationalists in educational research, we decided to expose engineering students to diversity of perspectives in two successive settings of increasing complexity: a) broad interdisciplinarity and b) transdisciplinarity. This was meant to cause epistemic and normative irritation of their a) disciplinary and b) academic conceptual framework. The inter- and transdisciplinary set-up thus functioned as vehicle to confront the students with increasing diversity of perspectives which was meant to rupture the students' perspective to observe how they reacted to that stimulus. Our research hypotheses were:

H1: Broad interdisciplinary collaboration irritates the disciplinary framework of reasoning and thinking and thus leads to an increase of engineering students' appreciation for other disciplinary perspectives.

H2: Transdisciplinary collaboration irritates the academic conception of knowledge and thus leads to an increase of engineering students' appreciation for non-academic perspectives.

In the case of verification of those hypotheses we expected to see first an increase in irritation in the students after each new stimulus, as expressed through emotional reactions to the new perspectives or perspective pluralism they encountered such as discomfort, insecurity, puzzlement or surprise. This would be followed by increased tolerance for those perspectives as expressed through comments of acceptance, respect or appreciation for the other perspectives or descriptions of changes of their own perspective due to the encounters.

3.1 Research environment

To test our hypotheses, we developed a new project course at TU Berlin as research environment, for which students from the city's three major universities could enroll as free election course in addition to their compulsory courses. In this course, engineering students were to identify societal challenges and plan a transdisciplinary project together with broadly interdisciplinary groups of other students, e.g. from philosophy, humanities, or natural sciences, to irritate their disciplinary perspective on problems and adequate scientific problem-solving approaches (testing H1). Subsequently, the groups should initiate and carry out the transdisciplinary projects together with non-academic stakeholders so that their attitudes and assumptions regarding academic knowledge and its role in society vis-à-vis other perspectives would get irritated (testing H2). To make the experienced irritation explicit and thus accessible for ethical reflection, the students were to write individual reflection papers after each project phase.

We chose the course topic "Transdisciplinary Technology Development for Sustainable and Fair Urban Mobility" as an overarching reference to responsible technology development as contribution to sustainable development. However, in the module description, the grading and in the interaction with the students, we set the focus on the reflection of the collaboration experiences rather than on project success. Failed collaborations or reflections that concluded that transdisciplinary research is useless, for example, did not automatically lead to poor grades. In this way, we wanted to ensure that the reflection papers were not written according to social desirability standards. The students were asked permission to use their data for scientific evaluation of the didactic approach and participation in the research project was voluntary.

3.2 Research method

The results of this study are based on three different sets of data from three different survey instruments. We chose this multi-method approach to include both the students' subjective perceptions of shifts in their appreciation for diversity of perspectives and more objectively observable indicators of such shifts over time.

For the latter, we collected students' reflection papers at the end of three different project phases: interdisciplinary identification of project topics (t1), interdisciplinary (partly transdisciplinary) development of a methodological design (t2) and working transdisciplinarily with stakeholders (t3). Thus, irritations of disciplinary values were to be expected for t1, even more so for t2 with initial irritations of academic values and strong irritation of academic values at t3.

The reflection papers were subjected to qualitative data analysis using double coding following a strict code book with descriptions and examples of how to code statements to determine intrapersonal changes in students' appreciation for diversity of perspectives. Six characteristic values were differentiated according to the students' conceptualization of knowledge. These were later translated into a nominal scale to help track and compare observed changes. Regarding the qualitative nature of the researched characteristics, the scale only marks qualitative differences and makes no claim to be an interval or ratio scale. The defined levels ranged from claiming a single truth, which denies the fragmented and situated nature of knowledge, to the assumed absolute necessity of inter- and transdisciplinary knowledge generation for certain research fields, which shows the highest possible recognition of knowledge fragmentation and situatedness. The characteristic values were defined as 0 – holistic knowledge claim, 1 – abstract recognition of fragmented knowledge, 2 – acceptance of concrete other disciplinary epistemic values, 3 – appreciation of interdisciplinary epistemic values, 4 – appreciation of transdisciplinary values, 5 – assumption of the necessity of knowledge integration through interdisciplinary collaboration, and 6 – assumption of the necessity of knowledge integration through inter- and transdisciplinary collaboration.

The students' reflections were analyzed and categorized according to this scheme, allowing for both intra- and interpersonal comparisons over time, although statements about averages must be treated as tendency, not as absolute values due to the qualitative origins of the data. It is important to note, however, that no reflection papers were written before the start of the course, so that even those from t1 were already written under the impressions of the course input and the first interdisciplinary exchange. Thus, no statement can be made about the level of appreciation the students showed when they decided to enroll in the course.

To assess the students' subjective perception of shifts in their appreciation for diversity of perspectives they were surveyed during the last course session using an online questionnaire that asked the items listed in

Table 1. All items were asked on a 5-point scale except item 2.3, which was an open-ended question.

Table 1. Items of the online questionnaire

No.	**Item**
1	***Comparison of perceived competence before and after taking the course***
1.1	Theoretical knowledge of td research
1.2	Skills for interdisciplinary (id) collaboration
1.3	Skills for transdisciplinary (td) research
1.4	Multi-perspectivity on societal challenges
1.5	Multi-perspectivity on technological solutions
1.6	Ethical reflection of challenges/ technology

No.	**Item**
3	***Comparison of meaning attribution before and after taking the module***
3.1	Meaning of id collaboration for societal challenges
3.1	Meaning of td collaboration for big challenges
4	***Influence of an id and td approach on ...***
4.1	Understanding other values
4.2	Reconsideration of one's own values
4.3	Probability of finding a fair solution

2	***Perception of the id of the project groups***
2.1	Perceived degree of group interdisciplinarity
2.2	Satisfaction with group interdisciplinarity
2.3	Reasons for satisfaction level
4.4	Probability of finding a feasible solution
4.5	Probability of finding a good solution

In addition, we organized a group reflection and discussion at the end of the course to find out what collective experiences and opinions the students would formulate regarding irritations and coping strategies in inter- and transdisciplinary collaboration.

4 FINDINGS FROM TEACHING FOR DISCIPLINARY AND ACADEMIC IRRITATION

Our sample so far consisted of the 16 students who were accepted into the course. Slightly more than half of the students were enrolled in bachelor's programs, and the other half were enrolled in master's programs. The sample had a diverse disciplinary background, with half of the students coming from engineering and the other half from philosophy, humanities, natural sciences, and computer science. The analysis showed that the characteristics of the engineering students' data did not differ on average from those of the other disciplines at t1, because the math and computer science students lowered the average appreciation level of the non-engineering students. Therefore, we decided to include all students in our analysis to have more data on the attitudinal change processes of students based on the element of irritation than if we had focused on the engineering sample alone.

4.1 Qualitative analysis of the reflection papers

Mapping the students' reflective statements onto the appreciation scale, the first observation is a great diversity of initial appreciation levels among the students in the early phases of the course as can be seen in Fig. 3. However, none of them showed a holistic claim to knowledge, i.e. all of them already had some perception of fragmented knowledge. Only one student started at level 1, recognizing other epistemic values but not necessarily accepting them as useful. Another student started at level 2, accepting other epistemic values as probably useful, but not necessarily valuing them. The remaining 14 students started at level 3+ and already expressed appreciation for perspectives other than their own. One student showed the highest level of appreciation from the beginning, leaving no room for improvement on our scale.

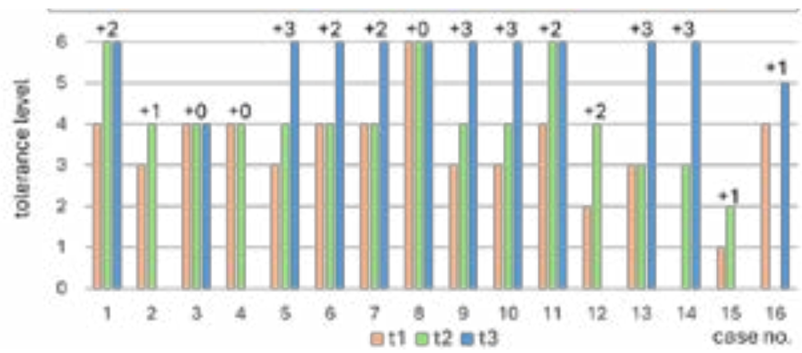

Fig. 3. Shift in students' appreciation for diversity of perspectives over time

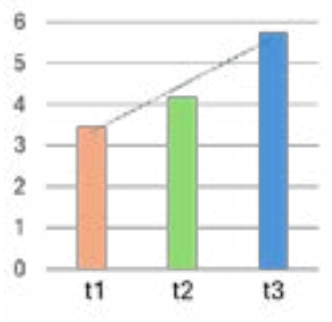

Fig. 4. Average increase in appreciation

Of the remaining 15 students who could show an increase in tolerance, 13 did. Three of them showed an increase of +1 level, five of +2 levels, and five of +3 levels. At the end of the course, 10 out of 12 students had reached the highest level of tolerance, assuming that knowledge integration through inter- and transdisciplinary collaboration is a compelling necessity for projects striving for societal impact. Four students did not submit their final reflection paper in time for this publication. On average, the increase in appreciation during the main phase of *disciplinary irritation* (t1 to t2) was from level 3.5 to 4.2, showing a shift from an already clear appreciation of interdisciplinary epistemic values to an appreciation of transdisciplinary epistemic values (Fig. 4). For the main phase of *academic irritation* (t2 to t3), the average increase in appreciation was from level 4.2 to 5.8, showing a shift from appreciation of transdisciplinary epistemic values to acceptance of the compelling necessity of knowledge integration through inter- and transdisciplinary collaboration. The average overall increase in tolerance was +2.3.

In-depth interpersonal analysis revealed not only a positive shift in expressed attitudes and assumptions on diversity of perspectives, but also a clear qualitative shift in the emphasis with which students argued their positions. At t1 many students showed a theoretical awareness of the importance of other perspectives in research and technology development and much appreciation for the interdisciplinary group constellation, but also exertion and insecurity about developing a common understanding of the project and their own role therein. Few weeks later, at t2, they gave many concrete examples of how extraordinarily fruitful interdisciplinary collaboration was, rating their group work as smooth and easy. However, they now expressed concern and, to some extent, overwhelm when reflecting on collaboration with extra-academic stakeholders, particularly in view of the low relevance that they and their scientific interests and approaches had in the practical context of the stakeholders. At t3, most students expressed high levels of confidence in transdisciplinary collaboration, often expressing strong emotions of surprise, pride, gratitude, and excitement. Thus, even the two students for whom our scale showed no increase in appreciation showed a very different level of personal commitment to their position in later stages of the course.

4.2 Quantitative analysis of data from the online questionnaire

The survey revealed that students felt that their participation in the course had led to a significant increase in their personal resources in all areas surveyed (Table 1), as shown in Fig. 5. While the arithmetic mean of all items was reported as low to medium at the beginning of the course, it was reported as rather high on average at the end of the course. The increase in knowledge (+2 scale points) and in one's own ability to act (+1.8 scale points) in relation to transdisciplinary research were perceived as the strongest effects. The smallest perceived increase was reported for the ability to act in interdisciplinary collaborative settings (+0.8 scale points). This is also the item that had the highest score at the beginning of the course, suggesting that students already had some previous experience with interdisciplinary collaboration. Regarding ethical reflection on societal challenges and technologies, there was an increase of 1.3 scale points.

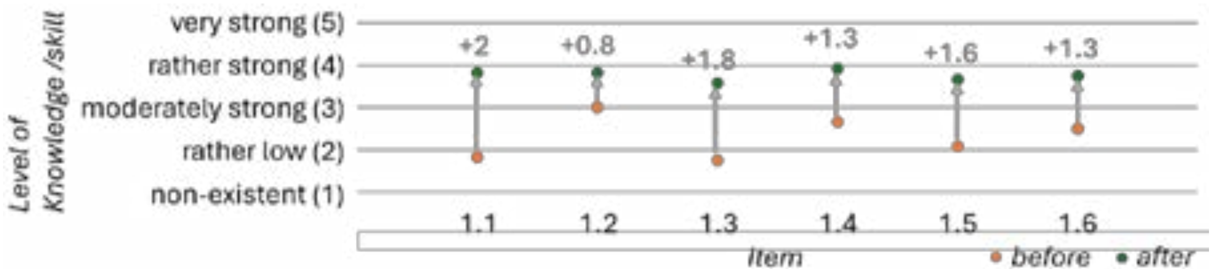

Fig. 5. Students' perception of their knowledge and skills development (n=11)

The greater prior familiarity with interdisciplinary than transdisciplinary approaches is also reflected in the responses to item 3. While students indicated that they considered interdisciplinary approaches to be important for solving major societal challenges already before taking the course (scale value 3.8) and very important at the end of the course (scale value 4.6), they gave transdisciplinary approaches only moderate importance at the beginning of the course (scale value 3.2). At the end of the course, however, they also considered these approaches to be very important (scale value 4.7). Thus, although the students rated interdisciplinary and transdisciplinary approaches almost equally at the end of the course, their attitudes toward transdisciplinary approaches had evolved significantly more.

4.3 Summarizing data from the group discussion

The group discussion showed that all students agreed that research questions whose outcome affect broader sections of society profit greatly from inter- and transdisciplinary diversity of perspectives. Especially students from technical subjects expressed that they would have never considered this in the realm of their usual disciplinary studies and that even during our course it was not before practically interacting with other perspectives that they could fully comprehend the advantage. Several students stated that the inter- and especially the transdisciplinary experience changed their entire perspective on science and academia, effecting the way they planned to continue their studies, their private engagement, and their job orientation. The participants of one group that turned out to be less broadly interdisciplinary than expected, expressed their regret about lacking the same interdisciplinary input that they had observed with the other teams. The students started by themselves to discuss moments of strong irritation and feelings of severe disorientation when collaborating with people from other fields, especially outside academia, which was replaced by confidence and powerful enrichment after a while.

5 DISCUSSION OF OUR FINDINGS

The sample size of this execution was too small to make valid statistic statements. At this early stage, the study must therefore be regarded as a case study intended to highlight tendencies rather than facts. The statements will become more valid as the sample size increases over the coming semesters in which we will repeat the study and accumulate the data. However, the found tendencies are encouraging. The results of the qualitative data analysis show an increase in appreciation for disciplinary diversity of perspectives among the students, following a phase of insecurity after confrontation with other disciplinary perspectives . However, the increase in appreciation for diversity of perspectives is even more pronounced after confrontation with non-academic perspectives in the transdisciplinary work phase. In fact, according to the reflection papers, the students showed a high level of appreciation towards other disciplinary perspectives at an early stage, which, under the task of increasingly integrating different epistemic perspectives into their projects, turned into a clear and continuously increasing appreciation for non-academic perspectives as well.

The student questionnaire revealed a similar picture. The students stated that they already felt they had a relatively positive attitude and competence regarding interdisciplinary collaboration from the start, which nevertheless increased further while taking the course. However, they perceived their increase in competence in transdisciplinary research as significantly stronger, as well as the change in their attitude towards transdisciplinary approaches in general.

Finally, the group discussion highlighted the irritational effect as a direct precursor to the students' changed perception and sense of competence regarding diversity of perspectives. The combined results of the multi-method approach thus tend to confirm H1 and H2. Disciplinary and, to an even greater extent, academic irritation can thus be expected to be an effective means of strengthening *appreciation for diversity of perspectives* as a basic prerequisite for the competence of *change of perspectives*, a central competence for responsible technology development in inter- and transdisciplinary teams. We therefore believe that the didactic element of irritation can make an important contribution to the education of engineers and shows that engineering ethics education is indeed inter-and transdisciplinary ethics education with benefits for all disciplines involved.

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REFERENCES

Ammon, S., A Kljagin, J. Rettschlag, and M. Vortel. “The Berlin Ethics Certificate: Conceptualizing Interdisciplinarity as a Core Building Block of Ethics in Engineering Education”. In *Towards a new future in engineering education: new scenarios that that European alliances of tech universities open up, Universitat Politècnica de Catalunya, 19.-22.09.2022*, 913–924. https://doi.org/10.5821/conference-9788412322262.1422.

APA. Frame of reference. APA Dictionary of Psychology,19.04.2018, https://dictionary.apa.org/frame-of-reference.

Barth, M., J. Godemann, M. Rieckmann, and U. Stoltenberg, “Developing key competencies for sustainable development in higher education”, *International Journal of Sustainability in Higher Education* 8, 4 (2007): 416-430. https://10.1108/14676370710823582

Blake, J., S. Sterling, and I. Goodson. “Transformative learning for a sustainable future: An exploration of pedagogies for change at an alternative college.” *Sustainability* 5, 12 (2013): 5347–5372. https://doi.org/10.3390/su5125347.

Boler, M. *“Feeling Power. Emotions and Education”. New York: Routledge, 1999.*

Brandstädter, S., Y. Schleiting, and K. Sonntag. „Interdisziplinäre Kompetenz in der Wirtschaft [Interdisciplinary competence in business].“ *Zeitschrift für*

Arbeitswissenschaft [Journal of Industrial Science] 72, 1:2018, 35–43. https://doi.org/10.1007/ s41449-017-0080-9

Cech, E. A. (2014). Culture of Disengagement in Engineering Education? *Science, Technology, & Human Values 39,* 1: 42-72. https://doi.org/10.1177/0162243913504305

Combe, A., and U. Gebhard. „Irritation und Phantasie: Zur Möglichkeit von Erfahrungen in schulischen Lernprozessen [Irritation and Phantasy: On the potential of experiences in school-based learning processes].” *Zeitschrift für Erziehungswissenschaft [Journal of Educational Siences]* 12 (2009): 549-571.

Faulkner, W. “Nuts and Bolts and People: Gender Troubled Engineering Identities.” In: S. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, B. Newberry (eds) *Engineering Identities, Epistemologies and Values: Philosophy of Engineering and Technology*, vol 21. Berlin: Springer, 2015: 23-40. https://doi.org/10.1007/978-3-319-16172-3_2

Godemann, J. “Knowledge Integration: A key challenge for transdisciplinary cooperation.” *Environmental Education Research* 14, 6 (2008): 625–641. https://doi.org/10.1080/13504620802469188

Grunwald, A. “A transdisciplinary approach to the process of socio-technical transformation: The case of German Energiewende.” In M. Padmanabhan (ed.) *Transdisciplinary Research and Sustainability: Collaboration, Innovation and Transformation.* London: Routledge, 2017: 35-52.

Haraway, D. “Situated Knowledges: The Science Question in

Feminism and the Privilege of Partial Perspective.” *Feminist Studies* 14, 3 (1988):

575–599. https://doi.org/10.2307/3178066

Klein, J. T. “Research integration: A comparative knowledge base.” In A. F. Repko, W. H. Newell, & R. Szostak (eds.), *Case studies in interdisciplinary research* (pp.). 2nd Edition, SAGE Publications: Thousand Oaks, 2012: 283–298.

Koller, H.-C. „Über die Notwendigkeit von Irritationen für den Bildungsprozess: Grundzüge einer transformatorischen Bildungstheorie [On the Necessity of Irritations for the Educational Process: Fundamentals of a transformational theory of education].“ In: A. Lischewski, (ed.): *Negativität als Bildungsimpuls: Über die pädagogische Bedeutung von Krisen, Konflikten und Katastrophen [Negativity as Educational Stimulus: On the Pedagogical Meaning of Crisis, Conflict, and Catastrophes]*. Paderborn: Schöningh, 2016: 215-235.

Lozano, R.; Merrill, M.Y.; Sammalisto, K.; Ceulemans, K.; Lozano, F.J. “Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal”. *Sustainability* 2017, 9: 1889. https://doi.org/10.3390/su9101889

Martin, D. A., E. Conlon, and B. Bowe. “A Multi-level Review of Engineering Ethics Education: Towards a Socio-technical Orientation of Engineering Education for Ethics”. *Science and Engineering Ethics* 27(5): Article 60.

https://doi.org/10.1007/s11948-021-00333-6Ethics”. *Science and Engineering Ethics* 27(5): Article 60. https://doi.org/10.1007/s11948-021-00333-6

Mezirow, J. “Transformation theory and social action: A response to Collard and Law”. *Adult Education Quarterly 39 (1989),* 3: 169–175. https://doi.org/10.1177/0001848189039003005

Mezirow, J. “Transformative Learning: Theory to Practice”. *New Directions for Adult and Continuing Education,* 74 (2002), 5-12. https://doi.org/10.1002/ace.7401

Parker, J.E. “Competencies for interdisciplinarity in higher education.” *International Journal of Sustainability in Higher Education* 11, 4 (2010): 325-338.

Repko, A. F., and R. Szostak. “Interdisciplinary research: Process and theory.” 3rd ed., Sage Publications: Thousand Oaks, 2017.

Swierstra, T. “Introduction to the Ethics of New and Emerging Science and Technology”. In: R. Nakatsu, M. Rauterberg, and P. Ciancarini (eds) *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer, 2017: 1271–1295. https://doi.org/10.1007/978-981-4560-50-4_33

Vogel, O., and M. Hunecke. “Fostering knowledge integration through individual competencies: the impacts of perspective taking, reflexivity, analogical reasoning and tolerance of ambiguity and uncertainty.” *Instructional Science* 52 (2024): 227-248. https://doi.org/10.1007/s11251-023-09653-5

Vitello, S., J. Greatorex, and S. Shaw. *What is competence?: A shared interpretation of competence to support teaching, learning and assessment.* Cambridge: Cambridge University Press & Assessment, 2021.

BELIEFS ON BELONGING: PERCEPTIONS OF FIRST YEAR ENGINEERING STUDENTS

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ABSTRACT

This study explores differences between perceptions of Traditional and Non-Traditional engineering students of their sense of belonging with a view to how this informs student intention to persist. This paper presents findings from an exploratory survey of (N=365) 1st year Bachelor of Engineering students at a Nordic Technical University. The survey was developed to explore background factors influencing student motivation and persistence. The results were analysed via R statistical software and reveal that nontraditional students, particularly those from diverse ethnic backgrounds, perceive a lower level of sense of belonging and academic support compared to traditional students. The results point to the need for universities to develop early-stage initiatives sensitive to the different challenges integrating academically and socially as is often experienced by non-traditional

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students. Thereby enhancing inclusivity and improving student persistence within engineering education.

1. INTRODUCTION

1.1 Background

In academic contexts, a sense of belonging is foundational for student success and well-being (Tinto, 2022; Strayhorn, 2018; Ulriksen, Madsen, & Holmegaard, 2015). A sense of belonging can enhance students' engagement in their studies, leading to increased effort, positively impacting achievement and increasing self-efficacy (Tinto, 2022). For students to perceive they belong is to perceive they are connected to and supported through their university experience by friends and colleagues, teaching staff and family (Strayhorn 2018; Tinto 2017a). Student connections to these groups and often to the university itself, contribute to their sense of identity (Ulriksen, Madsen, and Holmegaard 2010) and in turn their motivation (Tinto 2017a). Sense of belonging is often disrupted during transition to university, and so when necessary connections cannot be made, students may withdraw from activities, both social and academic, decreasing the likelihood of persistence (Tice et al., 2021; Rainey et al., 2018; Strayhorn, 2018; Tinto, 2017).

A sense of belonging for minority students can be especially important for persistence at university. This is emphasised further in STEM fields where altogether dropout is higher than other disciplines (Fan, Luchok, & Dozier, 2021) and minority students tend to dropout more than majority students, which is often influenced by non-inclusive learning environments (González-Pérez et al., 2022; Whitcomb & Singh, 2021; Hansen, Palakal, and White 2023).

Understanding and enhancing students' sense of belonging can therefore play a central role in promoting student persistence in higher education, as students who do not feel they belong are unlikely to persist (Tinto, 2017; Strayhorn,2018; Hansen, Palakal, and White 2023).

1.2 Literature Review

In many academic institutions the norms and values of university cultures are reflective of student groups that have traditionally been the majority, in terms of the characteristics they display. In many STEM academic settings, the majority of students have traditionally been white male students(Eastman, Miles, and Yerrick 2019; Park et al. 2020). This study uses the terms of "Traditional" and "Non-Traditional" students, introduced by Holmegaard, Madsen, and Ulriksen (2017), to explore the experiences and perceptions of those historically underrepresented in these fields, such as women and ethnically diverse students.

A student's journey into higher education, particularly within STEM degrees, is influenced by how well they can integrate socially and academically (Hansen, Palakal, and White 2023; Tinto 2022). As Ulriksen (2009) highlights, students who do not align with the traditional student archetype may find it challenging to be recognized and accepted as legitimate members of their academic community. This misalignment and resultant lack of recognition can set students apart. Those from non-traditional backgrounds may be especially affected, leading to a disengagement from their studies (Ulriksen, Holmegaard, and Madsen 2017; Strayhorn 2022;

González-Pérez et al. 2022). Therefore, the processes of integration and socialization will vary across different students in various STEM educations (Hansen, Palakal, and White 2023). These students engage in a continuous process of interpreting, balancing, and negotiating their educational experiences (Tinto, 2022). How students navigate this process is linked to their personal backgrounds and their cultural, ethnic, and socioeconomic origins (Tinto 2017; Ulriksen, Madsen, and Holmegaard 2017). Tinto (2022) and Strayhorn,(2018) emphasise the role of the university community in developing students' social integration and engagement. Teachers, support staff, and fellow students are key to fostering students' sense of belonging. This is particularly important in the first year of higher education, where the highest proportion of students leave (Tinto, 2017). However, it is not engagement per se, but the quality of the engagement which is important (Tinto, 2017). How the students interact and how they perceive their interactions, determines their sense of belonging (Gasiewski et al. 2012; Tinto, 2022). Conversely, the absence of belonging can erode students' commitment to the university and decrease their likelihood of persisting in their studies. This dynamic is particularly pronounced for non-traditional students in STEM fields, where the barriers to success are often greater (Holmegaard, Madsen, and Ulriksen 2017; Tinto 2022). A robust sense of belonging, therefore, becomes key for their academic advancement and persistence (Rainey et al., 2018; Strayhorn, 2018, 2022). While social belonging, fostered by shared interests and communal experiences within the university is key for the engagement of 'nontraditional' students', Tinto (2022) argues that it is academic belonging that exerts a more substantial influence on success. This form of belonging significantly boosts students' self-efficacy and enhances learning outcomes (Ibid). Supportive classroom environments and empathetic teachers underpin academic belonging through encouraging student motivation (Tormey, 2021; Hartikainen, Pylväs, and Nokelainen 2022). Consequently, this generates increased effort, leading to a more conducive environment for learning (Tormey 2021; Hartikainen, Pylväs, and Nokelainen 2022; Kirby and Thomas 2022; Holmegaard, Madsen, and Ulriksen 2017).

The objective of this study is to explore potential differences in the sense of belonging between traditional and non-traditional engineering students at a Nordic Technical University.

The research aims to identify specific areas where engineering institutions can enhance support and inclusivity measures which has resulted in the following research question:

Research Question: Are there differences in perceptions of belonging between traditional and non-traditional Bachelor of Engineering students?

2 METHODOLOGY

2.1 Study Design

In this exploratory study, we developed a survey targeting first-year engineering students at the end of their first semester in the Bachelor of Engineering degree. Data were collected from 365 first-year engineering students, representing 34% of the study population for that year. Among the participants, 67% identified as male, 32% as female, and 1% as non-binary or prefer not to say. Regarding ethnicity, 65%

identified as Nordic Traditional Ethnicity (NTE), 27% as Non-Traditional Ethnicity (NTE), and 8% as International (INT).

The survey included 11 items designed to measure various dimensions of sense of belonging, including academic support, social integration, and institutional support. These items were developed based on existing literature on student sense of belonging, motivation, and educational engagement. Responses were collected using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Additionally, the survey included demographic questions on ethnicity and gender.

Data were collected from 13 study lines across 12 Danish language engineering courses. Data collection commenced in January 2023 using an online survey tool (Surveyxact.dk) and was subsequently imported into R for analysis. The data collection period spanned the first and second weeks of a 3-week course period to avoid biases from study fatigue or exam stress.

In order to evaluate the internal consistency of the survey instrument, which has not been previously validated given its exploratory nature, a Cronbach's alpha analysis was performed. This analysis yielded a reliability coefficient of 0.83 (see Table 1), surpassing the acceptable threshold of 0.70 and thus affirming the interrelatedness of the survey items. However, it is important to note, following Grau (2007), that this score does not necessarily imply unidimentionality of the construct being measured.

To investigate differences in perceptions of belonging among students of different ethnicities and genders, we conducted a series of statistical tests on our survey data. The primary aim was to determine if there were significant differences in how various student groups perceive their academic and social belonging within the university.

Prior to analysis, data were cleaned to remove cases with missing values and to ensure the integrity of the dataset. Despite likert scales being ordinal and non-normally distributed, we refer to (Norman 2010; Mircioiu and Atkinson 2017) who state that parametric tests are appropriate for likert scale analysis.

We employed two main types of statistical tests to analyze the data: Welch's t-tests and Analysis of Variance as well as a Tukey's Honest Significant Difference (HSD) post-hoc tests to identify which specific groups differed from each other.

We used the Welch's t-test to compare the mean levels of agreement between male and female students for each variable related to the sense of belonging. We used this test instead of the standard t-test because it is preferred when dealing with unequal variances between groups robust against violations (Ruxton 2006; Delacre, Lakens, and Leys 2017).

2.2 Statistical Tests

To compare the mean levels of agreement across the three different ethnic groups simultaneously, we used ANOVA as advised by (Maxwell and Delaney 2004). When ANOVA indicated significant differences, we used Tukey's Honest Significant Difference (HSD) post-hoc tests to identify which specific groups differed from each other.

3 RESULTS AND DISCUSSION

3.1 Tables

Table 1. T-test Results by Gender (Percent Agreement and P-values)

Variables related to sense of belonging	**% Agreement Males (N=244)**	**% Agreement Females (N=124)**	**P-value (significance p ≤ 0.05) of observed differences between groups**
My teacher explains things well	54	40	**0.004****
My teacher encourages me to do well	45	37	0.326
The social relations with other students	63	66	0.421
I am well supported by my network	69	66	**0.750**
The university helps to provide a good social network	62	42	**0.0003*****
Good student-teacher interaction is important	84	82	0.458
I have a sense of belonging at university	55	51	0.261
My teachers respect me and act with empathy	49	41	0.246
The university values my opinions	46	33	0.027*
The university has an open-door policy and I am comfortable using it	50	42	**0.037***
The university creates an environment where I am included	63	54	**0.065**

* p < 0.05, ** p < 0.01, *** p < 0.001

Table 2: ANOVA and Tukey HSD Results by Ethnicity, the significant responses are highlighted in bold type.

Variables related to sense of belonging	**Proportions of agreement for each statement according to ethnicity group**			**P Value (significance p ≤ 0.05) of observed differences between groups**
In relation to my motivation to study I believe:	Nordic Traditional Ethnicity (NTE) (65%, n=238)	Non-Traditional Ethnicity (NE) (27% n=98)	International (INT.) (8% N=29)	
My teacher explains things well	0.57	0.31	0.62	**0.00*****
My teacher encourages me to do well	0.48	0.30	0.42	**0.03***

The social relations with other students are important	0.68	0.60	0.42	**0.04***
I am well supported by my network	0.76	0.56	0.42	**0.00*****
The university helps to provide a good social network (via activities and clubs)	0.62	0.42	0.50	**0.01***
I have a sense of belonging at university	0.58	0.44	0.50	**0.03***
The university creates an environment where I am included	0.64	0.51	0.65	**0.01***
Good student-teacher interaction is important	0.86	0.81	0.73	0.17
My teachers respect me and act with empathy	0.51	0.37	0.50	0.19
The university values my opinions	0.45	0.40	0.23	0.08
The university has an open-door policy and I am comfortable using it	0.50	0.45	0.38	0.49

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3.2 Perceptions of Belonging in Traditional and Non-Traditional Students

This study highlights the significant variation in students' perceptions of belonging and academic support across different ethnic backgrounds and, to a lesser extent, gender. Traditional students predominantly reported higher levels of agreement regarding positive interactions with faculty and a sense of being valued and supported within the academic environment. This comparison demonstrates a consistently higher level of agreement among traditional students for all statements relative to their non-traditional counterparts. The analysis, as detailed in Tables 1 and 2, utilizes Welch’s T-Tests and ANOVA tests to examine the differences in perceptions related to sense of belonging and motivation to study across both gender and ethnicity. Statistical significance conveyed those results that can be considered representative of student perceptions.

Academic Belonging

Regarding the statement ‘*My teacher explains things well’*, both Traditional (NTE) and International student groups displayed similar levels of agreement, contrasting with the Non-Traditional Ethnicity (NE) students, who exhibited a significantly lower rate of agreement at 31%. A gender disparity was also noted, with a higher percentage of males (54%) in agreement compared to females (40%), a difference that was statistically significant.

For the assertion '*My teacher encourages me to do well*', NE students again showed the lowest percentage of agreement compared to the other groups, with none surpassing 50% agreement. This was also statistically significant, and the finding suggests a universal perception of limited encouragement from teachers across ethnic groups. This aligns with the literature indicating that non-traditional students often struggle with recognition and acceptance in academic communities, which can lead to disengagement (Ulriksen, Holmegaard, and Madsen, 2017; Strayhorn, 2022; González-Pérez et al., 2022). Although this was not significant for the gender group, there were observed low levels of agreement, particularly among females, which may either underscore the challenges faced by women in feeling supported and encouraged within the academic setting or the lack of significance indicates that this is not an influential factor for motivation and belonging.

Although over 70% of respondents acknowledged the importance of student-teacher interaction for motivation, the actual agreement levels on good student-teacher interactions were not statistically significant. This highlights either a potential gap between the recognized importance of these interactions and the actual experiences of the students. Tinto (2022) and Strayhorn (2018), Tormey (2021) and Hartikainen et al. (2022) all agree teacher-student interaction can have yield a considerable influence on student sense of belonging. Alternatively, it could be interpreted as students are in agreement and uniformly experiencing these interactions, but the quality or depth of these interactions may not be meeting their expectations or needs.

Supportive classroom environments and empathetic teachers are an important part of developing academic belonging (Tinto, 2022; Tormey, 2021; Hartikainen, Pylväs, and Nokelainen, 2022). However, the notable decrease in agreement regarding the statement that teachers respect students and act with empathy, especially among non-traditional ethnic groups, signals that these supportive conditions are not universally experienced. Although this was not found to be statistically significant, this could be a case of students only 'knowing what they know' and may possibly reflect general norms in teaching as 51% or less agreed. Although students may not directly perceive this as an influence of motivation either at this stage or generally, it is nevertheless a factor that may impact student motivation over time, leading to lower self-efficacy and diminished learning outcomes for students in general but especially non-traditional students (Tinto, 2022; Holmegaard, Madsen, and Ulriksen, 2017).

Social Belonging

The assertion that '*The university has an open-door policy and I am comfortable using it*' received lower agreement rates from females compared to males, a difference that was statistically significant. This reveals gender disparities in perceived accessibility to support, aligning with findings from González-Pérez et al.(2022), that women in STEM often feel less included and supported.

Similarly, both International and NE students reported lower agreement levels than NTE students, albeit not significantly. This could suggest that non-traditional students may perceive institutional support structures as less accessible or welcoming, yet not to the extent that it influences motivation.

The statements regarding inclusivity of the university environment *'The university creates an environment where I am included'* highlighted lower agreement rates for NE students relative to NTE and International students, and lower for females than males – both differences reaching statistical significance. This supports the literature that non-traditional students often feel marginalized in academic settings that reflect the norms and values of the majority group (Ulriksen, 2009; Eastman, Miles, and Yerrick, 2019). Therefore, including students that are outside of the cultural norm, becomes a fundamental element when developing sense of belonging (Strayhorn, 2018; Tinto, 2022).

The perception that '*The university does well in providing a good social network*' showed reduced agreement among both female and NE students, compared to their male and NTE counterparts, respectively. This aligns with research indicating that social integration is a significant challenge for non-traditional students (Hansen, Palakal, and White, 2023; Tinto, 2022).

The significant finding that international students viewed social relations with other students as less important for their motivation further complicates the picture. It suggests that international students may prioritize other aspects of their university experience over social integration, potentially due to cultural differences or varying expectations of academic life – such as being temporary students (Tinto, 2022; Ulriksen, Madsen, and Holmegaard, 2017).

Conversely, the statement '*The university values my opinions*' received less than 50% agreement from all surveyed students but was not statistically significant. This suggests a broader issue where students across all demographics feel undervalued. This finding highlights the importance of creating a participatory and inclusive culture where all students feel their voices are heard and valued (Gasiewski et al., 2012; Tinto, 2022).

4 SUMMARY

The study's results show that indeed there are differences in the perceptions of sense of belonging variables between traditional and non-traditional students. Although there were differences between male and female perceptions, the differences were more pronounced between traditional students and non-traditional students based on ethnicity. This indicates that there are some underpinning cultural factors, perhaps related to communication styles, cultural norms, and the level of encouragement offered by teachers, that could be further studied in order to bridge the gap. There is a completely different make-up of the student population than has been traditionally. The new student population has a less positive perception of their experience at university in these initial months than traditional students, suggesting that the culture is still orientated to a previous type of student. As the first year is so important in order to mitigate dropout, paying attention to academic sense of belonging and in particular teacher encouragement and teacher explanations could be prudent. Studies show that more explicit communication is beneficial for non-traditional students, as they are less likely to be as fluent in the norms and values of university culture as traditional students. Furthermore, by creating a more 'humanised' approach enables students to develop more connections between each other, the teacher and the university.

Further studies should investigate effective initiatives to increase students' sense of belonging, considering how various student characteristics factor into this dynamic. For instance, it would be valuable to examine whether students who perform well academically tend to have a higher sense of belonging.

REFERENCES

Delacre, Marie, Daniël Lakens, and Christophe Leys. 2017. "Why Psychologists Should by Default Use Welch's t-Test Instead of Student's t-Test." *International Review of Social Psychology* 30 (1): 92–101. https://doi.org/10.5334/irsp.82.

Eastman, Michael G., Monica L. Miles, and Randy Yerrick. 2019. "Exploring the White and Male Culture: Investigating Individual Perspectives of Equity and Privilege in Engineering Education." *Journal of Engineering Education* 108 (4): 459–80. https://doi.org/10.1002/jee.20290.

Gasiewski, J.A., M.K. Eagan, G.A. Garcia, S. Hurtado, and M.J. Chang. 2012. "From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses." *Research in Higher Education* 53 (2): 229–61. https://doi.org/10.1007/s11162-011-9247-y.

González-Pérez, S., M. Martínez-Martínez, V. Rey-Paredes, and E. Cifre. 2022. "I Am Done with This! Women Dropping out of Engineering Majors." *Frontiers in Psychology* 13. https://doi.org/10.3389/fpsyg.2022.918439.

Hansen, Michele J., Mathew J. Palakal, and Le'Joy J. White. 2023. "The Importance of STEM Sense of Belonging and Academic Hope in Enhancing Persistence for Low-Income, Underrepresented STEM Students." *Journal for STEM Education Research*. https://doi.org/10.1007/s41979-023-00096-8.

Hartikainen, Susanna, Laura Pylväs, and Petri Nokelainen. 2022. "Engineering Students' Perceptions of Teaching: Teacher-Created Atmosphere and Teaching Procedures as Triggers of Student Emotions." *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2022.2034750.

Holmegaard, Henriette Tolstrup, Lene Møller Madsen, and Lars Ulriksen. 2017. "Why Should European Higher Education Care about the Retention of Non-Traditional Students?" *European Educational Research Journal* 16 (1): 3–11. https://doi.org/10.1177/1474904116683688.

Kirby, L.A.J., and C.L. Thomas. 2022. "High-Impact Teaching Practices Foster a Greater Sense of Belonging in the College Classroom." *Journal of Further and Higher Education* 46 (3): 368–81. https://doi.org/10.1080/0309877X.2021.1950659.

Maxwell, Scott E., and Harold D. Delaney. 2004. *Designing Experiments and Analyzing Data : A Model Comparison Perspective*. Lawrence Erlbaum Associates.

Mircioiu, Constantin, and Jeffrey Atkinson. 2017. "A Comparison of Parametric and Non-Parametric Methods Applied to a Likert Scale." *Pharmacy* 5 (4): 26. https://doi.org/10.3390/pharmacy5020026.

Norman, Geoff. 2010. "Likert Scales, Levels of Measurement and the 'Laws' of Statistics." *Advances in Health Sciences Education* 15 (5): 625–32. https://doi.org/10.1007/s10459-010-9222-y.

Park, Julie J., Young K. Kim, Cinthya Salazar, and Shannon Hayes. 2020. "Student–Faculty Interaction and Discrimination from Faculty in STEM: The Link with Retention." *Research in Higher Education* 61 (3): 330–56. https://doi.org/10.1007/s11162-019-09564-w.

Ruxton, Graeme D. 2006. "The Unequal Variance T-Test Is an Underused Alternative to Student's t-Test and the Mann-Whitney U Test." *Behavioral Ecology*. https://doi.org/10.1093/beheco/ark016.

Strayhorn, Terrell L. 2018. *College Students' Sense of Belonging*. *College Students' Sense of Belonging*. Routledge. https://doi.org/10.4324/9781315297293.

Strayhorn, Terrell L 2022. "Exploring Ethnic Minority First-Year College Students' Well-Being and Sense of Belonging: A Qualitative Investigation of a Brief Intervention." *American Journal of Qualitative Research* 6 (1): 42–58. https://doi.org/10.29333/ajqr/11422.

Tinto, Vincent. 2017. "Reflections on Student Persistence." *Student Success* 8 (2): 1–8. https://doi.org/10.5204/ssj.v8i2.376.

Tinto, Vincent. 2022. "Increasing Student Persistence: Wanting and Doing." In , 53–70. https://doi.org/10.1007/978-981-16-5852-5_33.

Tormey, Roland. 2021. "Rethinking Student-Teacher Relationships in Higher Education: A Multidimensional Approach." *Higher Education* 82 (5): 993–1011. https://doi.org/10.1007/s10734-021-00711-w.

Ulriksen, Lars. 2009. "The Implied Student." *Studies in Higher Education* 34 (5): 517–32. https://doi.org/10.1080/03075070802597135.

Ulriksen, Lars, Henriette T. Holmegaard, and Lene Møller Madsen. 2017. "Making Sense of Curriculum—the Transition into Science and Engineering University Programmes." *Higher Education* 73 (3): 423–40. https://doi.org/10.1007/s10734-016-0099-4.

Comparing and Exploring adjustments to an implemented Flipped classroom combined model: A follow-up study

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ABSTRACT

The aim of this research is to understand students' perceptions of the flipped classroom model used to teach sustainability in an operations management module, and moreover, to understand the extent to which students are self-regulating their learning outside of the classroom. This is a follow-on study, and a further aim is to examine whether changes to the online learning environment have made any difference. This research used a validated and ethically approved survey to collect data, which was analysed using descriptive statistical analysis that involved the calculation of frequency, means and standard deviation from the responses using SPSS and Excel software. Results indicate a surprising consistency with the findings of the previous research, with only one aspect, the VLE (Virtual Learning Environment) facilitating interactions within the cohort, recording a notable positive difference. Whilst this supports and reflects the changes made, the intention to facilitate self-regulated learning and students' engagement with online learning was not improved. Therefore, further research (and action) is required to address the lack

of student engagement with self-regulated learning. This study provides useful insights into student learning behaviour in a flipped classroom environment that requires self-regulated online learning. Furthermore, other research could use the same tool to evaluate their own students' perceptions and compare results.

1 Introduction

1.1 Literature

The Flipped Classroom (FC) paradigm has emerged as a compelling pedagogical approach, substantiated by ample empirical support (Mason, Shuman, and Cook 2013; Shih, Liang, and Tsai 2019). FC revolutionizes traditional learning dynamics by reversing the conventional sequence, shifting lecture content delivery to online platforms and allocating in-class time for active engagement in problem-solving or collaborative tasks (Lage, Platt, and Treglia 2000; Shih, Liang, and Tsai 2019). Contemporary FC frameworks integrate two primary components: Online Learning Activities (OLA) and Face-to-Face instruction, blending theoretical concepts with hands-on applications (Youhasan et al. 2022; Jowsey et al. 2020). However, the delineation between FC and blended learning, wherein both online and in-person approaches converge, remains blurred in scholarly discourse (Youhasan et al. 2022).

FC and blended learning models optimize face-to-face class time for higher-order cognitive tasks such as problem-solving and collaborative projects (Flumerfelt and Green, 2013; Shih, Liang and Tsai, 2019). Self-Regulated Learning (SRL) denotes learners' deliberate orchestration of the learning process (Cho, Kim, and Choi, 2017; Shih, Liang, and Tsai, 2019). Empirical evidence highlights a positive correlation between SRL and learning satisfaction, emphasizing its role in achieving educational objectives (Artino and Jones, 2012; Sun et al. 2008; Wang, Shannon, and Ross, 2013; Broadbent and Poon, 2015; Wu et al. 2023).

Scholars have noted enhanced student engagement and self-awareness through FC implementation, emphasizing its efficacy (Gilboy, Heinerichs, and Pazzaglia 2015; Joy et al. 2023) and positive effect on reducing dropout rates (López-Pérez, Pérez-López, and Rodríguez-Ariza 2011). Contrary to expectations, subsequent research confirms that, akin to traditional study outcomes, blended curriculum cohorts display substantially diminished satisfaction with their overall study experience, highlighting that the present iteration of online teaching technologies falls short of being a "panacea for higher education challenges" (Chingos et al. 2017).

Further challenges persist, particularly concerning educators' apprehension regarding increased workload and students' struggles with SRL (Hill, Riha, and Wysocki 2014; A Rahman et al. 2015) contrasting with the fact that when adequately used it can optimize educators' time and quality of the teaching process (Buran and Evseeva 2015). Successful FC deployment necessitates proactive academic support to scaffold students' engagement with learning materials (Jovanovic et al. 2019; Sletten 2017). Furthermore, academics need to actively and in a coordinated manner engage students to facilitate social interactions (Finlay, Tinnion, and Simpson 2022). Insufficient SRL skills hinder students' ability to effectively manage pre-class activities, impeding participation and learning outcomes (Mason, Shuman, and Cook 2013; McLaughlin et al. 2013)

Thorough course design, enriched with interactive online activities and instructor scaffolding, fosters SRL development (Lock et al. 2017; Cho, Kim, and Choi 2017). In the FC context, where autonomous learning is encouraged, students' adeptness in time management and strategic learning approaches are pivotal for academic success (Connor, Newman, and Deyoe 2014). Nonetheless, students may find it challenging adhering to prescribed online study schedules, affecting engagement and performance (You 2016; Jovanovic et al. 2019; Panzarasa et al. 2016) while the lack of live and reliable information about their diversity in personal motivations makes a gap in addressing those needs in the course design (Vanslambrouck et al. 2018).

Collaborative Learning (CL) complements FC by nurturing essential skills like problem-solving, teamwork, and communication, vital in engineering education fostering inclusivity and peer learning (Wieman 2019; Madland and Richards 2016).

Intentional Behaviour towards FC denotes students' willingness to engage with the FC model (Sletten 2017). Positive attitudes towards FC correlate with effective SRL strategies, underscoring the importance of aligning students' perceptions with learning objectives (Winne and Jamieson-Noel 2003). Blended learning practice reveals importance of the face-to-face (even brief) in managing and driving other learning activities (Baragash and Al-Samarraie 2018).

1.2 Context

Technical Operations Management is a mandatory module in the School of Engineering (SoE). The SoE uses a Learn-Apply-Reflect (LAR) model to structure learning in each module and the module was designed to meet these requirements:

a. Learn: intended to provide knowledge. A fortnightly face-to-face lecture provides content and scaffolding for the additional asynchronous online material on Moodle (the VLE) which provides additional depth through short videos, research papers and e-book chapters. The asynchronous learning requires students to demonstrate self-regulated learning (SRL) skills.
b. Apply: designed to encourage application of learning. Moodle contains activities/tasks/quizzes/questions aligned to the Learn SRL tasks and designed to deepen subject understanding and test knowledge. Again, SRL skills are required.
   'Apply' also occurs in the fortnightly face-to-face flipped classroom style seminars in which students collaborate to apply their knowledge and solve more challenging problems. Furthermore, these seminar activities are constructively aligned to the summative assessments.
c. Reflect: created to enable students to evaluate and self-assess their knowledge. Timetabled drop-in sessions, academic office hours and discussion forum (on Moodle) provide students with the opportunity to request further support and inform their self-directed study.

Therefore, the module (and VLE) is structured around 4 fortnightly learning cycles (weeks 1 and 10 introduce and conclude the module). Moodle is structured to mirror the LAR phases and has a consistent layout across the weeks. It should be noted the other modules concurrently studied whilst using LAR, maintain 3 one hour-long lectures each week and are all numerically based.

2 METHODOLOGY

2.1 The Study Aim

This longitudinal study examines the experience of 328 second year engineering students on a module in the UK. The study started in the autumn 2022 (year 1, 22-23), firstly to assess whether the implemented LAR Flipped classroom model that combines the teaching approaches of Flipped Classroom and Collaborative approach was perceived positively by students and secondly to explore how the students self-regulated their online experience (Cooke, et. al, 2024).

In response to the earlier research findings and student feedback, actions were implemented, and the study was repeated in academic year 23-24 (research study year 2). The specific changes focused on improving students' engagement with the VLE as follows: (i) simplification and consistency in Moodle asynchronimous material, (ii) forums to allow students ask questions on weekly material, (iii) videos shortened to 15-20 mins to maintain student interest and (iv) added Moodle activity progress indicators. Therefore, results will be critically compared between cohorts (22-23 versus 23-24).

2.2 Research question and Objectives

This study's primary research question is:

What are the students' perceptions of the LAR flipped classroom/Collaborative learning model?

The objectives are consistent with the previous study:

- Examine the students' perception of the interaction in the physical class (seminars) when the Flipped Classroom-LAR model is use.
- Explore how the students self-regulated their online learning experience. Identify the student's perception of the overall experience of the LAR-Flipped classroom model.

2.3 Methodological Approach

The research premise is based in objectivism; specifically, a pragmatism philosophical approach is adopted indicative of the research teams' ontology and epistemology in addition to the need to the focus on problem solving and informing future practice (Saunders, Lewis, and Thornhill 2019). Furthermore, positivism underpins a deductive approach. A mono-method quantitative study, using the pre-validated survey (Shih, Liang, and Tsai 2019) will be used to understand student perceptions of flipped classroom learning and their behaviours in online self-regulated learning. Permission to use the survey was sought and obtained.

2.4 Data Analysis

Likert-scale surveys (Shih, Liang, and Tsai 2019), with prior ethical approval, were administered online via Qualtrics during the week 9 seminars; and to ensure further consistency with the preceding year, students were advised about the study's purpose, confidentiality, and voluntary completion. The sample size was 80 students who attended week 9 seminar sessions, from which 75 students submitted their answers achieving a response rate of 94%. The answers were revised, and 24 answers were removed from the analysis during the cleaning process due to lack of

50% or more of the answers required from both questionnaires. This represents almost 16% of the cohort.

Responses from both questionnaires OSLQ- Online Self-Regulated Learning Questionnaire and PFCQ- Perception of Flipped Classroom Questionnaire, were analysed using SPSS and Excel.

OSLQ, consisted of 26 questions organised in six dimensions and PFCQ consisted of 17 questions organised in four dimensions (Shih, Liang and Tsai, 2019, Cooke, et al., 2024). Frequency, mean and standard deviation values were calculated for each question and dimension using the SPSS software and interpreted using the Table 1 shown below.

Table 1. Mean interpretation of the 5-point Likert type of questions (Mendoza et al. (2021)

5-point Likert scale	Mean range (μ)	Interpretation
1	1 – 1.80	Strongly disagree
2	1.81 – 2.60	Disagree
3	2.61 – 3.40	Neutral
4	3.41 – 4.20	Agree
5	4.21 – 5.00	Strongly Agree

3 RESULTS AND DISCUSSION

3.1 Online Self-Regulated Learning Questionnaire (OSLQ) results

The results from this first questionnaire (**Error! Reference source not found.**-full results available on request) suggest that students: manage well the aspects of online self-regulated learning that refers to setting goals(Goal setting dimension); study in an environment that is effective and suitable for online learning (Environment Structuring dimension); and are proactive seeking help from lecturers and colleagues to solve doubts encountered when using online learning (Help seeking dimension).

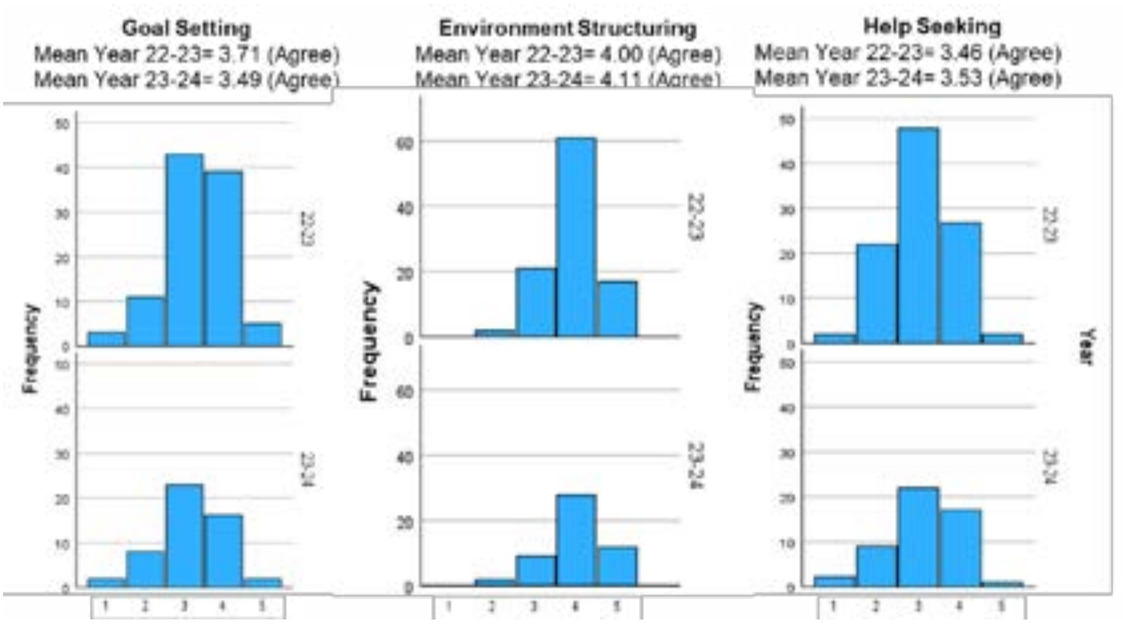

Figure 1. OSLQ results for Goal Setting, Environment Structuring and Help Seeking dimensions

Results in both academic years in the dimensions Task Strategy, Task Management and Self-Evaluation that show the lack of engagement with asynchronous material (see Figure 2). This behaviour can be observed specifically in the response to questions such as "*TS1-I prepare my questions before attending to seminars"* and *"TS2- I work through the problems in my online course on top of the set ones to master the course content*".

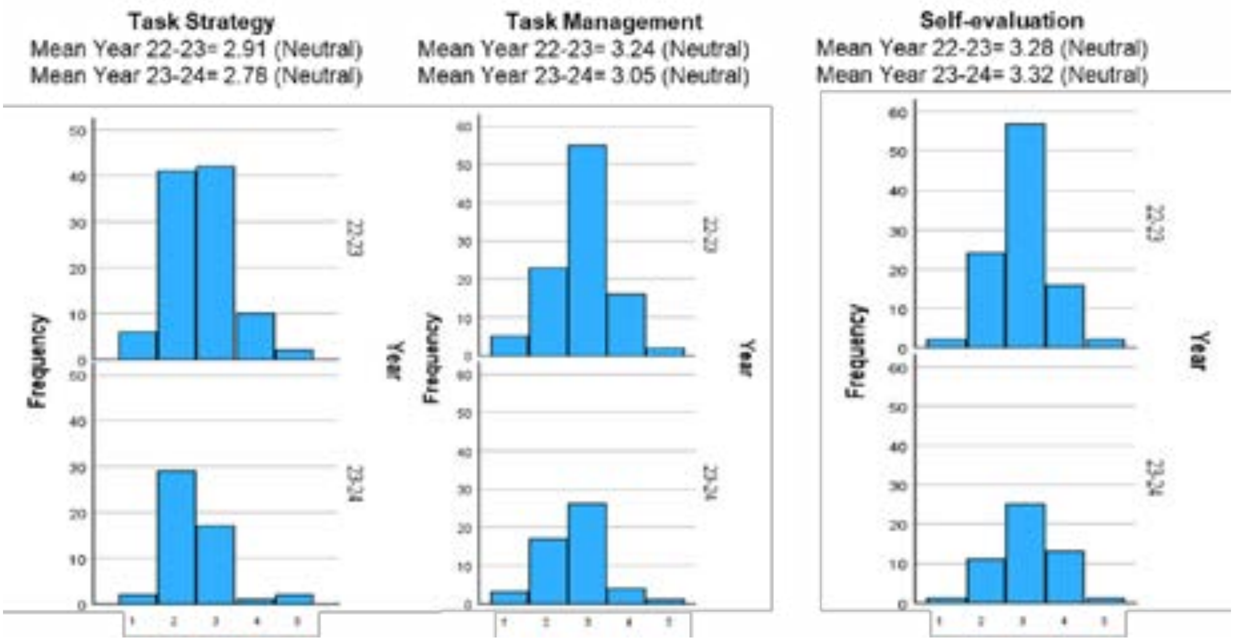

Figure 2.OSLQ results for Task Strategy, Task Management and Self-evaluation dimensions

Furthermore, the mean value for TS1 and TS2 decreases from year 22-23 to year 23-24 (TS1-year 22-23, $\mu=2.56$ to year 23-24 $\mu=2.13$ and TS2-year 22-23, $\mu=2.52$ to year 23-24, $\mu=2.43$). These results are in accordance with the lecturers' perception that the students from year 23-24 were less participative in class and demonstrated less evidence of using the material available online prior to the seminars.

Commensurate with the 22-23 study, the authors analysed the logs of access to online learning activities prior to seminars on Moodle. The percentage of students who accessed the asynchronous material provided prior to attending the fortnightly seminars was unsatisfactorily low (between 40% and only 6% of the whole cohort) and was dropping throughout the semester (Table 1).=

Table 2. Number of students actively engaging with the online material before the seminars and throughout the academic semester

Semester Week (out of 10)	**3**	**5**	**7**	**9**
Active use of the online resource before the f2f seminar				
AVG Active Engagements	130	25	24	19
% of the enrolled students	40	8	7	6
Active use of the online resource in the academic semester				
AVG Active Engagements	230	49	99	83
% of the enrolled students	70	15	30	25

Similar trends were observed in the literature (Jovanovic et al. 2019; Turhangil Erenler 2020; Wu et al. 2023). These findings agree with the behaviour observed by the authors and are in line with the questionnaire 1 results (**Error! Reference source not found.**). This validates the observation that, despite academic endeavours to enhance online resources, offer improved guidance to students in navigating the LAR model, and place increased emphasis on FC, there persists a deficiency in students' early engagement with the VLE and the LAR model. This can significantly affect the effectiveness of students' learning experience and their perception of usefulness of the FC combined approach as it is demonstrated further in the results from questionnaire 2.

3.2 Perception of Flipped Classroom Questionnaire (PFCQ) results

3.2.1. Interaction in face-to-face learning in class

Consistently, in both academic years, the results of the first dimension in PFCQ indicates that students value and perceive as positive the activities in the physical class. In addition, students indicated there is a positive impact from their participation and physical interaction with colleagues and lecturers on their learning (*Table 3*).

Table 3. Experience of the face-to-face seminar dimension results of the PFCQ

Code	***Description:*** ***Students perceive that in the physical class when using the Flipped Classroom model they...***	Mean (μ) Year 22-23	Mean (μ) Year 23-24
IPC1	Effectively exchange information and knowledge	*3.56*	*3.51*
IPC2	Get support from cooperative learning and group work with other participants.	*3.57*	*3.82*
IPC3	Easily get counselling and support of learning by the tutor.	*3.65*	*3.65*
IPC4	Learn more from my team members.	*3.45*	*3.41*

IPC5	Participate more in peer discussion that the lecturers tend to facilitate during the seminars.	*3.79*	*3.80*
IPC6	Can interact online and that the Online learning platform (Moodle) makes it easier the interaction with instructors and other students in the module.	*3.12*	*3.61*

Interestingly, year 23-24 results compared to those obtained in year 22-23, show a positive response to the changes implemented. In contrast to last year, in 23-24 most students agree that the use of Moodle makes it easier to interact with instructors and other students (Figure 3).

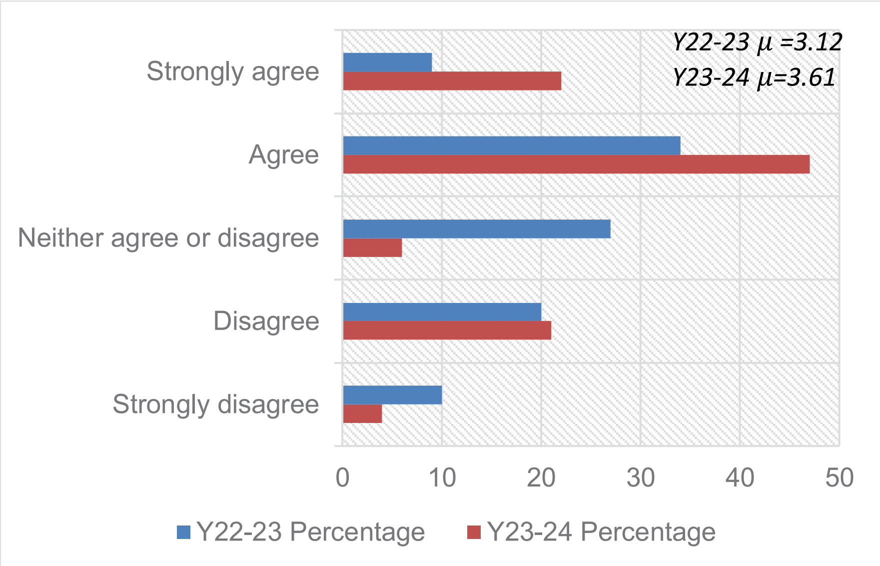

Figure 3. IPC6 Histogram of frequency results

3.2.3. Positive experience and Intentional Behaviours

Whilst the results of the Intentional behaviours in year 23-24 (IB1, IB2, IB3 and IB4 in Table 4) demonstrated, that students who engaged earlier with the online learning activities are largely satisfied with the overall learning experience using the LAR model and there is a consensus in feeling that the blended learning model used requires more self-regulated learning skills (PEFC4 in Table 5).

Table 4. Intentional Behaviours results for year 22-23 and 23-24

Code	**Intentional Behaviours – IB**	Mean (μ) Year 22-23	Mean (μ) Year 23-24
IB1	I feel I feel satisfied with flipped pedagogy.	*3.76*	*3.70*
IB2	I am satisfied feel I learn better in blended learning model.	*3.82*	*3.92*
IB3	I would like to continue using the FCM in my learning.	*3.76*	*3.84*
IB4	I would like to learn using the Moodle LAR activities as much as possible.	*3.65*	*3.92*

Table 5.PEFC results

Code	**Positive experience of Flipped Classroom - PEFC**	Mean (μ) Year 22-23	Mean (μ) Year 23-24
PEFC1	I feel in favour of participating in blend learning activities	*4.12*	*3.38*
PEFC2	I feel I learn better in blended learning model.	*3.76*	*3.23*
PEFC3	I feel that my learning time is more flexible with the use of the blended learning model.	*3.82*	*3.76*
PEFC4	I feel blended learning model requires more self-regulated learning skills.	*4.24*	*4.23*

These results demonstrated once again that the students are finding it difficult to adapt to the different mindset and to satisfy the demanding self-regulated learning skills of a combined FC and Collaborative learning delivery model.

It is worth noting that the consensus feeling that more self regulated skillls are required to learn using the combined approach (Table 5) could explain why even though the students are overall satisfied with the approach (Table 4), and would like to continue earning using the LAR model, the majority reported not to be in favour of participating in the online learning activities.

4 DISCUSSION

The positive findings associated with managing self-regulated learning, setting goals, a suitable study environment and seeking help to support online learning are consistent with research (He et al. 2022; Sletten 2017) and demonstrates the students are willing to engage. The challenges which result in failing to dedicate time in a consistent or structured manner to complete the online activities before the seminar also align to research (You 2016; Jovanovic et al. 2019). Whilst trends around low and reducing engagement with online learning material aligns to literature (Jovanovic et al. 2019; Turhangil Erenler 2020; Wu et al. 2023), this lack of engagement with asynchronous material before seminars impacted engagement in seminars and in turn learner satisfaction with the module; again, consistent with research (Sarker et al. 2023). This presents a challenge for the learning design which must be addressed; how can engagement with asynchronous online material prior to the seminars be enhanced? Additionally, how can students be equipped with self-regulated learning skills.

Furthermore, these results align to current literature that states FC encourages student collaboration and offers additional chances for teacher-student engagement through the teaching and learning process (Güler, Kokoç, and Önder Bütüner 2023; Cheng, Wu, and Su 2021; Okolie et al. 2022). Notably the updates to the VLE facilitated improvements in interactions.

5 CONCLUSIONS

The research aligns to the findings from research year 1 and indicates that students who engaged with the VLE prior face-to-face sessions found the LAR model useful and express overall satisfaction and intentions to continue using the LAR model.

Whilst there is evidence that the changes in VLE had a positive impact in students' engagement with asynchronous material prior to the face-to-face sessions, action is required to carry on supporting the transition from a traditional teaching approach to one that requires more self-regulated learning skills and externally motivated students to engage with the VLE. For future work the authors are also working on changes that involves linking and recognising engagement with VLE in summative assessment.

Despite lack of student engagement with the VLE, students find the seminars collaborative and activity led learning approach useful and agree the approach has a positive influence.

REFERENCES

A Rahman, Azlina, Baharuddin Aris, Mohd Shafie Rosli, Hasnah Mohamed, Zaleha Abdullah, and Norasykin Zaid. 2015. *Significance of Preparedness in Flipped Classroom*. *Advanced Science Letters*. Vol. 21. https://doi.org/10.1166/asl.2015.6514.

Artino, Anthony R., and Kenneth D. Jones. 2012. "Exploring the Complex Relations between Achievement Emotions and Self-Regulated Learning Behaviors in Online Learning." *The Internet and Higher Education* 15 (3): 170–75.

https://doi.org/10.1016/J.IHEDUC.2012.01.006.

Baragash, Reem Sualiman, and Hosam Al-Samarraie. 2018. "Blended Learning: Investigating the Influence of Engagement in Multiple Learning Delivery Modes on Students' Performance." *Telematics and Informatics* 35 (7): 2082–98. https://doi.org/10.1016/J.TELE.2018.07.010.

Broadbent, J., and W. L. Poon. 2015. "Self-Regulated Learning Strategies & Academic Achievement in Online Higher Education Learning Environments: A Systematic Review." *The Internet and Higher Education* 27 (October): 1–13. https://doi.org/10.1016/J.IHEDUC.2015.04.007.

Buran, Anna, and Arina Evseeva. 2015. "Prospects of Blended Learning Implementation at Technical University." *Procedia - Social and Behavioral Sciences* 206 (October): 177–82. https://doi.org/10.1016/J.SBSPRO.2015.10.049.

Cheng, Fei Fei, Chin Shan Wu, and Po Cheng Su. 2021. "The Impact of Collaborative Learning and Personality on Satisfaction in Innovative Teaching Context." *Frontiers in Psychology* 12 (September): 713497. https://doi.org/10.3389/FPSYG.2021.713497/BIBTEX.

Chingos, Matthew M., Rebecca J. Griffiths, Christine Mulhern, and Richard R. Spies. 2017. "Interactive Online Learning on Campus: Comparing Students' Outcomes in Hybrid and Traditional Courses in the University System of Maryland." *The Journal of Higher Education* 88 (2): 210–33. https://doi.org/10.1080/00221546.2016.1244409.

Cho, Moon Heum, Yanghee Kim, and Dong Ho Choi. 2017. "The Effect of Self-Regulated Learning on College Students' Perceptions of Community of Inquiry and Affective Outcomes in Online Learning." *The Internet and Higher Education* 34 (July): 10–17. https://doi.org/10.1016/J.IHEDUC.2017.04.001.

Cooke, G., Smith-Ortiz, A. and Mazurkiewicz, P. 2024 "Evaluation of a flipped classroom model base on students' perceptions: An undergraduate engineering module case study." In *UK and Ireland Engineering Education Research Network Conference Proceedings 2023. Coventry, UK: EERN Conference.* https://doi.org/10.31273/10.31273/9781911675167

Connor, Kenneth A., Dianna L. Newman, and Meghan Morris Deyoe. 2014. "Flipping a Classroom: A Continual Process of Refinement." In *ASEE Annual Conference and Exposition, Conference Proceedings*. Indianapolis, Indiana: ASEE Conferences. https://doi.org/10.18260/1-2--20506.

Finlay, Mitchell J., Daniel J. Tinnion, and Thomas Simpson. 2022. "A Virtual versus Blended Learning Approach to Higher Education during the COVID-19 Pandemic: The Experiences of a Sport and Exercise Science Student Cohort." *Journal of Hospitality, Leisure, Sport & Tourism Education* 30 (June): 100363. https://doi.org/10.1016/J.JHLSTE.2021.100363.

Flumerfelt, Shannon, and Greg Green. 2013. "Using Lean in the Flipped Classroom for At Risk Students." *Journal of Educational Technology & Society* 16 (1): 356–66. http://www.jstor.org/stable/jeductechsoci.16.1.356.

Gilboy, Mary Beth, Scott Heinerichs, and Gina Pazzaglia. 2015. "Enhancing Student Engagement Using the Flipped Classroom." *Journal of Nutrition Education and Behavior* 47 (1): 109–14. https://doi.org/10.1016/j.jneb.2014.08.008.

Güler, Mustafa, Mehmet Kokoç, and Suphi Önder Bütüner. 2023. "Does a Flipped Classroom Model Work in Mathematics Education? A Meta-Analysis." *Education and Information Technologies* 28 (1): 57–79. https://doi.org/10.1007/S10639-022-11143-Z/TABLES/5.

He, Jie, Tingjuan Ma, Yongliang Zhang, Lin Chen, and Yajuan Zhang. 2022. "Multivariate Research on Satisfaction Influencing Factors of Flipped Classroom Teaching Mode." *Frontiers in Artificial Intelligence and Applications* 352 (August): 156–72. https://doi.org/10.3233/FAIA220094.

Hill, Nikki, Susan Riha, and Mark Wysocki. 2014. *Teaching Physics to Environmental Science Majors Using a Flipped Course Approach*.

Jovanovic, Jelena, Negin Mirriahi, Dragan Gašević, Shane Dawson, and Abelardo Pardo. 2019. "Predictive Power of Regularity of Pre-Class Activities in a Flipped Classroom." *Computers & Education* 134 (June): 156–68. https://doi.org/10.1016/J.COMPEDU.2019.02.011.

Jowsey, Tanisha, Gail Foster, Pauline Cooper-Ioelu, and Stephen Jacobs. 2020. "Blended Learning via Distance in Pre-Registration Nursing Education: A Scoping Review." *Nurse Education in Practice* 44 (March). https://doi.org/10.1016/J.NEPR.2020.102775.

Joy, Praisy, Rajeev Panwar, R. Azhagiri, Asha Krishnamurthy, and Mallikarjun Adibatti. 2023. "Flipped Classroom – A Student Perspective of an Innovative

Teaching Method during the Times of Pandemic." *Educacion Medica* 24 (2). https://doi.org/10.1016/J.EDUMED.2022.100790.

Lage, Maureen J, Glenn J Platt, and Michael Treglia. 2000. "Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment." *The Journal of Economic Education* 31 (1): 30–43. https://doi.org/10.1080/00220480009596759.

Lock, Jennifer, Sarah Elaine Eaton, Elaine Kessy, Jennifer ; Lock, and Sarah Elaine; Eaton. 2017. "Fostering Self-Regulation in Online Learning in K-12 Education." *Northwest Journal of Teacher Education* 12 (2): 2. https://doi.org/10.15760/nwjte.2017.12.2.2.

López-Pérez, M. Victoria, M. Carmen Pérez-López, and Lázaro Rodríguez-Ariza. 2011. "Blended Learning in Higher Education: Students' Perceptions and Their Relation to Outcomes." *Computers & Education* 56 (3): 818–26. https://doi.org/10.1016/J.COMPEDU.2010.10.023.

Madland, Colin, and Griff Richards. 2016. "Enhancing Student-Student Online Interaction: Exploring the Study Buddy Peer Review Activity." *The International Review of Research in Open and Distributed Learning* 17 (3 SE-Research Articles). https://doi.org/10.19173/irrodl.v17i3.2179.

Mason, Gregory S., Teodora Rutar Shuman, and Kathleen E. Cook. 2013. "Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course." *IEEE Transactions on Education* 56 (4): 430–35. https://doi.org/10.1109/TE.2013.2249066.

McLaughlin, Jacqueline E, LaToya M Griffin, Denise A Esserman, Christopher A Davidson, Dylan M Glatt, Mary T Roth, Nastaran Gharkholonarehe, and Russell J Mumper. 2013. "Pharmacy Student Engagement, Performance, and Perception in a Flipped Satellite Classroom." *American Journal of Pharmaceutical Education* 77 (9): 196. https://doi.org/10.5688/ajpe779196.

Okolie, Ugochukwu Chinonso, Beth N Oluka, Fasina Bosede Oluwayemisi, Beatrice Adanna Achilike, and Chucks Marcel Ezemoyih. 2022. "Overcoming Obstacles to Collaborative Learning Practices: A Study of Student Learning in Higher Education-Based Vocational Education and Training." *International Journal of Training Research* 20 (1): 73–91. https://doi.org/10.1080/14480220.2021.1965904.

Panzarasa, Pietro, Bernard Kujawski, Edward J Hammond, and C Michael Roberts. 2016. "Temporal Patterns and Dynamics of E-Learning Usage in Medical Education." *Educational Technology Research and Development* 64 (1): 13–35. https://doi.org/10.1007/s11423-015-9407-4.

Sarker, Pramath Chandra, Md. Nur-E-Alam Siddique, Sabina Sultana, and Subrata Kumer Pal. 2023. "Comparison between Traditional Classroom and Flipped Classroom on Student's Engagement and Satisfaction." *International Journal of Multidisciplinary: Applied Business and Education Research* 4 (2): 624–35. https://doi.org/10.11594/IJMABER.04.02.29.

Saunders, M N K, Philip Lewis, and Adrian Thornhill. 2019. *Research Methods for Business Students*. Eighth. Harlow, England: Pearson.

Shih, Meilun, Jyh Chong Liang, and Chin Chung Tsai. 2019. "Exploring the Role of University Students' Online Self-Regulated Learning in the Flipped Classroom: A

Structural Equation Model." *Interactive Learning Environments* 27 (8): 1192–1206. https://doi.org/10.1080/10494820.2018.1541909.

Sletten, Sarah Rae. 2017. "Investigating Flipped Learning: Student Self-Regulated Learning, Perceptions, and Achievement in an Introductory Biology Course." *Journal of Science Education and Technology* 26 (3): 347–58. https://doi.org/10.1007/s10956-016-9683-8.

Sun, Pei Chen, Ray J. Tsai, Glenn Finger, Yueh Yang Chen, and Dowming Yeh. 2008. "What Drives a Successful E-Learning? An Empirical Investigation of the Critical Factors Influencing Learner Satisfaction." *Computers & Education* 50 (4): 1183–1202. https://doi.org/10.1016/J.COMPEDU.2006.11.007.

Turhangil Erenler, Hale H. 2020. "A Structural Equation Model to Evaluate Students' Learning and Satisfaction." *Computer Applications in Engineering Education* 28 (2): 254–67. https://doi.org/10.1002/CAE.22189.

Vanslambrouck, Silke, Chang Zhu, Koen Lombaerts, Brent Philipsen, and Jo Tondeur. 2018. "Students' Motivation and Subjective Task Value of Participating in Online and Blended Learning Environments." *The Internet and Higher Education* 36 (January): 33–40. https://doi.org/10.1016/J.IHEDUC.2017.09.002.

Wang, Chih-Hsuan, David M Shannon, and Margaret E Ross. 2013. "Students' Characteristics, Self-Regulated Learning, Technology Self-Efficacy, and Course Outcomes in Online Learning." *Distance Education* 34 (3): 302–23. https://doi.org/10.1080/01587919.2013.835779.

Wieman, Carl Edwin. 2019. "Expertise in University Teaching & the Implications for Teaching Effectiveness, Evaluation & Training." *Daedalus* 148 (4): 47–78. https://doi.org/10.1162/daed_a_01760.

Winne, Philip H., and Dianne Jamieson-Noel. 2003. "Self-Regulating Studying by Objectives for Learning: Students' Reports Compared to a Model." *Contemporary Educational Psychology* 28 (3): 259–76. https://doi.org/10.1016/S0361-476X(02)00041-3.

Wu, Yuhang, Xiaohui Xu, Jinyang Xue, and Ping Hu. 2023. "A Cross-Group Comparison Study of the Effect of Interaction on Satisfaction in Online Learning: The Parallel Mediating Role of Academic Emotions and Self-Regulated Learning." *Computers & Education* 199 (July): 104776. https://doi.org/10.1016/j.compedu.2023.104776.

You, Ji Won. 2016. "Identifying Significant Indicators Using LMS Data to Predict Course Achievement in Online Learning." *The Internet and Higher Education* 29 (April): 23–30. https://doi.org/10.1016/J.IHEDUC.2015.11.003.

Youhasan, Punithalingam, Yan Chen, Mataroria P. Lyndon, and Marcus A. Henning. 2022. "University Teachers' Perceptions of Readiness for Flipped Classroom Pedagogy in Undergraduate Nursing Education: A Qualitative Study." *Journal of Professional Nursing* 41 (July): 26–32. https://doi.org/10.1016/j.profnurs.2022.04.001.

CONCEPTUALISING AN INCLUSIVE MINDSET: A SCOPING REVIEW AND FRAMEWORK FOR ENGINEERING EDUCATION

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Keywords: *Inclusive Mindset, Engineering Education, Inclusive Design, Sustainable Engineering, Scoping Review*

ABSTRACT

Engineers have a particular role in fostering an inclusive society since engineering solutions can either advance or hinder inclusion. Educating engineers about inclusivity involves not only teaching inclusive principles but also fostering an inclusive mindset. However, the concept of an 'inclusive mindset' lacks a universally agreed-upon definition and conceptual framework. To address this gap, we conducted a scoping review of existing literature that discussed an inclusive mindset as their main theme to explore and clarify the concept of an 'inclusive mindset'. Our review encompassed 47 papers from diverse global regions and research domains, including education and organisation research. Data extraction and coding were conducted systematically, focusing on research areas, types of inclusivity addressed, definitions, related attributes, and factors influencing an inclusive mindset. Through numeric and thematic analysis, we provided insights into the prevalent themes and concepts surrounding an inclusive mindset. We then developed an inclusive mindset model to conceptualise our scoping review findings. This model offers a conceptual framework to identify factors influencing inclusivity and guide interventions aimed at educating inclusive mindsets among engineering students.

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1 INTRODUCTION

Engineers have a particular role in fostering an inclusive society since engineering solutions can either advance or hinder inclusion. Notably, inclusive design innovations not only provide products, services, and built environments that are accessible to all but also offer business opportunities to expand into new markets and cultivate long-term customer loyalty (Dong et al. 2004). Conversely, biased technology as shown in predictive software (Angwin et al. 2016), medical implants (Hutchison 2019), and facial recognition systems (Taati et al. 2019) perpetuates inequalities and exacerbates exclusion. These examples underscore the importance of educating an inclusive mindset and inclusive principles in engineering education.

Currently, the primary approach to teaching inclusivity in engineering education is through inclusive and universal design (Blaser et al. 2015; Clarkson et al. 2003; Valgeirsdottir 2021). These approaches not only teach students how to design inclusively but also aim to motivate them to do so. Some scholars (e.g., Nezafati et al. 2022; Valgeirsdottir 2021; Zallio and Clarkson 2021) refer to this latter process as fostering an 'inclusive mindset'. However, despite being widely discussed, the term ‘inclusive mindset’ lacks a universally agreed-upon definition. Existing definitions, such as Forsberg's (2022) workplace-oriented conceptualisation, may not fully encapsulate the nuances of inclusivity within engineering education. To better nurture an inclusive mindset in engineering students, we need first to clarify the constructs of an inclusive mindset.

Therefore, this study aims to develop an inclusive mindset model to represent various constructs underlying an inclusive mindset. We first explored the concept of an 'inclusive mindset’ through a scoping review of existing literature. Since the overall societal context can influence engineering solutions (Kille-Speckter and Nickpour 2022), the reviewed literature extends beyond engineering education research. The findings from the review then inform the development of the inclusive mindset model, encapsulating the diverse dimensions and implications of an inclusive mindset. Ultimately, this study seeks to provide a framework that guides the enhancement of the interventions, tools, and methods for promoting inclusivity within engineering design research, education, and practice.

2 METHODOLOGY

This study is part of a larger research project aimed at enhancing inclusive mindset educational strategies (e.g., workshops, courses, and learning materials) in engineering education. Following an iterative approach of Educational Design Research (McKenney and Reeves 2019), this study is situated in the analysis/orientation phase. To clarify an ‘inclusive mindset’ concept, we employed Arksey and O'Malley's (2005) five-stage framework for scoping reviews.

2.1 Identifying the Initial Research Questions

The focus of this review was to identify the key constructs of an 'inclusive mindset' and its related attributes. The research questions guiding this inquiry were:

RQ: How might we conceptualise the constructs of an inclusive mindset?

1.1 In which research areas or disciplines has the concept of an inclusive mindset been discussed, and to what extent?

1.2 What kind of inclusivity (e.g., disability, gender, age) are addressed?

1.3 What are the definitions and conceptualisations of an inclusive mindset?

1.4 What are the related attributes of ‘inclusive mindset?

1.5 What influences an inclusive mindset?

2.2 Identifying Relevant Studies

A systematic search was conducted across three major databases: Scopus, Web of Science, and Google Scholar. The search strategy focused exclusively on identifying studies that explicitly discussed the search terms "inclusive mindset" or "inclusive mind-set" as their primary theme, whether in the title, abstracts, or keywords. As societal context can influence engineering solutions (Kille-Speckter and Nickpour 2022), we did not limit our search to engineering education papers alone. This broader scope allowed us to capture diverse perspectives on the inclusive mindset concept, thereby enhancing the current understanding and practices of inclusivity in engineering education. Both published and unpublished literature were considered for inclusion. This search yielded 65 results in total (38 from Scopus, 12 from Web of Science, and 15 from Google Scholar). After duplicate records were removed, 47 relevant papers were identified.

2.3 Study Selection

Studies were included if they addressed the concept of an inclusive mindset in any context or domain in the title, abstracts, or keywords.

2.4 Charting the Data

We conducted data extraction from the reviewed studies to gather bibliographic details, such as authors, title, year of publication, and document types, along with responses to the five guiding research questions. The extracted data was manually coded and organised using Microsoft Excel.

The coding process followed an inductive approach, where key information from the studies was systematically categorised to facilitate further analysis. The categories included research areas and related terms, types of inclusivity addressed, definitions of an inclusive mindset, related attributes of an inclusive mindset, and factors influencing an inclusive mindset. As part of this iterative approach, the coding categories were continuously developed, revised, and refined over time to accommodate new insights emerging from the data. This iterative process allowed for a comprehensive exploration of coding categories, ensuring a thorough understanding of the reviewed literature (Thomas 2003).

To ensure the reliability and validity of the coding process, a subset of the papers was independently coded by the second author. The second author conducted the coding process without access to the initial codes generated by the first author to minimise potential bias. Following the completion of coding, a comparison was made between the codes. Discrepancies were identified and resolved through collaborative discussion and consensus-building. This process aims to enhance the consistency and accuracy of the coding process and validate the reliability of the findings.

2.5 Collating, Summarising, and Reporting the Results

We conducted a numerical and thematic analysis of the coded data (Levac et al. 2010). The numerical analysis involves frequency counts to quantify the occurrence of different categories and concepts within the data. Meanwhile, thematic analysis qualitatively searches for themes or patterns within the dataset concerning research questions (Braun and Clarke 2006). Detailed findings from these analyses are reported in the next section.

3 FINDINGS

The scoping review comprised 47 papers from diverse geographical regions, reflecting a global engagement with an inclusive mindset concept. The literature encompassed various publication types, including journal articles, conference proceedings, book chapters, and theses.

Temporal analysis revealed an increasing trend in scholarly engagement with an inclusive mindset concept. While the earliest paper was from 2002, the major contributions were published post-2020 (see *Figure 1*).

The key findings according to each guiding research question are presented below.

3.1 Research Areas or Disciplines

The concept of an inclusive mindset has been mentioned across various research areas and disciplines, with a predominant focus on education and organisation contexts (see *Figure 2*).

Over two-thirds of the papers (n=32) discussed an inclusive mindset in educational settings, covering topics such as inclusive pedagogy, educational policy, and curriculum development. Within this category, higher education emerged as the most prominent sub-discipline, comprising 20 papers. These studies addressed an inclusive mindset in multiple disciplines including engineering education (n=7), teacher education (n=4), and management education (n=2). Additionally, other education levels (e.g., primary and secondary education), and areas (e.g., special and music education), were also represented.

Organisational contexts accounted for approximately one-third of the literature (n=11). Among these papers, four addressed the role of inclusive mindsets in fostering diverse and inclusive workplace environments. An additional four papers focused on inclusive leadership, highlighting the significance of leaders' attitudes and behaviours in shaping inclusive organisational cultures. The remaining studies discussed inclusive mindsets within the context of recruitment processes, emphasising the necessity for unbiased and inclusive hiring approaches.

A small subset of the literature (n=3) discussed the concept of an inclusive mindset within the realm of accessibility, addressing issues related to web accessibility, museum design, and architectural accessibility.

Lastly, a few papers explored inclusive mindset within other domains such as AI, tourism, and social quality. Notably, several studies addressed more than one research area, demonstrating the multifaceted nature of the inclusive mindset concept across diverse contexts.

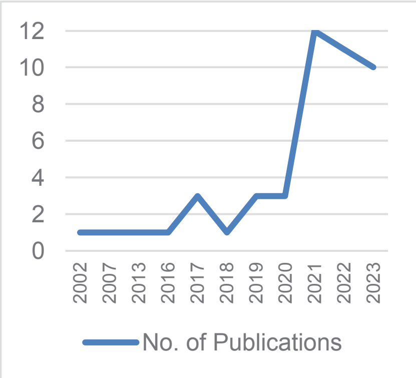

Fig. 1. Publications per year

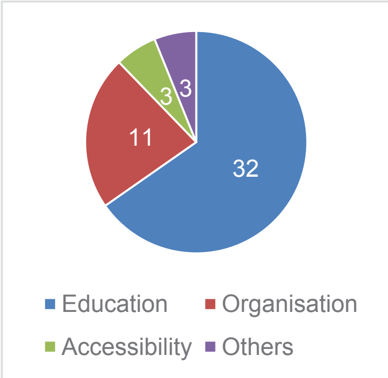

Fig. 2. Research area

3.2 Types of Inclusivity

An analysis of the reviewed literature uncovered various types of inclusivity and beneficiary groups when discussing an inclusive mindset.

Slightly more than half of the papers (n=25) focused on a specific dimension of inclusivity or targeted groups. Disabilities emerged as a prevalent theme in these papers, with 14 studies centring their discussions on individuals with disabilities (e.g., physical impairments, learning disparities, and neurodiversity). Additionally, the remaining 11 papers in this category addressed various types of inclusivity including genders, sexual orientations, races, cultural and sociological backgrounds, opinions, and individuals with criminal records. While these studies emphasised specific forms of inclusivity, many also acknowledged other kinds of inclusivity in their papers.

Conversely, another half of the papers (n=22) adopted a broader perspective. They discussed multiple types of inclusivity or the general concept of inclusion. These types of inclusivity included, but were not limited to, disabilities, gender, sexuality, age, generation, ethnicity, culture, region, socioeconomic status, physiological differences (e.g., left-handed, obese), organisational tenure, political view, and academic background. Some studies explored general inclusion principles, referring to terms such as 'under-represented groups', 'different social identities', 'team inclusivity', and 'diverse learners'. Besides, two papers did not explicitly state the types of inclusivity they addressed but referred to an 'inclusive mindset' as part of an Essential Skill (Chan et al. 2023) and a trait of Generation Z (Seibert 2021).

3.3 Inclusive Mindset Definition

Among the 47 papers reviewed, only one study by Forsberg (2022) provided an explicit definition of an inclusive mindset. Derived from the concept of workplace inclusion, her definition emphasised actions that conveyed perceptions of value and respect for different perspectives. Additional 10 papers implied that an inclusive mindset involved learning and embracing differences (Eadens and Eadens 2016), providing flexibility (Wiebusch 2013; Young Jones 2022), embracing social justice (Cherrez et al. 2023), respecting diversity (Cohen Carrus 2017; Purwanto et al. 2019), designing with accessibility in mind (Altinier et al. 2022), serving all stakeholders (Prasad et al. 2019), pursuing diversity and equity (Bosio 2023), and thinking inclusively (Valgeirsdottir 2021).

Nevertheless, most papers did not offer explicit definitions of an inclusive mindset. This absence may have stemmed from an assumption that the term is widely understood; however, our review demonstrated a diverse range of interpretations among scholars. This dissimilarity underscores the complexity of the concept and the necessity for further clarification and exploration of its related attributes.

3.4 Related Attributes of an Inclusive Mindset

A content analysis of the 47 reviewed papers exposed a wide range of attributes associated with an inclusive mindset. These attributes can be classified into two intertwined categories: invisible and visible.

3.4.1 Invisible Attributes

Invisible attributes encompassed cognitive facets such as motivations, awareness, emotions, attitudes, and viewpoints that exist within an individual's mind. They are essential components of an inclusive mindset as they constitute the internal mechanisms that propel inclusive behaviour. These invisible attributes included open-mindedness, awareness of biases and social issues, self-reflection, empathy for diverse individuals, inclusive competencies and knowledge, inclusion and diversity value, positive attitudes and feelings towards inclusion and diversity, respect, sensitivity, compassion, and acceptance.

3.4.2 Visible Attributes

Visible attributes are observable actions or behaviours that demonstrate inclusivity. They serve as tangible indicators of an individual's inclusive mindset. These visible attributes included designing with accessibility in mind, providing flexibility, involving others, challenging current approaches, creating supportive relationships, using inclusive language, going beyond legal requirements, and treating others with respect.

3.5 Factors Influencing an Inclusive Mindset

An analysis of the literature revealed that an inclusive mindset is influenced by both internal and external factors.

3.5.1 Internal Factors

Internal factors encompass individuals' attributes and characteristics, such as self-reflection and awareness, attitude and beliefs, understanding, intention and motivation, competency, personality traits, bias and assumptions, feeling, relationship, learning, experience, and sense-making.

3.5.2 External Factors

On the other hand, external factors include broader societal influences, such as learning intervention, social and work environment, standard and dominant practice, social norms, regulatory framework, resources and barriers, interaction with diverse individuals, global trends, and communication.

A table summarising the references to those related attributes and factors can be found in the appendix.

4 AN INCLUSIVE MINDSET MODEL

We developed an inclusive mindset model to conceptualise the findings of the scoping review. The model intends to identify the factors influencing the development of an inclusive mindset and its translation into inclusive behaviours. While the model is still a work in progress, the initial draft is presented below.

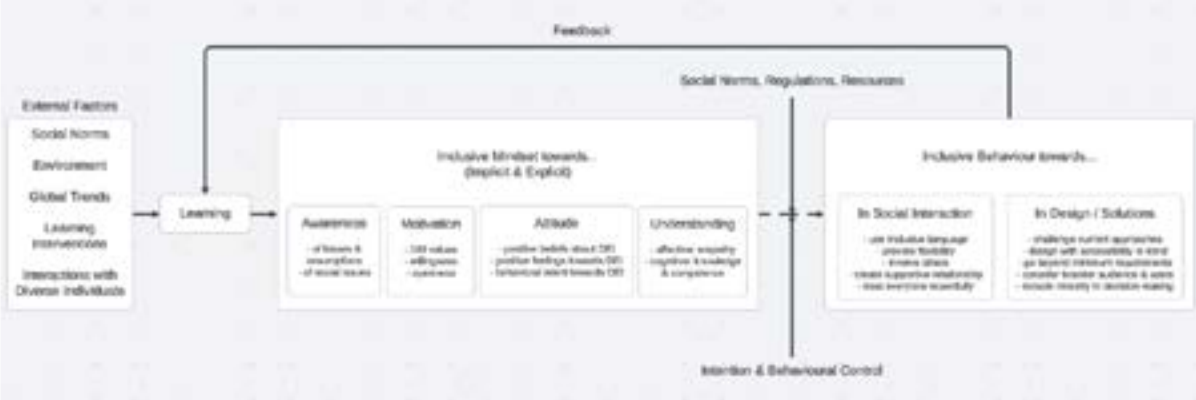

Fig. 3. An inclusive mindset model (version 1)

The model is structured into three main sections: the factors influencing an inclusive mindset, the constructs of an inclusive mindset, and the manifestation of inclusive behaviour.

4.1 The Factors Influencing an Inclusive Mindset

According to the findings in *section 3.5*, an inclusive mindset is shaped by various external factors, including social norms, cultural influences, global trends, learning interventions (e.g., training or education programmes), as well as interactions with individuals with diverse backgrounds and abilities. Learning from these experiences and surroundings, people form a mindset that either supports or opposes inclusion. We define the mindset that supports inclusivity as an inclusive mindset.

4.2 The Constructs of an Inclusive Mindset

An inclusive mindset consists of awareness, motivation, attitude and understanding. These constructs are informed by the findings presented in *section 3.4.1.*

Awareness refers to individuals being aware of their biases and social issues. Motivation involves valuing diversity and demonstrating a willingness to learn about differences (i.e., openness). Attitude has three main components: cognitive, affective and behavioural (Eagly and Chaiken 1998). Thus, attitudes within an inclusive mindset comprise positive beliefs about DEI and people with different backgrounds, positive feelings towards them, and intention to behave accordingly. Understanding encompasses both affective empathy and cognitive knowledge and competence in inclusion principles and practices.

An inclusive mindset can exist implicitly or explicitly. One may believe that they value inclusiveness but have an implicit bias towards some minority groups. Additionally, an inclusive mindset varies depending on the population under consideration. Individuals may exhibit inclusivity towards certain groups but not others.

4.3 The Manifestation of Inclusive Behaviour

While an inclusive mindset lays the foundation for inclusive behaviour, its translation into action is influenced by external and internal factors. External factors include social norms, cultural expectations, regulatory frameworks, and resources. Meanwhile, internal factors encompass intentions and behavioural control.

Based on the findings in *section 3.4.2*, inclusive behaviour can manifest in both social interactions and design solutions. Examples of inclusive behaviour in social interaction include using inclusive language, accommodating diverse needs, treating others respectfully, and actively involving individuals from different backgrounds. Inclusive behaviour can also be observed in design solutions, such as products, innovations, learning interventions, and policies. This inclusive behaviour often impacts broader audiences and involves challenging conventional approaches, prioritising accessibility, going beyond minimum requirements, and including under-represented groups in a decision-making process.

Lastly, feedback received from engaging in inclusive behaviours further reinforces or prohibits the development of an inclusive mindset.

5 DISCUSSION AND CONCLUSION

This study explored the concept of an 'inclusive mindset' through a scoping review of existing literature. Our primary objective was to conceptualise an inclusive mindset and provide a structured framework for enhancing interventions, tools, and methods promoting inclusivity within engineering education.

To our knowledge, this is the first study that provides a conceptual framework of an inclusive mindset based on a systematic literature search. As our literature search did not focus exclusively on engineering education, it aids in understanding the concept of an inclusive mindset from a broader perspective. We found discrepancies in the meaning of an inclusive mindset even within engineering education literature. Therefore, we took a broader approach to define an inclusive mindset as a mindset that supports inclusivity. This definition differs from Forsberg's (2022) definition of an inclusive mindset as it covers contexts beyond workplace interpersonal relationships. In engineering education, an inclusive mindset is needed in both interpersonal interactions and design practices (Nezafati et al. 2022).

While our inclusive mindset definition is broad, our inclusive mindset model offers a structured framework for identifying the constructs of an inclusive mindset, its influencing factors, and its translation into inclusive behaviours. Educators can use this model to analyse and enhance their pedagogical approaches, measurement frameworks, and related policies. For example, they can examine whether their learning programmes address all four constructs (awareness, motivation, attitude, and understanding) of an inclusive mindset or identify specific areas for improvement. It can also serve as a guideline for setting learning objectives and developing measurement tools.

The model also calls for attention to other factors influencing an inclusive mindset. Six of the seven papers that discussed an inclusive mindset in engineering education in our review attempted to foster an inclusive mindset through interventions including learning programmes (Nezafati et al. 2020; Nezafati et al. 2021; Nezafati et al. 2022, Wu 2021), learning materials (Valgeirsdottir 2021), and virtual reality (Vignola et al. 2019). However, factors beyond these learning interventions, such as social norms, regulatory frameworks, and institutional resources, also play a crucial role in shaping an inclusive mindset. Furthermore, even with the successful adoption of an inclusive mindset, its translation into inclusive behaviour depends largely on external factors. For instance, Moriarty (2007) found that lack of time and resources are significant barriers for STEM faculty members in adopting inclusive pedagogy. Thus, to successfully promote inclusivity in engineering education, it is important to consider environmental factors such as social norms, regulatory frameworks, and resources that facilitate or hinder an inclusive mindset. More research is needed in this area.

In conclusion, our research offers valuable insights for both theory and practice. Through a comprehensive scoping review, we have clarified the multifaceted nature of an inclusive mindset, highlighting its various dimensions and the factors that shape its development. By synthesising this knowledge into an inclusive mindset model, we provide a practical framework for stakeholders to understand and promote inclusivity within engineering education. This research lays the foundation for future studies aimed at validating the model and exploring diverse dimensions of inclusivity within engineering education. By implementing this model, engineering educators can enhance the inclusivity of their teaching practices and learning environment to better prepare students to develop accessible and equitable technologies.

REFERENCES

Altinier, Armony, Estella Oncins, Gabriele Sauberer, and Tracey Mehigan. 2022. “Demystifying Digital Accessibility and Fostering Inclusive Mindsets. Compliance with the European Standard for Digital Accessibility EN 301 549.” In *Systems, Software and Services Process Improvement*, edited by Murat Yilmaz, Paul Clarke, Richard Messnarz, and Bruno Wöran, 1646:595–609. Communications in Computer and Information Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-15559-8_42.

Angwin, Julia, Jeff Larson, Surya Mattu, and Lauren Kirchner. 2016. “Machine Bias.” ProPublica. May 23, 2016. https://www.propublica.org/article/machine-bias-risk-assessments-in-criminal-sentencing.

Arinaitwe, Judith, and Arthur Ahumuza. 2023. “Girl-Child Inclusive Mindset Change Education in Uganda.” https://ir.bsu.ac.ug//handle/20.500.12284/574.

Arksey, Hilary, and Lisa O’Malley. 2005. “Scoping Studies: Towards a Methodological Framework.” *International Journal of Social Research Methodology* 8 (1): 19–32. https://doi.org/10.1080/1364557032000119616.

Ashton-Hay, Sally, and Dylan Williams. 2023. “What Student Voice Is and Is Not: Connecting Dialogue to Evidence-Based Practice and Inclusive Mindsets.” *Journal of University Teaching & Learning Practice* 20 (6). https://doi.org/10.53761/1.20.6.1.

Bandyopadhyay, Kaushik Ranjan, Kasturi Das, and Ritika Mahajan. 2021. “Addressing Diversity, Equity and Inclusion (DEI) through Service Learning in Management Education: Insights from India.” *International Journal of Educational Management* 36 (4): 470–94. https://doi.org/10.1108/IJEM-08-2021-0327.

Blake-Beard, Stacy, Mary Shapiro, and Cynthia Ingols. 2021. “A Model for Strengthening Mentors: Frames and Practices.” *International Journal of Environmental Research and Public Health* 18 (12): 6465. https://doi.org/10.3390/ijerph18126465.

Blaser, Brianna, Katherine Steele, and Sheryl Burgstahler. 2015. “Including Universal Design in Engineering Courses to Attract Diverse Students.” In *2015 ASEE Annual Conference and Exposition Proceedings*, 26.935.1-26.935.12. Seattle, Washington: ASEE Conferences. https://doi.org/10.18260/p.24272.

Blaskova, Lenka Janik, and Jenny L Gibson. 2023. “Children with Language Disorder as Friends: Interviews with Classroom Peers to Gather Their Perspectives.” *Child Language Teaching and Therapy* 39 (1): 39–57. https://doi.org/10.1177/02656590221139231.

Bosio, Emiliano. 2024. “Leveraging Online Teaching and Learning to Foster Critical Global Citizenship Education: Higher Education Faculty’s Perceptions and Practices from Japan.” *Journal of Creative Communications* 19 (1): 43–58. https://doi.org/10.1177/09732586231191027.

Bradford, Lorena, Abigail Diaz, and Ruth Schilling. 2021. “Expanding Museum Communities: International Perspectives on Access in Exhibition Design and Public Programs.” *Journal of Museum Education* 46 (1): 38–47. https://doi.org/10.1080/10598650.2020.1842624.

Braun, Virginia, and Victoria Clarke. 2006. “Using Thematic Analysis in Psychology.” *Qualitative Research in Psychology* 3 (2): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Brooks, Benita R., and Abbie Strunc. 2022. “Do I Lead With an Inclusive Mindset?: Higher Education Department Chairs Reflect on Their Leadership.” In *Advances in Higher Education and Professional Development*, edited by Stephanie P. Huffman, Denise D. Cunningham, Marjorie Shavers, and Reesha Adamson, 18–33. IGI Global. https://doi.org/10.4018/978-1-6684-3819-0.ch002.

Chan, David Y., Nina T. Dorata, and Mark M. Ulrich. 2023. “The Essential Skills for Candidates Entering the Accountancy Profession:” In *Advances in Finance, Accounting, and Economics*, edited by Nina T. Dorata, Richard C. Jones, Jennifer Mensche, and Mark M. Ulrich, 1–13. IGI Global. https://doi.org/10.4018/978-1-6684-5483-1.ch001.

Cherrez, Nadia Jaramillo, Elisabeth Babcock McBrien, and Christine Scott. 2023. “Cultivating a Mindset for Inclusive Learning Design.” In *Toward Inclusive Learning Design*, edited by Brad Hokanson, Marisa Exter, Matthew M. Schmidt, and Andrew A. Tawfik, 31–41. Educational Communications and Technology: Issues and Innovations. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-37697-9_3.

Chitra K.N. and Chandra Mohan A. 2017. “ORGANIZATIONAL CULTURE AND ITS INFLUENCE ON WORKPLACE DIVERSITY AND INCLUSION.” *INTERNATIONAL JOURNAL OF CIVIL ENGINEERING AND TECHNOLOGY (IJCIET)* 8 (8): 1032–38.

Chng, Huang Hoon, Katarina Mårtensson, and Brenda Leibowitz. 2020. “Leading Change from Different Shores: The Challenges of Contextualizing the Scholarship of

Teaching and Learning." *Teaching and Learning Inquiry* 8 (1): 24–41. https://doi.org/10.20343/teachlearninqu.8.1.3.

Clarkson, John, Keates, Simeon, Coleman, Roger, and Lebbon, Cherie, eds. 2003. *Inclusive Design: Design for the Whole Population*. London ; New York: Springer.

Cohen Carrus, Tali. 2017. "Cultivating an Inclusive Mindset in Your Jewish Community: Turning Good Intentions into Tangible Outcomes." Bank Street College of Education. https://educate.bankstreet.edu/independent-studies/188.

Culp, Mara E., and Sara K. Jones. 2023. "Creativity Is Instrumental: Instrument-Specific Strategies and Suggestions for Assisting Learners with Physical Disabilities and Differences in General and Instrumental Music." *Music Educators Journal* 110 (1): 41–53. https://doi.org/10.1177/00274321231199411.

Dodge, Autumn M. 2017. "Reading Toward Equity: Creating LGBTQ+ Inclusive Classrooms Through Literary and Literacy Practices." In *Literacy Research, Practice and Evaluation*, edited by Evan Ortlieb and Earl H. Cheek, 135–54. Emerald Publishing Limited. https://doi.org/10.1108/S2048-045820170000008007.

Dong, Hua, Simeon Keates, and P. John Clarkson. 2004. "Inclusive Design in Industry: Barriers, Drivers and the Business Case." In *User-Centered Interaction Paradigms for Universal Access in the Information Society*, edited by Christian Stary and Constantine Stephanidis, 3196:305–19. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-30111-0_26.

Eadens, Danielle M., and Daniel W. Eadens. 2016. "(Dis)Ability in the Elementary School Classroom: Embracing an Inclusive Mindset." In *Social Justice Instruction*, edited by Rosemary Papa, Danielle M. Eadens, and Daniel W. Eadens, 247–57. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-12349-3_22.

Emmers, Elke, Dieter Baeyens, and Katja Petry. 2021. "The Subjective Norm and Attitudes of Preservice Teachers Toward Pupils With a Disability: An Experiment Based on the Cognitive Dissonance Theory." *Australasian Journal of Special and Inclusive Education* 45 (1): 49–61. https://doi.org/10.1017/jsi.2020.18.

Forsberg, Elin. 2022. "Assessing Inclusive Mindset : The Development and Initial Validation of the Inclusive Mindset Situational Judgement Test." Master's Thesis, Uppsala University. https://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-500180.

Hutchison, Katrina. 2019. "Gender Bias in Medical Implant Design and Use: A Type of Moral Aggregation Problem?" *Hypatia* 34 (3): 570–91. https://doi.org/10.1111/hypa.12483.

Israel, Maya, Rui Huang, Janice Mak, Andrew B. Bennett, and Richard T. Bex. 2023. "A Community of Practice for Elementary Teachers Promoting Inclusion of Students with Disabilities in CS Instruction." In *Proceedings of the 54th ACM Technical Symposium on Computer Science Education V. 2*, 1280. SIGCSE 2023. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3545947.3576226.

Japar, Muhammad, Hermanto Hermanto, Siti Muyaroah, Heni Rita Susila, and Hendra Alfani. 2023. "Digital Literacy-Based Multicultural Education through Civic

Education in Indonesian Junior High Schools." *Journal of Social Studies Education Research* 14 (4): 328–49.

Jefferson-Buchanan, Rachael. 2022. "Teaching Fundamental Movement Skills Through Play-Based Pedagogy." *Journal of Physical Education, Recreation & Dance* 93 (8): 28–33. https://doi.org/10.1080/07303084.2022.2108171.

Jones Young, Nicole C. 2022. "Adapting a New Inclusive Mindset in the Hiring Process." In *Now Hiring*, by Nicole C. Jones Young, 29–42. Emerald Publishing Limited. https://doi.org/10.1108/978-1-80262-085-620221004.

Kille-Speckter, Luka, and Farnaz Nickpour. 2022. "The Evolution of Inclusive Design: A First Timeline Review of Narratives and Milestones of Design for Disability." *DRS Biennial Conference Series*, June. https://dl.designresearchsociety.org/drs-conference-papers/drs2022/researchpapers/255.

Kopmann, H., and H. Zeinz. 2018. "Special Needs and Inclusive Education from the Perspective of Teachers: What Attitudinal Factors Make up an Inclusive Mindset?" In *Progress in Education*, 50:47–78.

La Fors, Karolina. 2022. "Toward Children-Centric AI: A Case for a Growth Model in Children-AI Interactions." *AI & SOCIETY*, October. https://doi.org/10.1007/s00146-022-01579-9.

Levac, Danielle, Heather Colquhoun, and Kelly K O'Brien. 2010. "Scoping Studies: Advancing the Methodology." *Implementation Science* 5 (1): 69. https://doi.org/10.1186/1748-5908-5-69.

Lowy, Rachel, Lan Gao, Kaely Hall, and Jennifer G Kim. 2023. "Toward Inclusive Mindsets: Design Opportunities to Represent Neurodivergent Work Experiences to Neurotypical Co-Workers in Virtual Reality." In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, 1–17. CHI '23. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3544548.3581399.

Malhotra, Smitu, and Venugopal Pingali. 2020. "Rural Immersion Program in India: Integrating Management Education with Community." *Development and Learning in Organizations: An International Journal* 34 (2): 13–15. https://doi.org/10.1108/DLO-08-2019-0200.

Massouti, Ayman. 2021. "A New-Institutional Analysis of Inclusion Policy Enactment in Teacher Education: A Case from Ontario." *Canadian Journal of Educational Administration and Policy / Revue Canadienne En Administration et Politique de l'éducation*, no. 195, 17–30. https://doi.org/10.7202/1075670ar.

McKenney, Susan E., and Thomas C. Reeves. 2019. *Conducting Educational Design Research*. Second edition. London ; New York: Routledge/Taylor & Francis Group.

Moriarty, Mary A. 2007. "Inclusive Pedagogy: Teaching Methodologies to Reach Diverse Learners in Science Instruction." *Equity & Excellence in Education* 40 (3): 252–65. https://doi.org/10.1080/10665680701434353.

Nezafati, Maysam, Mel Chua, and Joseph M. LeDoux. 2020. "WIP: A Case Study of Integrating Inclusive Engineering Skills into a Middle-Years Biomedical Engineering Course via Model-Based Reasoning." In . https://peer.asee.org/wip-a-case-study-of-integrating-inclusive-engineering-skills-into-a-middle-years-biomedical-engineering-course-via-model-based-reasoning.

Nezafati, Maysam, Joseph M. LeDoux, Kelvin D'wayne Pierre, and Katherine Tsai Shook. 2021. "WIP: Integration of Inclusive Mindset in a Middle-Year Biomedical Engineering Course: A Study Over Healthcare Disparities via Story-Driven Learning." In . https://peer.asee.org/wip-integration-of-inclusive-mindset-in-a-middle-year-biomedical-engineering-course-a-study-over-healthcare-disparities-via-story-driven-learning.

Nezafati, Maysam, Sara Schley, and Joseph M Le Doux. 2022. "Responsible Innovation in Biomedical Engineering: A Value Sensitive Design Intervention." In *2022 IEEE Frontiers in Education Conference (FIE)*, 1–8. Uppsala, Sweden: IEEE. https://doi.org/10.1109/FIE56618.2022.9962507.

Nicole C. Young Jones. 2022. "Adapting a New Inclusive Mindset in the Hiring Process." In *Now Hiring*, 29–42. Emerald Publishing Limited. https://doi.org/10.1108/978-1-80262-085-620221004.

Ochrach, Chase, Kathryn Thomas, Brian Phillips, Ngonidzashe Mpofu, Tim Tansey, and Stacie Castillo. 2022. "Case Study on the Effects of a Disability Inclusive Mindset in a Large Biotechnology Company." *Journal of Work-Applied Management* 14 (1): 113–25. https://doi.org/10.1108/JWAM-06-2021-0045.

Owen, Renee. 2021. "Using Mindfulness to Promote Transformative Learning in Implicit Racial Bias Training." *Adult Learning* 32 (3): 125–31. https://doi.org/10.1177/1045159520981165.

Prasad, Kdv, Mruthyanjaya M Rao, and Rajesh Vaidya. 2019. "GAMIFICATION AND RESOURCE POOLING FOR IMPROVING OPERATIONAL EFFICIENCY AND EFFECTIVE MANAGEMENT OF HUMAN RESOURCES: A CASE STUDY WITH AN ECOMMERCE COMPANY." *INTERNATIONAL JOURNAL OF MANAGEMENT* 10 (6). https://doi.org/10.34218/IJM.10.6.2019.008.

Purwanto, Muhammad Roy, Tamyiz Mukharrom, Yusdani, and Ahmad Munjin Nasih. 2019. "Inclusivity of Lecturers with Nahdlatul Ulama Background in Political and Religious Views in Indonesia." *International Journal of Innovation, Creativity and Change* 9 (10): 96.

Seibert, Susan A. 2021. "Problem-Based Learning: A Strategy to Foster Generation Z's Critical Thinking and Perseverance." *Teaching and Learning in Nursing* 16 (1): 85–88. https://doi.org/10.1016/j.teln.2020.09.002.

Steinthorsson, Runolfur Smari. 2021. "Reflections on Tourism Business Viability and Competitiveness in Rural Regions." In *The Rural Enterprise Economy*. Routledge.

Taati, Babak, Shun Zhao, Ahmed B. Ashraf, Azin Asgarian, M. Erin Browne, Kenneth M. Prkachin, Alex Mihailidis, and Thomas Hadjistavropoulos. 2019. "Algorithmic Bias in Clinical Populations—Evaluating and Improving Facial Analysis Technology in Older Adults With Dementia." *IEEE Access* 7:25527–34. https://doi.org/10.1109/ACCESS.2019.2900022.

Thomas, Kathryn A., Brian N. Phillips, Beatrice Lee, Timothy N. Tansey, Chase M. Ochrach, Cayte A. Anderson, and Deborah Lee. 2021. "Facilitating Disability

Inclusive Mindsets in Two Small Businesses: A Case Study.” *Journal of Rehabilitation* 87 (4): 12–18.

Valgeirsdottir, Dagny. 2021. “Promoting an Inclusive Mind-Set through Method Support: Universal Design Playbook.” In *ISPIM Conference Proceedings; Manchester*, 1–7. Berlin, Germany. https://www.proquest.com/openview/d706b61f096b49483b615410c16bda3d/1?pq-origsite=gscholar&cbl=1796422.

Vignola, Claudio, Nicholas Flowers, and Brooke Charae Coley. 2019. “Engineering a New Reality: Using Virtual Reality to Cultivate Inclusive Mindsets among Engineering Faculty.” In *2019 CoNECD-The Collaborative Network for Engineering and Computing Diversity*.

Weaver, Joan. 2002. “Implementing Change with Understanding and Respect--Guidelines for a Flexible, Creative, Inclusive Mind-Set.” *Child Care Information Exchange* 146:20–23.

Weber-Lewerenz, Bianca, and Ingrid Vasiliu-Feltes. 2022. “Empowering Digital Innovation by Diverse Leadership in ICT – A Roadmap to a Better Value System in Computer Algorithms.” *Humanistic Management Journal* 7 (1): 117–34. https://doi.org/10.1007/s41463-022-00123-7.

Wiebusch, Marek. 2013. “Towards Social Quality in Europe by Integrating Its Central Elements into the Problem Solving Process : Analyzing Family Group Conferences with an Inclusive Mindset.” Info:eu-repo/semantics/bachelorThesis. University of Twente. March 29, 2013. https://essay.utwente.nl/62950/.

Wu, Jiayue Cecilia. 2021. “An Innovative and Inclusive Mindset: Teaching Embodied Sonic Meditation in Higher Education.” In *Audio Engineering Society Conference: 2021 AES International Audio Education Conference*. Audio Engineering Society.

Zallio, Matteo, and P. John Clarkson. 2021. “Inclusion, Diversity, Equity and Accessibility in the Built Environment: A Study of Architectural Design Practice.” *Building and Environment* 206 (December):108352. https://doi.org/10.1016/j.buildenv.2021.108352.

APPENDIX

Table 1. References of the related attributes of an inclusive mindset

Related Attributes		Papers Addressed the Attributes
Invisible Attributes	Open-mindedness	(Altinier et al. 2022) (Bosio 2023) (Bradford et al. 2021) (Cherrez et al. 2023) (Cohen Carrus 2017) (Culp and Jones 2023) (Forsberg 2022) (Jones Young 2022) (Japar et al. 2023) (Moriarty 2007) (Ochrach et al. 2022) (Owen 2021) (Purwanto et al. 2019) (Seibert 2021) (Wagemans 2022) (Weaver 2002) (Wu 2021)
	Awareness of Biases and Social Issues	(Adams 2021) (Blake-Beard et al. 2021) (Brown and Clark 2021) (Doe et al. 2023) (Garcia et al. 2021) (Green and Patel 2021) (Harris 2022) (Israel et al. 2023) (Jones Young 2022) (Lee and Thompson 2020) (Lopez 2021) (Massouti 2021) (Miller 2022) (Parker 2020) (Smith and Liu 2023) (Wright 2021))
	Self-reflection	(Blake-Beard et al. 2021) (Doe et al. 2023) (Jones Young 2022) (Kumar 2021) (Lopez 2021) (Lopez 2021) (Miller 2022) (Moore 2022) (Parker 2020) (Wright 2021)

	Empathy for Diverse Individuals	(Eadens and Eadens 2016) (Garcia et al. 2021) (Green and Patel 2021) (Israel et al. 2023) (Johnson et al. 2023) (Jones Young 2022) (Miller 2022) (Parker 2020) (Smith et al. 2021) (Williams 2020)
	Inclusive Competencies and Knowledge	(Alvarez 2021) (Blake-Beard et al. 2021) (Brown and Clark 2021) (Chen 2022) (Garcia et al. 2021) (Johnson et al. 2023) (Kumar 2021) (Lee and Thompson 2020) (Taylor et al. 2022)
	Inclusion and Diversity Value	(Brown and Clark 2021) (Doe et al. 2023) (Eadens and Eadens 2016) (Martinez 2022) (Nguyen et al. 2022) (Walker 2021) (Williams 2020) (Wilson 2022)
	Positive Attitude and Feelings towards Inclusion and Diversity	(Chen 2022) (Israel et al. 2023) (Johnson et al. 2023) (Lee and Thompson 2020) (Massouti 2021) (Moore 2022) (Smith and Liu 2023)
	Respect	(Ahamad et al. 2022) (Bennett 2021) (Davis 2023) (Jones Young 2022) (Martinez 2022) (Nguyen et al. 2022) (Williams 2020)
	Sensitivity	(Alvarez 2021) (Collins 2021) (Massouti 2021) (Nguyen et al. 2022) (Williams 2020)
	Compassion and Acceptance	(Ahamad et al. 2022) (Davis 2023) (Green and Patel 2021) (Lee and Thompson 2020) (Massouti 2021)
Visible Attributes	Designing with Accessibility in Mind	(Alvarez 2021) (Doe et al. 2023) (Garcia et al. 2021) (Kumar 2021) (Lopez 2021) (Miller 2022) (Parker 2020) (Smith et al. 2021) (Wright 2021) (Young 2022)
	Providing Flexibility	(Alvarez 2021) (Brown and Clark 2021) (Eadens and Eadens 2016) (Evans 2023) (Harris 2022) (Jones Young 2022) (Massouti 2021) (Rodriguez 2023) (Smith and Liu 2023) (Wilson 2022)
	Involving Others	(Blake-Beard et al. 2021) (Davis 2023) (Lopez 2021) (Miller 2022) (Rodriguez 2023) (Smith et al. 2021) (Williams 2020)
	Challenging Current Approach	(Blake-Beard et al. 2021) (Doe et al. 2023) (Harris 2022) (Jones Young 2022) (Kumar 2021) (Parker 2020)
	Creating Supportive Relationships	(Brooks and Strunc 2022) (Eadens and Eadens 2016) (Forsberg 2022)
	Using Inclusive Language	(Eadens and Eadens 2016) (Forsberg 2022) (Thomas et al. 2021)
	Going Beyond Legal Requirements	(Dodge 2017) (Ochrach et al. 2022)
	Treating Others with Respect	(Massouti 2021) (Wagemans 2022)

Table 2. References of the influencing factors of an inclusive mindset

	Influencing Factors	Papers Addressed the Attributes
Internal Factors	Self-reflection and Awareness	(Arinaitwe and Ahumuza 2023) (Bandyopadhyay et al. 2022) (Blake-Beard et al. 2021) (Blaskova and Gibson 2023) (Bradford et al. 2021) (Cherrez et al. 2023) (Eadens and Eadens 2016) (Jones Young 2022) (Lowy et al. 2023) (Malhotra and Pingali 2020) (Massouti 2021) (Moriarty 2007) (Nezafati et al. 2020) (Nezafati et al. 2022) (Ochrach et al. 2022) (Owen 2021) (Valgeirsdottir 2021) (Vignola et al. 2019) (Wagemans 2022) (Weber-Lewerenz and Vasiliu-Feltes 2022) (Wiebusch 2013) (Zallio and Clarkson 2021)
	Attitude, Belief and Perception	(Bandyopadhyay et al. 2022) (Bosio 2023) (Bradford et al. 2021) (Cohen Carrus 2017) (Culp and Jones 2023) (Emmers et al. 2021) (Forsberg 2022) (Kopmann and Zeinz 2018) (Lowy et al. 2023) (Massouti 2021) (Moriarty 2007) (Ochrach et al. 2022) (Owen 2021) (Steinthorsson 2021) (Thomas et al. 2021) (Vignola et al. 2019) (Weber-Lewerenz and Vasiliu-Feltes 2022) (Zallio and Clarkson 2021)
	Understanding	(Altinier et al. 2022) (Bandyopadhyay et al. 2022) (Cohen Carrus 2017) (Dodge 2017) (Jones Young 2022) (Lowy et al. 2023) (Massouti 2021) (Moriarty 2007) (Nezafati et al. 2022) (Owen 2021) (Thomas et al. 2021) (Valgeirsdottir 2021) (Vignola et al. 2019) (Wiebusch 2013) (Zallio and Clarkson 2021)
	Intention and Motivation	(Altinier et al. 2022) (Bandyopadhyay et al. 2022) (Bosio 2023) (Brooks and Strunc 2022) (Chitra and Chandra 2017) (Forsberg 2022) (Massouti 2021) (Moriarty 2007) (Nezafati et al. 2022) (Ochrach et al. 2022) (Steinthorsson 2021) (Thomas et al. 2021) (Vignola et al. 2019) (Zallio and Clarkson 2021)

	Influencing Factors	Papers Addressed the Attributes
	Competency	(Altinier et al. 2022) (Arinaitwe and Ahumuza 2023) (Cohen Carrus 2017) (Lowy et al. 2023) (Massouti 2021) (Nezafati et al. 2020) (Nezafati et al. 2022) (Owen 2021)
	Personality Trait	(Altinier et al. 2022) (Ashton-Hay and Williams 2023) (Bandyopadhyay et al. 2022) (Bradford et al. 2021) (Forsberg 2022) (Wiebusch 2013) (Wu 2021)
	Bias and Assumption	(Blaskova and Gibson 2023) (Jones Young 2022) (Moriarty 2007) (Nezafati et al. 2022) (Vignola et al. 2019) (Zallio and Clarkson 2021)
	Feeling	(Altinier et al. 2022) (Emmers et al. 2021) (Forsberg 2022) (Jones Young 2022) (Owen 2021) (Wagemans 2022)
	Relationship	(Altinier et al. 2022) (Eadens and Eadens 2016) (Nezafati et al. 2022) (Wagemans 2022) (Zallio and Clarkson 2021)
	Learning	(Bandyopadhyay et al. 2022) (Cohen Carrus 2017) (Eadens and Eadens 2016) (Owen 2021)
	Experience	(Emmers et al. 2021) (Kopmann and Zeinz 2018) (Nezafati et al. 2022)
	Sense-making	(Forsberg 2022) (Jones Young 2022)
External Factors	Learning Intervention	(Altinier et al. 2022) (Bandyopadhyay et al. 2022) (Blaskova and Gibson 2023) (Brooks and Strunc 2022) (Chan et al. 2023) (Cherrez et al. 2023) (Cohen Carrus 2017) (Israel et al. 2023) (Japar et al. 2023) (Kopmann and Zeinz 2018) (Lowy et al. 2023) (Malhotra and Pingali 2020) (Massouti 2021) (Nezafati et al. 2020) (Nezafati et al. 2021) (Nezafati et al. 2022) (Owen 2021) (Prasad et al. 2019) (Thomas et al. 2021) (Vignola et al. 2019) (Wagemans 2022) (Weber-Lewerenz and Vasiliu-Feltes 2022) (Wiebusch 2013) (Wu 2021)
	Social or Work Environment	(Bandyopadhyay et al. 2022) (Blake-Beard et al. 2021) (Brooks and Strunc 2022) (Chitra and Chandra 2017) (Chng et al. 2020) (Cohen Carrus 2017) (Eadens and Eadens 2016) (Emmers et al. 2021) (Forsberg 2022) (Japar et al. 2023) (Jones Young 2022) (Kopmann and Zeinz 2018) (Lowy et al. 2023) (Massouti 2021) (Moriarty 2007) (Ochrach et al. 2022) (Prasad et al. 2019) (Thomas et al. 2021) (Vignola et al. 2019) (Wagemans 2022) (Weber-Lewerenz and Vasiliu-Feltes 2022) (Zallio and Clarkson 2021)
	Standard and Dominant Practice	(Altinier et al. 2022) (Blake-Beard et al. 2021) (Chan et al. 2023) (Cohen Carrus 2017) (Dodge 2017) (Jones Young 2022) (Kopmann and Zeinz 2018) (Massouti 2021) (Moriarty 2007) (Nezafati et al. 2022) (Ochrach et al. 2022) (Thomas et al. 2021) (Vignola et al. 2019) (Wagemans 2022) (Weber-Lewerenz and Vasiliu-Feltes 2022) (Zallio and Clarkson 2021)
	Social Norms	(Altinier et al. 2022) (Arinaitwe and Ahumuza 2023) (Blaskova and Gibson 2023) (Cherrez et al. 2023) (Cohen Carrus 2017) (Culp and Jones 2023) (Dodge 2017) (Emmers et al. 2021) (Jones Young 2022) (Kopmann and Zeinz 2018) (Lowy et al. 2023) (Massouti 2021) (Moriarty 2007) (Zallio and Clarkson 2021)
	Regulatory Framework	(Altinier et al. 2022) (Bradford et al. 2021) (Chan et al. 2023) (Massouti 2021) (Ochrach et al. 2022) (Wagemans 2022) (Weber-Lewerenz and Vasiliu-Feltes 2022) (Zallio and Clarkson 2021)
	Resources and Barriers	(Brooks and Strunc 2022) (Moriarty 2007) (Nezafati et al. 2022) (Thomas et al. 2021) (Valgeirsdottir 2021) (Wagemans 2022) (Zallio and Clarkson 2021)
	Interaction with Diverse Individuals	(Ashton-Hay and Williams 2023) (Blake-Beard et al. 2021) (Cohen Carrus 2017) (Kopmann and Zeinz 2018) (La Fors 2022) (Valgeirsdottir 2021) (Wagemans 2022)
	Global Trends	(Arinaitwe and Ahumuza 2023) (Bandyopadhyay et al. 2022) (Moriarty 2007) (Ochrach et al. 2022) (Wiebusch 2013)
	Communication	(Chng et al. 2020) (Emmers et al. 2021) (Jones Young 2022) (Ochrach et al. 2022)

UNIVERSITY ATTRACTIVENESS AND COVID-19 INFLUENCE: A FOCUS ON INDUSTRIAL ENGINEERING AND MANAGEMENT STUDENTS IN PORTUGUESE UNIVERSITIES

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ABSTRACT

The Industrial Engineering and Management (IEM) degree merges engineering and managerial concepts, and has reaffirmed itself as an attractive degree for students in the Portuguese university landscape. This paper aims to investigate the attractiveness factors of 5 Universities in Portugal, according to their IEM students at those mentioned universities and how these compare between pre- and post-pandemic times. This analysis was done through two quantitative surveys shared among students of the ESTIEM network (European Students of Industrial Engineering and Management), in 2021 and 2024. The universities under analysis were Porto, Minho, Aveiro, Coimbra and Lisbon (IST). Responses showed that the most relevant factor for choosing universities is its prestige, followed by the city the university is located in, with over half the students inquired pointing to these two factors. Corporate-related factors such as the university's recognition by companies and the employment rate of the degree were highlighted as very relevant too. Differences were also found between the universities studied from Lisbon and Porto giving a bigger importance to prestige, while Aveiro's, Coimbra's and Minho's students prioritise the city of the campus. The results from 2021 and 2024 have coincident findings, pointing to the conclusion that the Covid-19 pandemic did not play a significant role when it comes to shifting Portuguese IEM students' attractiveness perspective. These findings not only allow universities to have an overview of their main potential selling points and what students deem as critical factors, but they also indicate that pre-Covid-19 studies' conclusions are likely still

relevant, as there are no critical differences seen between responses from 2021 and 2024.

1 INTRODUCTION

Industrial Engineering and Management (IEM) is a university degree that encompasses both a strong engineering basis and relevant management concepts. The degree has established itself as one of the preferred options of Portuguese high school students, gaining an increased visibility in the country since its introduction around 30 years ago. This was particularly evident in the last 7 years, where engineering degrees have become the top choice for students, having the highest entrance grades. In fact, Industrial Engineering and Management is a clear example of this, with the degree from the University of Porto in the top 4 since 2016, which in the academic year 2023/2024 held the fourth place, with an entrance grade of 18.55 out of 20[1].

These consistent results can be tied to the high employability of IEM graduates in Portugal, associated also with the diversity of careers and fields that an industrial engineer can partake in. Once graduated, the students can work in fields ranging from supply chain management, quality control, operations optimization, management, marketing, strategy, among others.

The *numerus clausus*, number of the students who applied, and number of students who enrolled in each university and degree as their first option are summarised in Table 1, for five of the top Portuguese universities, with data from 2023.[1]

Table 1. Numerus clausus, number of applicants and number of students that selected first option for each University

University	Aveiro	Coimbra	Lisboa	Minho	Porto
Numerus Clausus	74	57	81	68	111
Nº applicants	500	363	362	425	514
Nº students in their first option	45	30	75	35	111

Several factors contribute to a student's choice of university, and IEM being a degree with a consistent high demand, before, during and after Covid-19, it is interesting to explore further factors that make it attractive to students, and if these factors could have shifted due to the pandemic. This knowledge is highly valuable for the universities, who can work towards improving these factors and communicating them more efficiently to prospective students. It is also critical for them to understand if these factors changed during the pandemic, so that they can update their knowledge. Such an impactful event, tied to the digitalisation that it brought, could potentially have a strong influence on students' choices. Therefore, this paper aims

[1] Data from the Direção-Geral de Estatísticas da Educação e Ciência (DGEEC) - General Center for Statistics of Education and Science.

to address not only the attractiveness factors for students, but also how they compare to the most relevant factors pointed by students before Covid-19.

For this, a quantitative study was conducted by ESTIEM (European Students of Industrial Engineering and Management), a student organisation that operates at a European level, connecting Industrial Engineering students with each other, as well as with academics and professionals in the field. This study is tied to previous research conducted in 2021, to allow for a comparison between a pre- and post-pandemic scenario.

2 LITERATURE REVIEW

With the transformation of higher education to a highly competitive and globalised environment, and especially now in post Covid times, there is a high interest in researching the choices that potential engineering and IEM students make regarding their university, and if these have changed over the Covid-19 pandemic.

Students undergo a difficult decision process when facing the choice of degree and university. Han (2014) reported that it ultimately results from a combination of interconnected factors, such as demography or institutional characteristics. Perna (2006) addressed this multitude of factors through a four-attribute conceptual model that grouped several influences of students' choices. These attributes were habitus, school and community context, higher education context and social-economic context. Habitus encompasses demographic characteristics and social and cultural capital, while school and community context englobe the availability of resources, type of resources, structural supports, as well as barriers. As for higher education context, the focus was on institutional characteristics, location, marketing and recruitment. Several studies highlight the prestige and recognition of the university as one of the main influences of high school graduates' choice regarding their university (Cyrenne and Grant 2008; Do and Le 2020; Briggs 2006). Other research also points to the city the university is located in, and the distance from the student's hometown as being relevant factors (Baharun et al. 2011; Briggs 2006). On the other side, information availability by the university and research reputation were considered factors with low relevance (Briggs 2006).

Narrowing it to Engineering, Alpay (2013) provided research on the attractiveness of general engineering degrees in the UK with high school graduates. Special emphasis was put on the attractiveness traits of flexibility in engineering specialisation, combined degree options and exposure to non-technical courses. These were deemed as very attractive factors for students that were already considering an engineering degree before, as well as those who were not pondering it so far.

Regarding potential changes in the attractiveness factors for university students since previous years, Nanath et al. (2022) shows that the perspectives of students' decision-making criteria have indeed changed and there is a new perspective for university selection. The critical factors affecting a university choice in the digital era are the cost of education (such as tuition fees), the quality of student life at a university, the presence of e-learning and the opportunities in terms of employment and earnings. Indeed, Ramalhete et al. (2020) highlights that the transition to an e-learning model in Portuguese universities was made possible by the use of new information and communication technologies that come with advantages. One of the main benefits for this new teaching methodology is the absence of commuting times, followed by the development of students' autonomy and therefore has potential to transform teaching and learning contexts in the future, and making factors such as distance to the university less relevant.

Looking specifically at changes coming from the pre-pandemic students to the ones that made the choice to enroll in the university during and after that time, this research will be based on the factors previously presented by Serodio et al. (2021). In that quantitative study, an analysis of factors that influence Industrial Engineering and Management students' choice of university in Portugal was presented, dating from the beginning of the Covid-19 pandemic, with students that enrolled before this period. The most important factors concluded were the prestige of the university and the city of the institutions, followed by job market opportunities that students expect to access after their graduation.

3 METHODOLOGY

To identify the most important attributes for Industrial Engineering and Management students in Portugal and how these preferences were affected by the pandemic, a comparative analysis was made between two quantitative studies, based on online surveys to students.

The survey was filled two times, the first time in March of 2021, when it was created, in full pandemic times, and one time during March 2024 in a post pandemic scenario. In order to ensure the answers from both years were comparable, new items were not added in 2024 as options for the relevant factors.

The data was collected through the student associations that are members of ESTIEM (European Students of Industrial Engineering and Management), with the student's permission and taking into consideration the general data protection regulation, with all data being handled anonymously. Five relevant Portuguese Universities with IEM degrees were selected for this study: Universities of Aveiro, Coimbra, Lisbon, Minho and Porto. It was ensured all answers collected within the survey are from engineering students in the Industrial Engineering and Management degree.

While in the first survey in 2021, the target group were both bachelors and masters' students, the second survey in 2024 was only sent to bachelor IEM students, all from the above-mentioned five universities. This study will compare only the results from Bachelor students, as the aim is to be able to distinguish between pre- and post-Covid-19 university applicants.

In the current study, 209 answers were collected. From 2021's study, we used 214 of the 255 answers completely filled, corresponding to a selection of only Bachelor students. The distribution between female and male respondents was approximately 60% and 40%, respectively, in both years. The percentage of answers from each of the five Universities analysed is displayed in Table 2.

Table 2. Distribution of responses per surveyed university

% respondents (Bachelor students) per survey run	Aveiro	Coimbra	Lisbon	Minho	Porto
2021	17%	25%	20%	19%	19%
2024	35%	16%	14%	14%	21%

The survey questions investigate IEM students' first choice of university. Participants of the survey were asked about the university they selected as first choice, and were able to give multiple answers and indicate other possibilities besides the already presented, to make sure all options were considered. This was then compared to their current university to understand the degree of mismatch between preferred and current universities. The survey also focused on the factors that influenced their decision, asking students what were the features that lead them to put that university as their first choice for bachelors, in a closed multiple selection question, with a total of 16 answer possibilities. The definition of the options had as basis the revised literature. Finally, students were also questioned on whether they would change their university if they could, to which one they would have preferred to go, and if they would consider now taking their degree abroad.

The data collected was analysed and compared to the data collected in the previous survey. The influencing factors for first choice were through percentages, having each percentage calculated through the number of times that factor was pinpointed as relevant in the total number of survey responses for the five main universities. The answers were also subsequently separated by location, in order to obtain the top 5 factors indicated for each university.

4 RESULTS

The first choice of university was analysed on the perspective of influencing factors associated with universities' characteristics, related to its location, teaching, interaction with the corporate landscape of the country, among others. Figure 1 shows the general results obtained in both questionnaires. For 2021, 207 out of the 214 answers were used for this analysis, as four students stated they would have liked to study in University Nova Lisbon (FCT/UNL) and three in Instituto Superior de Engenharia do Porto (ISEP), universities not considered in the study, similarly to one student in 2024 who also chose this last university as first choice.

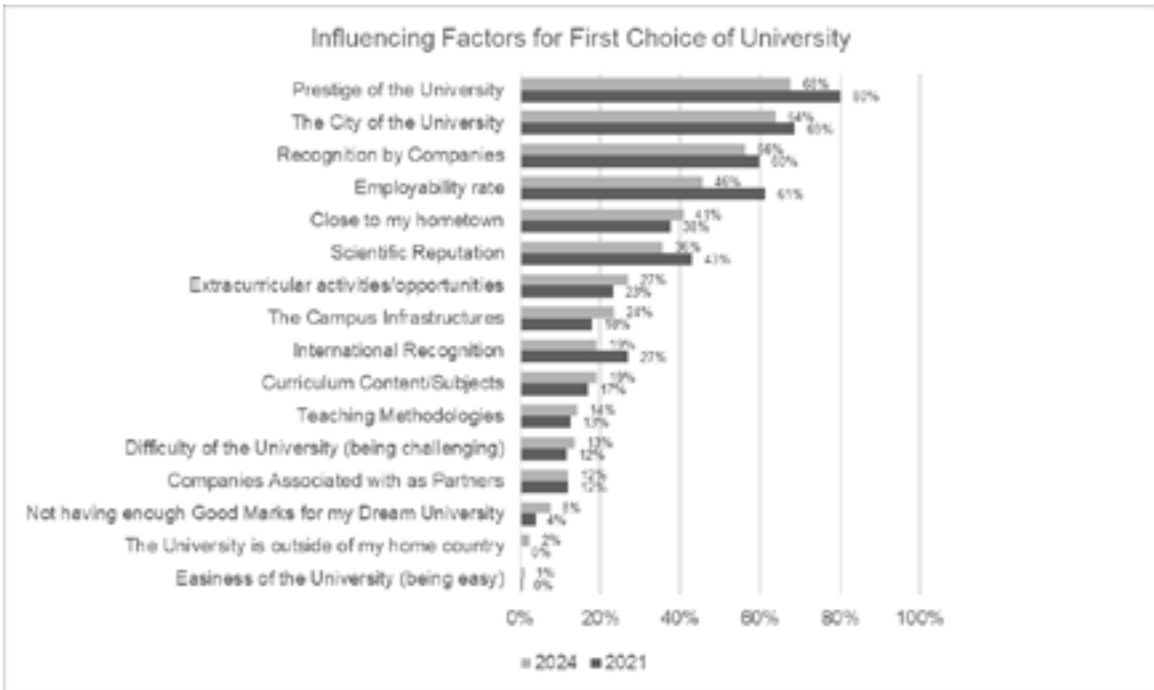

Fig. 1. Distribution of influences of student's first choice factors for 2021 and 2024

From the overall results it is possible to see that the first four influencing factors are the same between the two analyses, even though the percentage of people that selected them was lower in 2024. The prestige of the university is once more the most influential factor, followed by the city the university is located in. These results are in line with the literature, being mentioned by several previous studies performed in different countries. Furthermore, recognition by companies and employability rate are also to be highlighted, as it was also described by Nanath et al. (2022), who underlined the importance of good employment in the area and potential earnings. These factors are in line with the Portuguese landscape where engineers, and particularly industrial engineers, have an extremely high employability rate and a wide range of career options available. Comparing 2021 to 2024, the percentage of people that selected recognition by companies and employability rate decreased and the employability rate ranked lower in 2024 than recognition by companies, being the inverse in 2021.

Overall, the least relevant factors of students' choice are the easiness/difficulty of the university, not having a sufficient application grade to enter their most preferred option and the partner companies of the University.

When making a division per city, the conclusions are slightly different. The top 5 factors for each university can be seen in Figure 2.

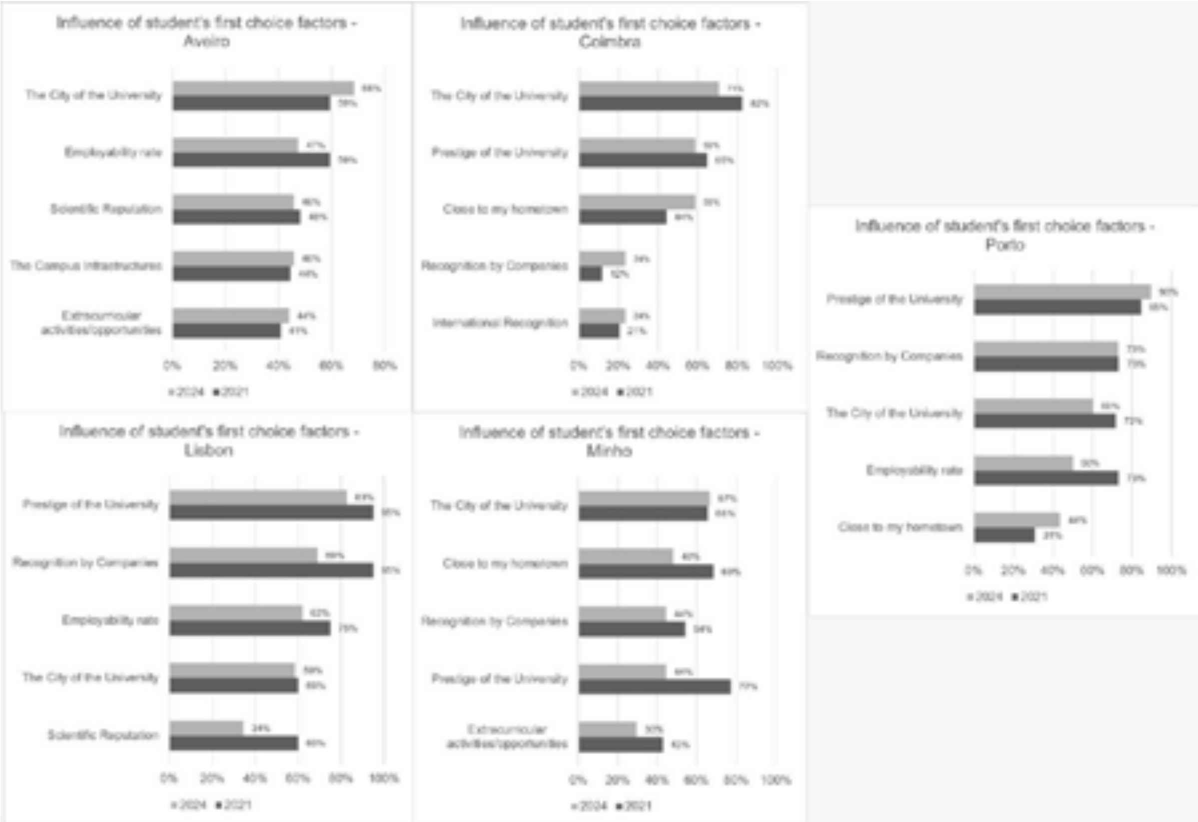

Fig. 2. Top 5 Influencing factors for first choice per university

Unlike the overall results, the city of the university is the main factor for Aveiro, Coimbra and Minho, being still in the main five factors for all universities. Students from Coimbra, Minho and Porto underline not only the city itself, but also the importance of it being close to their hometown.

For Lisbon and Porto, the most influential factors are the prestige of the university and the recognition by companies, in this order. Prestige is stated in the top factors for all universities except Aveiro. Students from Coimbra are the only ones selecting international recognition as a top factor.

Some factors that are not in the main five of the overall results are however part of the main five factors of some cities. For example, Scientific reputation is a chosen factor for only Aveiro and Lisbon, while Minho and Aveiro have their extra-curricular activities highlighted. Finally, only Aveiro students pinpoint the campus' infrastructures as one of the main five factors.

Overall, the results from 2021 and 2024 point in the same direction, except for university of Minho, where there was a shift in the main factors in 2024, with prestige exchanging positions with city and proximity to hometown. As for Coimbra, in 2024 students give the same importance to company and international recognition, while in 2021 the second had more weight. Porto maintains the general trend, but having in 2024 the factors of company recognition, city and employability more balanced.

It is important to note that while some factors such as the city, closeness to hometown and the grades of the students, several others are directly or indirectly changeable by the Universities. Universities can directly impact their infrastructures, factors related to teaching (teaching methodologies, course curriculum and how easy or hard it is to complete the degree) and opportunities for students (extracurricular activities and partner companies). The remaining factors - scientific reputation, recognition by companies, prestige, international recognition and employability rate – are not directly changeable, but are the result of the decisions and investments of the Universities.

Besides the factors for first choice, the match between the first choice of the inquired students and the university they were currently attending was also analysed. The 2021 study concluded that 16% of students were not enrolled in their first choice, and that the University of Porto was the main first choice among them. Results from 2024 are coincident, with a 17% mismatch, and 36% of these students having preferred to study at the University of Porto.

Finally, students were also questioned on whether they would now change the University they chose, if they could. The conclusion for both years is that students are comfortable with their choices and would not change them after joining their university, as indicated by 71% of the 2024 study participants. However, 14% of students still indicated that they would like to change to University of Porto, and the remaining percentage would have preferred other universities, in the country or abroad, or were unsure if they would want to change.

This study poses some limitations, such as the fact that both times only IEM students from the above-mentioned universities were respondents, and therefore due to practical reasons, if a first-choice university was not one of those (which was permitted in the survey), the data was excluded from our analysis. Regarding the distribution of the data collected, the distribution between locations, with Aveiro having a bigger percentage of the students surveyed, could influence the overall results. Also, the timing of the two surveys generated that the student samples are not clean when it comes to the two groups being compared. The study done in 2021 had a minority of the students surveyed making the university choice in the summer of 2020. However, despite the date, the general expectation in the country was that there would not be a significant impact of the disease on the school year, since overall in the country restrictions were low (*Jornal de Negócios* 9 Nov. 2020), so the answers were still considered. As for 2024, although the research objective was communicated to the IEM students completing the survey, there is no assurance that everyone considered this aspect when deciding whether or not to fill the survey. Lastly, the generalisation of this data conducted from IEM students in Portugal to other fields of study or other countries. Arguably, being the results in line with previous literature, it could be inferred that they can provide relevant insights.

5 CONCLUSIONS

This paper portrays an analysis of the attractiveness factors perceived by students when choosing their universities, and makes a comparison between the most relevant factors chosen by Bachelor students in 2021, with students that chose their university before the pandemic years, and students from 2024, which started their Bachelor in pandemic times.

The overall results for the first-choice attractiveness were aligned between the two studies, with the prestige of the University being the most influential one. The campus's city was the second most voted factor, also for both years, followed by company recognition and employability rate. The scenario is different when looking into the universities individually, both in terms of the selected top factors and the shifts between the two years. This shows that the different students associate each place with distinct valuable assets, which is highly valuable information for these Universities. Moreover, it was concluded that most students (70%) were happy in their current university and would not change, but when questioned on studying abroad a relevant percentage (40%) would consider it.

The conclusions drawn from these studies provide an overview of the Portuguese landscape when it comes to attractiveness factors affecting IEM students, as well as allowing universities to understand the reasoning behind the students that selected them as first choice. This allows universities to have a better understanding of their potential selling points when attracting new recruits, and adapt recruitment and marketing strategies to this.

Plus, this study also indicates that there are no significant differences between the main factors impacting student's choices before and after the pandemic, which indicates that other pre-pandemic studies conducted still provide valuable input and could be used by the corresponding universities with a certain degree of confidence.

Further research could, on the one hand, compare different research questions with 2021 data, such as the most relevant factors of student's current universities, rather than on their first choice, or how influential different people and channels (parents, media, high school professors, etc.) are to a students' decisions. Also, new options could be added as factors for the first choice, to update the study according to new factors mentioned in the literature, namely related to e-learning. On the other hand, a larger study could also be conducted, collecting and comparing data between different countries to validate if the results can be generalised for European students and if there is a European alignment on what makes Universities attractive for IEM students.

REFERENCES

Alpay, E. "Student Attraction to Engineering through Flexibility and Breadth in the Curriculum." European Journal of Engineering Education 38, 1 (2013): 58–69. https://doi.org/10.1080/03043797.2012.742870.

Baharun, Rohaizat, Zubaidah Awang, and Siti Falinda Padlee. "International students' choice criteria for selection of higher learning in Malaysian private universities." African Journal of Business management 5, 12 (2011): 4704.

Briggs, Senga. "An exploratory study of the factors influencing undergraduate student choice: the case of higher education in Scotland." Studies in Higher Education 31, 6 (2006): 705-722.

Cyrenne, Philippe, Hugh Grant. "University decision making and prestige: An empirical study." Economics of Education Review 282 (2009): 237-248

Do, Thai Dinh, Lan Chi Le. "Factors affecting High School Student’s decision on choosing university: case study of Ho Chi Minh City." Journal of Entrepreneurship Education 23, 3 (2020): 1-11.

Han, Pingping. "A literature review on college choice and marketing strategies for recruitment." Family and Consumer Sciences Research Journal 43, 2 (2014): 120-130.

Lusa. 2020. "Os principais momentos dos oito meses da pandemia em Portugal". *Jornal de Negócios.* November 9. https://www.jornaldenegocios.pt/economia/coronavirus/detalhe/os-principais-momentos-dos-oito-meses-da-pandemia-em-portugal.

Nanath, Krishnadas, Ali Sajjad, and Supriya Kaitheri. "Decision-making system for higher education university selection: Comparison of priorities pre-and post-COVID-19." Journal of Applied Research in Higher Education 14, 1 (2022): 347-365.

Perna, Laura W. "Studying college access and choice: A proposed conceptual model." Higher education: Handbook of theory and research. Dordrecht: Springer Netherlands, 2006. 99-157.

Ramalhete, Filipa, et al. "Changing from face to face to e-learning in emergency contexts: experiences from Covid-19 2020 pandemic crisis in university contexts in Portugal." EDULEARN20, 12th annual International Conference on Education and New Learning Technologies proceedings. 2020.

Serodio, Sá, et al. “Introspection into Portuguese universities attractiveness: a focus on Industrial Engineering and Management Students.” Annual SEFI conference 2021.

ASSESSING ENGINEERING EPISTEMOLOGY: A SYSTEMATIC LITERATURE REVIEW OF INSTRUMENTS

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ABSTRACT

This research paper presents an overview and evaluation of existing instruments utilized to assess epistemological beliefs, beliefs people hold regarding the nature of knowledge and knowing, including how knowledge is constructed and its certainty or tentativeness, within the context of engineering education.

Assessment of epistemological beliefs in engineering education is crucial for understanding students' perspectives on knowledge and learning. To successfully carry out such an assessment, we need validated reliable psychometric tools. A literature review on the subject revealed a lack of evidence on the state of knowledge on epistemology in engineering education.

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To address that gap, we conducted a systematic literature review spanning from 1997 to 2023 across representative databases and journals in the field and guided by the question, "What existing instruments are designed to measure or characterize epistemological beliefs in engineering?"

The search revealed two instruments, and upon further examination, we concluded that none of the quantitative instruments already available are based on a conceptually coherent and empirically robust model of epistemic development in engineering, and hence can't be used to produce reliable measures.

The engineering education research community need to dedicate efforts towards designing and validating an engineering-specific epistemological tool. The creation and validation of such an instrument is a step towards understanding epistemological beliefs among engineering students, which in turn is crucial for effective instructional design and curriculum development. We posit that such development offers a nuanced supplement to conventional grading-centric assessments.

1 INTRODUCTION

1.1 Background

There are four popular types of beliefs typically studied in engineering education: epistemic, self-efficacy, mindset, and goal-orientation beliefs (Kramer et al., 2024). This study will focus on epistemic beliefs, which are the beliefs that people have about the nature of knowledge and knowing, such as what counts as knowledge, how knowledge is constructed, and how certain or tentative knowledge is (Hetherington, 2012).

Assessing epistemological beliefs in engineering education is crucial for understanding students' perspectives on knowledge and learning. They also have implications for various aspects of cognition, motivation, and achievement (Chai et al., 2006; Muis et al., 2006). Carberry (2010) and Frye et al. (2012) both found that engineering students often hold simplistic and certain views of knowledge, which can impact their learning and comprehension of engineering concepts. Ghazali et al. (2021) further emphasizes the importance of understanding and shaping students' epistemological beliefs, suggesting that educators play a key role in this process. An educator's own epistemological beliefs influence teaching and learning (Bendixen & Rule, 2004; Green & Hood, 2013; Montfort et al., 2014) which underline all instructional design aspects including teaching strategies, learning objectives, and assessment techniques. Educators need to know what the students know to in turn design better educational experiences (Turns et al., 2005), further proving the practical implications of measuring and characterizing epistemic beliefs (Yildirim et al., 2010). These studies collectively highlight the significance of assessing and addressing epistemological beliefs in engineering education, which in turn responds to recent calls in the field for explicitly defining and measuring beliefs as a construct (Kramer et al., 2024), and addressing the lack of philosophical engagement with epistemology in the context of engineering disciplines (Boon & Baalen, 2018).

1.2 Literature Review

Looking at all existing instruments to measure epistemic beliefs, we grouped existing instruments into three groups: 1- Domain-general: typically have been created by psychologists to be widely applied to various contexts or majors of study e.g. Epistemic Beliefs Inventory. 2-domain-specific-non-engineering: Instruments that are designed for a specific field or context outside of engineering, and at times borrowed and applied to engineering. e.g. MED NORD a tool designed for medical students' conceptions of knowledge (Lonka et al., 2008) 3- Domain-specific engineering: Instruments that are designed for engineering and have been validated to be used with engineering students. This paper and the following analysis focused only on instruments falling in the third category mentioned above, engineering-specific instruments.

Research in the field of epistemological beliefs among university students has revealed notable disparities in how individuals perceive knowledge across different academic disciplines. Hofer (2000) discovered such disparities between first-year college students studying science and psychology. Similarly (Palmer & Marra, 2004) found similar differences in epistemological perspectives of science and engineering university students varying across the disciplinary areas of the sciences and the humanities. Faber & Benson (2017) further emphasized that epistemic cognition in engineering may diverge from other fields due to the distinctive nature of engineering knowledge and problem-solving demands. A component of studying knowledge – epistemology- is looking at individuals' justification of knowledge claims. DeBacker et al. (2008) argue that epistemic beliefs are domain-specific, as individuals may employ varying standards and justifications across different fields.

Hence, the study of epistemic beliefs can't be separated from the standards and practices in a given context, because those beliefs are contextualized within a context and hence ruled by disciplinary boundaries (Pintrich, 2002; Yu & Strobel, 2011) which raised criticism against domain-general instruments for their inability to capture the nuances of disciplinary differences (Hofer, 2000). These arguments collectively point towards the discipline-dependent nature of epistemic beliefs and consequently should be the instruments measuring them, therefore the focus of our paper here is on domain-specific engineering instruments.

2 METHODOLOGY

2.1 Method

Systematic Literature Review (SLR) is a research methodology aimed at critically appraising patterns or gaps in a given topic through synthesizing prior work on a given subject within a defined time frame to better identify new directions of research (Petticrew & Roberts, 2006). SLR can be done for different primary goals including tracing historical development, describing the state of knowledge or practice, or evaluating or developing theory (Borrego et al., 2014). This review will focus on the second purpose which is to identify existing research instruments designed to characterize epistemological beliefs. The particular focus of the search was on seminal research that documents the creation of such instruments, as well as research done on the validation and use of those instruments across contexts. The search is guided by the question: What are the existing instruments designed to measure/characterize epistemological beliefs in engineering?

The selection of the search terms was informed by the team's expertise as well as referencing the engineering education research taxonomy (Finelli & Borrego, 2015).

The resulting search combination is Epistem* AND Engineer* AND (Beliefs OR persp* OR cogniti* OR thinking) AND (instrument OR test OR questionnaire OR survey).

To define the inclusion and exclusion criteria of the papers found, we considered the language of publication, type of content (excluded editorials), population targeted by studies (exclude studies of children, K-12), discipline (as explained by the typology) and bounded the search with a year range.

Following the official language of our institution, our intended study will be conducted in English. Therefore the instrument has to be originally written in English, or a version translated to English is validated [when an instrument is translated or adapted from a different language, new evidence of validity should be conducted (American Educational Research Association et al., 2014)].

Data collected included studies from 1997 to 2023. The start of the date range was decided based on the publication of Hofer and Pintrich's (1997) meta-analysis of students' epistemological belief research that critically examined different research projects' use of definitions and theoretical framework related to the subject and presented theoretical and methodological issues in those studies.

The number and categories of databases to use for the SLR is a vital step in ensuring accurate search results and reducing selection bias as much as possible. While there is an agreement on the importance of defining and restricting the number and type of databases to include in a search (Mengist et al., 2020) the exactness of the criteria is less agreed upon. To decide on that step, we referenced multiple sources (Borrego et al., 2014; Bramer et al., 2017) and decided to focus on the databases Web of Science and Scopus to guarantee efficient coverage.

2.2 Analysis

Studies were screened following the pre-defined criteria, as reported in Table 1. Initial screening was performed by studying the title of the publication and categorizing it into one of three buckets: To include (Yes, No, or Maybe). Publications that didn't develop an instrument, or use a domain-general instrument to address engineering university-level education were labelled "No" and excluded. The publications where it wasn't clear from the title whether they developed or applied an instrument were labelled "maybe". The second round of the search tackled the group labelled as "maybe" by reading the abstract and deciding whether or not to include them. The last round of the search retrieved the full papers that got labelled as "Yes". If any of those papers didn't discuss an instrument, they were further excluded. This resulted in two instruments discussed across six papers as shown in Table 2.

Table 1: SLR search results and filtration

Database searched	Example journals and conference proceedings included in the database search	No. of results yielded in the initial search	Results based on initial categorization	Results based on intermediate categorization	Final results
Web of Science	International Journal of Engineering	112	Yes: 4 No: 86	Yes: 17 No: 95	Yes: 6 No: 106

	Education; Journal of Engineering Education; Frontiers in Education		Maybe: 22		
Scopus	European Journal of Engineering Education; American Society of Engineering Education	134 (55 overlapped with WoS results, 79 new papers)	Yes: 0 No: 63 Maybe: 16	Yes: 0 No: 16	No new papers added beyond the 5 above

Table 2: Finalized list of papers included following the search criteria

Instrument	Paper	Paper purpose
The Epistemological Beliefs Assessment for Engineering (EBAE)	1- A Pilot Validation Study of the Epistemological Beliefs Assessment for Engineering (EBAE): First-Year Engineering Student Beliefs (Carberry et al., 2010)	Instrument developing
	2- Assessing Engineering Service Students' Characteristics (Carberry, 2010)	Instrument application
The Engineering Related Beliefs Questionnaire (ERBQ)	3- A first step in the instrument development of engineering-related beliefs questionnaire (Yu & Strobel, 2012)	Instrument developing; Analysis of EBAE
	4- Exploring engineering students' epistemic beliefs and motivation: a case of a South African university (Makhathini et al., 2020)	Instrument application
	5- Measuring engineering epistemic beliefs in undergraduate engineering students (Faber et al., 2016)	Instrument application
	6- Engineering Students' Epistemic Cognition in the Context of Problem Solving (Faber & Benson, 2017)	Instrument application

3 RESULTS

3.1 Summary of Papers

3.1.1 A Pilot Validation Study of the Epistemological Beliefs Assessment for Engineering (EBAE): First-Year Engineering Student Beliefs

EBAE (Carberry et al., 2010) is a quantitative instrument to assess engineering students' epistemological beliefs. It is based on Hofer and Pintrich's (1997) dimensions of epistemological beliefs and includes items concerning the nature of engineering knowledge (certainty of knowledge, simplicity of knowledge) and the nature of engineering knowing (source of knowing, and justification of knowledge). It was piloted with 43 first-year engineering students in the US context resulting in thirteen validated items in four constructs.

3.1.2 Assessing Engineering Service Students' Characteristics

This paper studies students' epistemological development in the context of service learning. To understand how to integrate service opportunities into engineering education, the author set out to understand why students are drawn to these experiences and the reasons behind their inclination towards service. The paper has a significant focus on assessing students' engineering epistemological beliefs, and hence its inclusion in our selected papers. Using EBAE as a data collection tool, preliminary results suggested students exhibiting sophisticated engineering epistemological beliefs.

3.1.3 A first step in the instrument development of engineering-related beliefs questionnaire

The paper presents a framework for understanding engineering-related beliefs, which are crucial for students' learning and problem-solving in engineering. They aim to develop a reliable and valid Engineering-related Beliefs Questionnaire, focusing on engineering knowledge, skills, attitudes, identity, and values. The paper contributes to the field by attempting to measure and support the change in students' beliefs, hence its inclusion in our final list of papers.

3.1.4 Exploring engineering students' epistemic beliefs and motivation: a case of a South African university

The paper investigates the epistemic beliefs and motivations of chemical engineering students from low-income communities in South Africa. The study explores how students perceive knowledge construction, using the Engineering Related Beliefs Questionnaire (ERBQ). It reveals that many students view engineering knowledge as unchallengeable and learning as a passive process.

3.1.5 Measuring engineering epistemic beliefs in undergraduate engineering students

The paper investigates undergraduate bioengineering students' epistemic beliefs. It utilizes ERBQ and open-ended items to validate the instrument, hence we included the paper in the final list. The researchers' analysis revealed inconsistencies in students' interpretations of survey items, suggesting a need for clearer language to accurately capture their epistemic beliefs.

3.1.6 Engineering Students' Epistemic Cognition in the Context of Problem Solving

The study explores the connection between engineering students' epistemic cognition and their motivation when solving open-ended problems. Utilizing a mixed methods approach, partially based on ERBQ, the research identifies clusters of students based on their beliefs about the source and certainty of engineering knowledge, as well as their openness to new ideas. Findings suggest that students' approaches to problem-solving are influenced by their epistemic beliefs and motivations.

3.2 Analysis of Papers

3.2.1 The Epistemological Beliefs Assessment for Engineering (EBAE)

As reported by the authors of the instrument, the sample size they used (N = 43) is smaller than the minimum recommended for performing a factor analysis, which affects the validity of the results they reported. Also, no internal consistency measures (Cronbach alpha) were reported. The authors also ran into the problem of low participation rate (27%) which raises concerns about the generalizability of the findings to all first-year engineering students.

In terms of other works that tried using this instrument, (Carberry, 2010) didn't validate the instrument items using factor analysis or test for reliability as the study reported in the publication was a work-in-progress. (Yu & Strobel, 2011) analysis of the instrument found that only two items were directly related to engineering epistemology, while the rest addressed learning or general epistemological beliefs without adopting domain-specific constructs. (Faber et al., 2016) reported a similar critique that although the instrument is intended for engineering-specific epistemology, it is not specific enough to engineering.

Overall, the limitations reported for the EBAE suggest that further refining of the items to accurately measure engineering-specific epistemological beliefs is needed, as well as validating the instrument with a larger and more diverse sample of responders.

3.3 The Engineering Related Beliefs Questionnaire (ERBQ)

To establish this instrument, the researchers (Yu & Strobel, 2011) first developed a conceptual framework that acknowledges the connection between epistemological beliefs, epistemic beliefs, and ontological beliefs. Following that framework, as well as Hofer and Pintrich's (1997) framework (similar to EBAE) the researchers collected several engineering-related beliefs items from existing studies that address each of the three aforementioned constructs, and after refinement, they presented a total of 22 items.

Although content validity testing was performed by the research team where they discussed the instrument in focus groups, they acknowledged that further testing of the instrument with engineering students is needed to produce the final version of the instrument. Their paper introduces a version of what the instrument could look like, but does not pilot test it. According to our search, this pilot was never performed by the research team or by other researchers.

Similar to the lack of addressing engineering-specific domain constructs reported for EBAE, Faber & Benson (2017) reported that ERBQ only includes two items directly related to engineering epistemology. Also, in their attempt to use the instrument they faced low internal consistency for the sub-scale of simplicity and knowledge. Faber et al.(2016) used ERBQ along with open-ended items to study how the students interpreted the items. Their analysis revealed inconsistencies between how the items are worded and the student's understanding of the items, which goes to show the importance of including some qualitative measures along with the numerical instrument.

Some researchers tried to implement that suggestion (Makhathini et al., 2020) by augmenting the items on the ERBQ with open-ended responses to invite the students to engage more deeply with the items on the instrument, and those responses were used for further validation. Their results discarded four of the original twelve items under the source of engineering knowledge construct due to claimed low-reliability factors. Similarly, they also discarded two of the original seven items under the certainty of knowledge construct, leaving 16 out of the original 22 items.

Overall, ERBQ needs iterative refinement of its items, as well as further testing, especially with engineering student populations to ensure the development of a robust and reliable instrument.

4 SUMMARY AND FUTURE WORK

In summary, the EBAE, as it stands, is compromised by several methodological limitations, including a small sample size (N = 43) for factor analysis, a lack of internal consistency measures, and a low participation rate (27%). These factors undermine the validity and generalizability of its findings. Additionally, critiques from subsequent studies (Carberry, 2010; Yu & Strobel, 2011; Faber et al., 2016) suggest that the EBAE fails to adequately capture engineering-specific epistemological beliefs, instead addressing more general epistemological constructs. To address these concerns, there is a clear need for refining the EBAE items to better reflect the unique aspects of engineering epistemology and for conducting rigorous validation studies with larger and more representative samples.

Similarly, the ERBQ also faces significant challenges. The absence of pilot testing and the reported low internal consistency of some sub-scales (Faber & Benson, 2017) cast doubt on its reliability. Furthermore, the findings from Faber et al. (2016) highlight the necessity of incorporating qualitative measures to complement quantitative data. Efforts by Makhathini et al. (2020) to augment the ERBQ with open-ended responses represent a promising step towards enhancing the instrument's validity. However, their results also led to the elimination of several items due to low reliability, underscoring the need for iterative refinement.

Overall, we were surprised by the small number of engineering epistemology-specific instruments found. In contrast to the science field where various quantitative instruments have been developed and utilized to measure epistemological beliefs about the nature of science e.g. the Nature of Scientific Knowledge Scale (NSKS), engineering lacks a contrasting domain-specific instrument dedicated to engineering knowledge.

Given the importance of domain-specific instruments (Faber & Benson, 2017; Hofer, 2000; Palmer & Marra, 2004), the engineering education research community needs to dedicate efforts towards designing and validating an engineering-specific epistemological tool. Such a tool would serve to guide, enable, and constrain the analysis and articulation of how knowledge is produced within the engineering field (Boon & Baalen, 2018). Which in turn enhances students' learning, motivation, and achievement (Chai et al., 2006; Muis et al., 2006), and teacher education (Bendixen & Rule, 2004; Green & Hood, 2013; Montfort et al., 2014) ultimately enabling educators to design better learning experiences for students (Tan et al., 2019; Turns et al., 2005).

Future work will expand the analysis by comparing the engineering-specific instruments presented here with some of the domain-general instruments like the

Epistemic Belief Inventory. In accordance with (Muis et al., 2006) epistemic beliefs are both domain-general and domain-specific, and such comparison will enable us to test this argument and consequently design an instrument that potentially provides a balance between domain-general and domain-specific beliefs. We believe this will be particularly useful in characterizing epistemic beliefs at interdisciplinary boundaries when more fluid dimensions are needed to account for the moving lines of context and domain in interdisciplinary work.

REFERENCES

American Educational Research Association, American Psychological Association, & National Council on Measurement in Education. (2014). *Standards for educational and psychological testing*.

Bendixen, L. D., & Rule, D. C. (2004). An Integrative Approach to Personal Epistemology: A Guiding Model. *Educational Psychologist*, *39*(1), 69–80. https://doi.org/10.1207/s15326985ep3901_7

Boon, M., & Baalen, S. van. (2018). Epistemology for Interdisciplinary Research – Shifting Philosophical Paradigms of Science. *European Journal for Philosophy of Science*, *9*(1). https://doi.org/10.1007/s13194-018-0242-4

Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education*, *103*(1), 45–76. https://doi.org/10.1002/jee.20038

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., & Franco, O. H. (2017). Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. *Systematic Reviews*, *6*(1), 245. https://doi.org/10.1186/s13643-017-0644-y

Carberry, A. (2010). Work in Progress - Assessing Engineering Service Students' Characteristics. *IEEE Frontiers in Education*.

Carberry, A., Ohland, M., & Swan, C. (2010). A Pilot Validation Study of the Epistemological Beliefs Assessment for Engineering (EBAE): First-Year Engineering Student Beliefs. *American Society for Engineering Education*.

Chai, C. S., Khine, M. S., & Teo, T. (2006). Epistemological Beliefs on Teaching and Learning: A Survey Among Pre-service Teachers in Singapore. *Educational Media International*, *43*(4), 285–298. https://doi.org/10.1080/09523980600926242

DeBacker, T. K., Crowson, H. M., Beesley, A. D., Thoma, S. J., & Hestevold, N. L. (2008). The challenge of measuring epistemic beliefs: An analysis of three self-report instruments. *Journal of Experimental Education*, *76*(3), 281–312. https://doi.org/10.3200/JEXE.76.3.281-314

Faber, C., & Benson, L. C. (2017). Engineering Students' Epistemic Cognition in the Context of Problem Solving. *Journal of Engineering Education*, *106*(4), 677–709. https://doi.org/10.1002/jee.20183

Faber, C., Vargas, P., & Benson, L. (2016). Measuring engineering epistemic beliefs in undergraduate engineering students. *IEEE Frontiers in Education Conference*.

Finelli, C., & Borrego, M. (2015). *EER Taxonomy Version 1.0.* University of Michigan.

Frye, N., Montfort, D., Brown, S., & Adesope, O. (2012). I'm absolutely certain that's probably true: Exploring epistemologies of sophomore engineering students. *Frontiers in Education Conference Proceedings*, 1–6.

Ghazali, N. E., Bakar, Z. A., Shafie Bakar, M., Nur, T., Tengku, Z., Busu, M., Farahwahidah, N., Rahman, A., Effiyana Ghazali, N., & Abu Bakar, Z. (2021). Epistemology in Engineering Education: An Overview. In *ASEAN Journal of Engineering Education* (Vol. 5, Issue 2).

Green, H. J., & Hood, M. (2013). Significance of epistemological beliefs for teaching and learning psychology: A review. *Psychology Learning and Teaching*, *12*(2), 168–178. https://doi.org/10.2304/plat.2013.12.2.168

Hetherington, S. (Ed.). (2012). *Epistemology: the key thinkers*. Continuum International Publishers.

Hofer, B. K. (2000). Dimensionality and Disciplinary Differences in Personal Epistemology. *Contemporary Educational Psychology*, *25*(4), 378–405. https://doi.org/10.1006/ceps.1999.1026

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140. https://doi.org/10.2307/1170620

Kramer, A., Leonard, A., Desing, R., & Dringenberg, E. (2024). Beliefs in engineering education research: A systematic scoping review for studying beliefs beyond the most popular constructs. *Journal of Engineering Education*, 1–38. https://doi.org/10.1002/jcc.20583

Lonka, K., Sharafi, P., Karlgren, K., Masiello, I., Nieminen, J., Birgegård, G., & Josephson, A. (2008). MED NORD - A tool for measuring medical students' well-being and study orientations. *Medical Teacher*, *30*(1), 72–79. https://doi.org/10.1080/01421590701769555

Makhathini, T. P., Mtsweni, S., & Bakare, B. F. (2020). Exploring engineering students' epistemic beliefs and motivation: A case of a South African university. *South African Journal of Higher Education*, *34*(4). https://doi.org/10.20853/34-4-3625

Mengist, W., Soromessa, T., & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX*, *7*, 100777. https://doi.org/https://doi.org/10.1016/j.mex.2019.100777

Montfort, D., Brown, S., & Shinew, D. (2014). The personal epistemologies of civil engineering faculty. *Journal of Engineering Education*, *103*(3), 388–416. https://doi.org/10.1002/jee.20050

Muis, K. R., Bendixen, L. D., Haerle, F. C., Muis, K. R., Bendixen, · L D, & Haerle, F. C. (2006). Domain-Generality and Domain-Specificity in Personal Epistemology Research: Philosophical and Empirical Reflections in the Development of a

Theoretical Framework. *Educ Psychol Rev*, *18*, 3–54. https://doi.org/10.1007/s10648-006-9003-6

Palmer, B., & Marra, R. M. (2004). College student epistemological perspectives across knowledge domains: A proposed grounded theory. In *Higher Education* (Vol. 47).

Petticrew, M., & Roberts, H. (2006). Systematic Reviews in the Social Sciences: A Practical Guide. In *Systematic Reviews in the Social Sciences: A Practical Guide* (Vol. 11). https://doi.org/10.1002/9780470754887

Pintrich, P. (2002). Future challenges and direction for theory and research on personal epistemology. *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing*.

Tan, E., Barton, A. C., & Benavides, A. W. (2019). Engineering for Sustainable Communities: Epistemic Tools in Support of Equitable and Consequential Middle School Engineering. *Science Education*, *103*(4), 1011–1046. https://doi.org/10.1002/sce.21515

Turns, J., Atman, C. J., Adams, R. S., & Barker, T. (2005). Research on engineering student knowing: Trends and opportunities. *Journal of Engineering Education*, *94*(1), 27–40. https://doi.org/10.1002/j.2168-9830.2005.tb00827.x

Yildirim, T. P., Besterfield-Sacre, M., & Shuman, L. J. (2010). *Estimating the Impact of Epistemological Beliefs on Modeling Ability*. https://api.semanticscholar.org/CorpusID:146561160

Yu, J. H., & Strobel, J. (2011). Instrument Development: Engineering-specific Epistemological, Epistemic and Ontological Beliefs. *Proceedings of the Research in Engineering Education Symposium*.

Yu, J. H., & Strobel, J. (2012). A First Step in the Instrument Development of Engineering-related Beliefs Questionnaire. *American Society for Engineering Education Conference*.

An overview of the professional skills encountered through capstone engineering projects

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ABSTRACT

We present an analysis of the professional competencies encountered by engineering students during their capstone projects. We collected weekly reflective journals from 32 students completing their capstone projects at ETH Zurich. Through a deductive quantitative content analysis, we identified the professional competencies posing the greatest challenges for students and examined the frequency of their resolution. Additionally, we explored the distribution of challenges across different project phases and assessed their difficulty levels. Our findings reveal that while capstone projects aim to cultivate professional skills, they primarily challenge students' technical abilities. Moreover, most encountered challenges are those directly assessed through project deliverables, such as applying technical foundations that are assessed through technical artifacts and communicating effectively which is assessed through the final presentation. The majority of challenges arise during the implementation, testing, and prototyping phases, with fewer reported during problem definition and solution design phases, suggesting potential disparities in attention and time allocation across project stages. Notably,

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although the problem definition phase encounters fewer challenges, students perceive the challenges within this stage as more difficult. Consequently, we conclude that allocating additional time and importance to solution design and problem definition phases may effectively foster a broader range of professional skills among students, including creative thinking and decision-making abilities.

1 INTRODUCTION

Today, engineering students will graduate into a workspace characterized by constant changes in technologies and an increase in automation, and will also be asked to solve complex issues. To confront these challenges successfully, students must possess professional skills to find creative solutions to new problems, promote sustainable development, and adapt to the constantly changing workplace.

To prepare engineers for such challenges, there has been a rise in the past 50 years of engineering programs adopting inquiry-based learning due to its anticipated benefits in fostering professional skills (Bielefeldt, Paterson, and Swan 2009; C.-H. Chen and Yang 2019; Jamison et al. 2022). For example, project-based learning (PBL), an instructional approach in which students learn new skills by solving real-world challenges, has been integrated into curricula. Most engineering students encounter projects for the first time during their capstone projects (C.-H. Chen and Yang 2019; Dutson et al. 1997) and are expected to develop various professional skills by completing them. A capstone project is designed to bring all aspects of an undergraduate student's experience together by allowing students to apply the breadth of knowledge and skills they have learned. Traditionally, engineering curricula have typically included major group and/or individual design projects aimed at cultivating graduates with essential professional engineering skills. These skills encompass data interpretation, application of theory, problem-solving, design, multidisciplinary teamwork, communication skills, and ethical considerations (Ward 2013)

PBL is a learning method that extends over a longer time and follows a process. Stoller defines PBL as "having a process and a product" and "extending over a period of time" (Stoller 2006). Projects have different phases such as problem definition, solution design, implementation, evaluation and testing, and presentation (Honglin and Yifan 2022). The project process is not linear, and each phase may require different professional competencies. Understanding which competencies students use during different project phases would allow instructors to provide better support for the activities. Few studies have discussed PBL theory or practice from this perspective. In their paper, (English and Kitsantas 2013) described teaching practices to foster students' self-regulating activities in each phase of PBL. They highlighted the fact that accounting for PBL phases when studying PBL may lead to a better understanding of learning processes during PBL and help educators better facilitate the development of self-regulated learning (English and Kitsantas 2013).

Typically, the evaluation of projects explicitly targets some professional competencies, such as problem-solving through the delivery of the end product and communication skills through the final presentation of the work. However, many important competencies are neither evaluated nor explicitly taught. In this study, we are interested in the professional competencies encountered by students in capstone projects. We analyze weekly reflective journals collected during students' capstone projects to: 1) extract the professional competencies encountered by students as a challenge during capstone projects, 2) identify how frequently students encounter the different specific challenges, and 3) identify how the challenges are distributed across project phases.

We assumed that when students encounter difficulties practicing a certain competency, they experience that competency in a meaningful way, which could eventually lead to learning.

1.1 Professional competencies

Passow and Passow's review highlighted that such research has been extensive, involving interviews with over 500 individuals, analyzing over 36,000 job postings, and surveying more than 1,500 employers and employees (Passow and Passow 2017). Interestingly, the identified competencies do not always align with the outcomes specified by accreditation bodies. As an example, Passow (2012) found in a survey involving graduates from 11 programs across different graduation years that eight competency sets did not match the ABET categories.

In this work, we adapt the professional competencies identified by Passow and Passow as the foundation for our analysis. Our selection is influenced by the fact that these competencies are derived from the most extensive meta-analysis we encountered. The analysis draws upon a significant number of quantitative studies (27 studies with 14,429 participants) and qualitative thematic analyses (25 studies with 2,174 participants plus 36,100 job postings). Furthermore, they prioritized high-quality studies that take into account the presence of a comparison group, the use of validated measures, and a detailed description of participants' experiences. Their research identified 16 key engineering competencies, which are categorized into:

- Applying technical foundation (e.g., interpreting data, applying knowledge),
- Collaborating (e.g., effective communication, coordinating efforts),
- Engineering effectively (e.g., taking initiative, thinking creatively),
- Managing personal performance (e.g., devising processes, taking responsibility).

2 METHODOLOGY

We collected reflective journals from 32 engineering students enrolled in the Department of Information Technology and Electrical Engineering, conducting their theses at ETH Zurich. The students were working on their bachelor's thesis, semester thesis (which they undertake at the end of their second semester during their master's degree), or their master’s thesis. The complexity of the projects varied depending on whether the students were working on their bachelor's thesis, semester thesis, or master's thesis. Some students were conducting group projects, while others were working alone as it is common practice in the world's top-ranked engineering universities to simulate authentic engineering projects and working environments (Ward 2013).

The thesis advisors met with the students once a week. During these meetings, the students shared their progress, discussed any issues blocking their work, and briefed the advisors about their plans. Although the students did not have access to the evaluation criteria, they could inquire about them if interested, and very few did so. All students were required to submit a report describing their work, along with any resulting prototypes or code. Additionally, they had to present their thesis in a 30-minute presentation open to members of their groups and to the department.

2.1 Data collection

At the beginning of the semester, the students were introduced to the purpose of the study and asked to fill out their reflective journals at the end of each class. The reflective journal included open-ended questions about the tasks they worked on that week, the challenges they faced, and the difficulty of the challenges they faced on a Likert scale ranging from 1 to 5. We also asked them whether they were able to resolve the challenge. We sent out weekly reminders every week, asking the students to fill out the reflective journal that contained the guiding questions. To protect the anonymity of students and make sure that their fear of being identified does not constrain their reporting, we asked them to use the nickname of their choice instead of their name in the weekly journal entry. There were no inquiries about background, gender, or any other information that might be used to identify students. Furthermore, the surveys were disseminated via a QR code and were not associated with the students' email addresses. It was also emphasized that completing the journal was optional and would not influence their grades. The student responses were accessed only by the researchers and were not made available to the instructors. There were 192 entries submitted by the students. Each of these entries contains one or more encountered challenges.

2.2 Data Analysis

We analyzed the data using a deductive quantitative content analysis following Mayring’s recommendations (Mayring 2015). Our choice was motivated by three main reasons: 1) Professional competencies have been extensively defined, making a deductive approach suitable for further study comparisons. 2) Mayring's method accommodates inductive reasoning, enabling us to refine categories based on emerging patterns. 3) Given our large dataset, quantitative content analysis facilitates potentially generalizable statistical comparisons. We chose the Passow and Passow 16 competencies as a sampling unit to code the students’ answers. We used the definitions and examples of the competencies provided by Passow and Passow as coding guidelines. We coded students' answers based on Passow and Passow's competencies, adding new categories as they emerged. Through an initial categorization of the data, we found categories that are missing from Passow and Passow's list of competencies. Students’ answers to the question “What are the challenges you faced this week?”

Two coders initially coded approximately 20% of the data and then compared their codings, revising the categories accordingly. The discussion led to merging two codes, "Applying knowledge" and "Applying skills," into a single category. Additionally, the code "Regulating emotions" was added while the code "Defining constraints" was removed. The two coders agreed to reorganize the categories by adding the code "Solving problems" and expanding the code "Skills" into the category "Applying technical foundation." After these revisions, the two coders continued coding the remaining answers. They subsequently met again to review the codes together, discussing any differences that emerged. The final codes as well as corresponding examples are shown in Appendix 1.

Furthermore, students' activities were coded to correspond with the various stages of a project. Since the project process is inherently iterative, we used their accounts of the activities they engaged in as a proxy for determining the main stage they were focused on each day. We analyzed the competencies experienced by students by computing the percentage of students encountering each competency.

3 RESULTS

We first analyzed the challenges experienced by students when they conduct projects. Table 2 shows the percentage of students who encountered difficulties with each of the different competencies. The results show that "expanding skills" is the competency that is encountered by most students (n= 17, 53.12%), followed by solving problems (n= 16, 50%), and applying knowledge skills (n= 12, 37.5%). These three competencies belong to the category of *Applying technical foundation*. Other competencies that are highly experienced by students are *communicating effectively* (n= 11 34.38%), gathering information (n= 10, 31.25%), and devising process (n= 9, 28.12%).

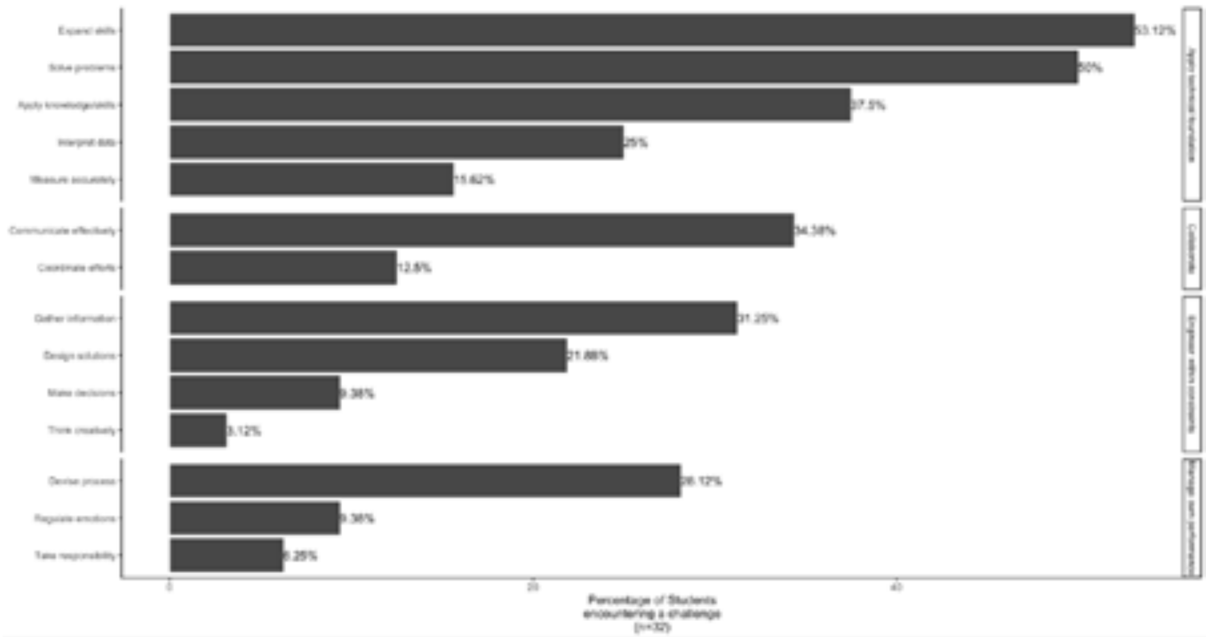

Fig.1 Percentage of students experiencing a professional skill as a challenge.

In analyzing the challenges, we focused on the frequency with which each challenge was successfully resolved, rather than the number of students who resolved each challenge. This means we counted every instance a challenge was resolved, even if the same student encountered it multiple times. We specifically examined challenges that occurred at least 5 times. As shown in Figure 2, Among the challenges, the challenge that remained least resolved related to the competency "designing solutions" (n= 8, resolved 12.5% of the times) followed by "applying knowledge/skills"(n= 17, resolved 35.29% of the times), and "expanding skills" (n=29, resolved 41.38%

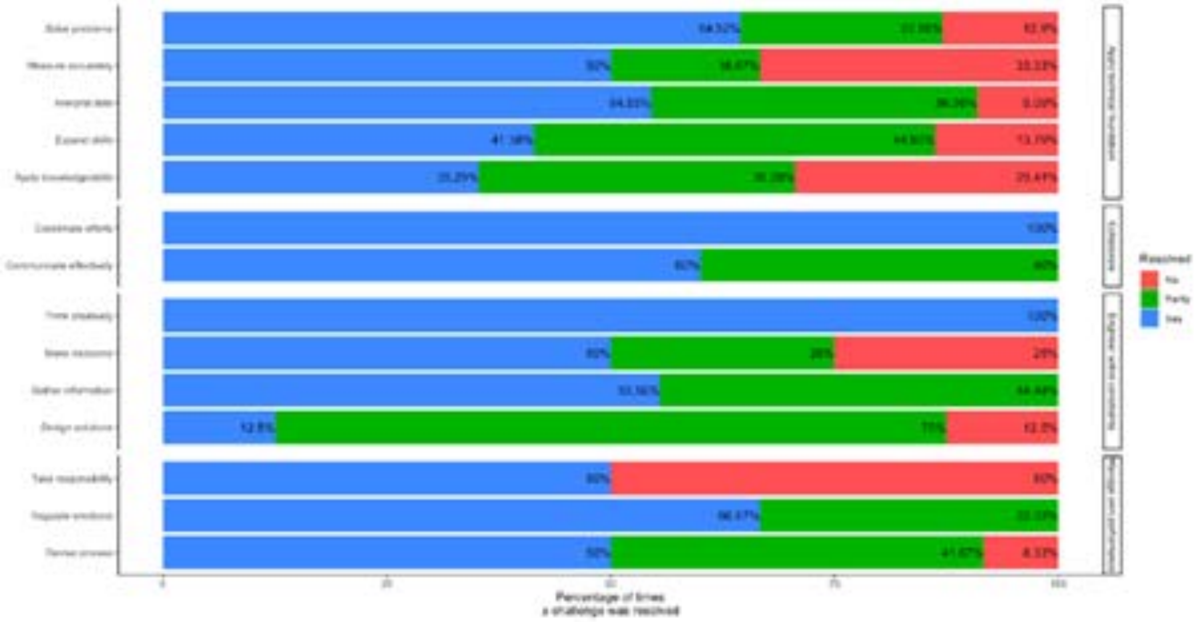

Fig. 2 Percentage of times a challenge was resolved.

Further on, we looked at the distribution of challenges by project phase. Most of the challenges are encountered during the implementation phase (n=45, 52.3%), followed by the prototyping and testing phase (n=21, 24.4%). The least represented phases during the challenges were problem definition (n=10, 5.8%), and solution design (n=10, 5.8%).

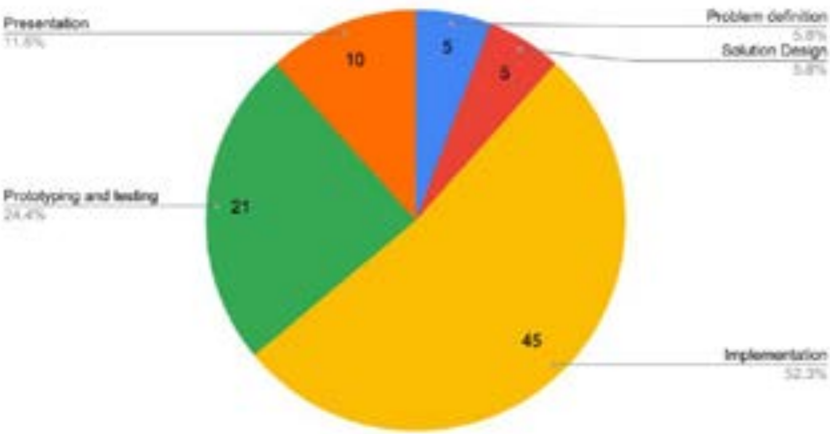

Fig. 3 Distribution of challenges by project phase

Finally, we looked into the perceived difficulty of challenges by project phase. We see that students perceived the challenges encountered during the Problem definition phase and presentation phase as more difficult compared to the other project phases.

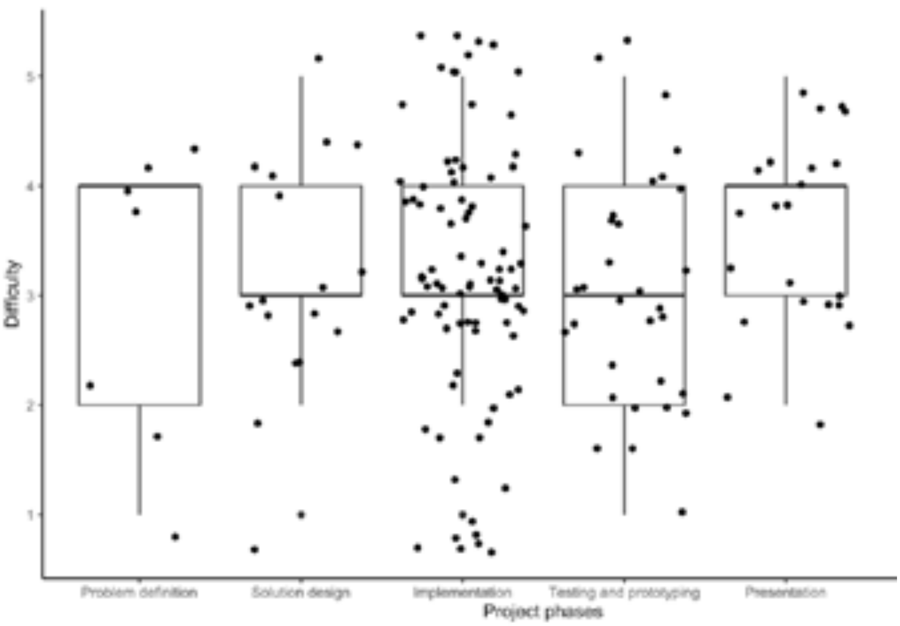

Fig. 4 Perceived difficulty of the challenges by project phase

4 DISCUSSION AND CONCLUSIONS

We identified the professional skills that students experience during project work by analyzing the weekly journal responses of 32 engineering students during their capstone projects. We also analyzed the frequency of the challenges that students were able to resolve. Finally, we identified the change in competencies experienced by students at the different phases of the project. In the following section, we discuss our results in relation to the previous literature.

Limitations

Some limitations affect the study's generalizability. We relied on self-reports to identify the competencies that students are exposed to. Students might have experienced competencies in a form that was not a challenge. They could have also missed reporting some challenges. They also could have reported additional challenges to appear socially desirable or more in distress than they were and gain certain benefits like appealing to the indulgence of the faculty (Nederhof 1985). To mitigate this risk, we designed an anonymous reflective journal and clarified that the results were not shared with the instructors.

In this study, bachelor's theses, semester theses, and master's theses are collectively analyzed under the term "capstone engineering projects," with both group and individual projects considered together. Future studies could benefit from investigating the professional competencies in different types of project and group work.

Capstone projects challenge students' technical competencies

Capstone projects' goal is to provide engineering graduate students with professional skills that are desired in the workplace such as problem-solving, design, communication skills, and ethics (Ward 2013). Our results show that the capstone projects mostly challenge students in technical competencies such as expanding their technical skills, solving problems, and applying the theoretical knowledge and practical skills they had learned during their course.

The competencies that are the most encountered are the ones that are explicitly evaluated

Additionally, we show that other highly experienced competencies include effective communication and information gathering. These competencies, along with technical skills, are directly evaluated through project deliverables. Applying technical foundations is assessed through technical artifacts, while effective communication is assessed through the final report and presentation. This emphasis on evaluated competencies may stem from students investing more effort in areas that directly impact their grades. Although capstone projects' evaluations usually include diverse professional skills, these criteria are often not explicitly communicated to students, potentially affecting their focus during the project. Introducing alternative evaluation methods could positively impact the development of professional skills. For instance, Friess and colleagues proposed a peer-evaluation method that encourages students to practice professional communication, including giving and receiving critical feedback (Friess and Goupee 2020).

We also show that some critical competencies are not, or little experienced by students during projects. These competencies include thinking creatively, making decisions, taking responsibility, and coordinating efforts. This sheds light on the need to design projects that specifically target these competencies since stronger learning takes place when there is explicit teaching and regular feedback on professional skills (Picard et al. 2022). Arguably, students could be learning these competencies without experiencing them as a challenge. For instance, existing papers showed that PBL has a positive effect on students' ability to work in a team (Berbegal Mirabent, Gil Doménech, and Alegre 2017; Reis, Barbalho, and Zanette 2017; Vogler et al. 2018) which is not reflected in our results. However, these effects should be considered with care as they most often result from self-reported measures. Students tend to report positively about an experience when the activity is fun and engaging, which is often the case with PBL (Thomas 2000).

Under focus on problem definition and solution design phases

We also show that students face fewer challenges in the project phases that involve defining the problem and designing the solution. This could indicate a lack of time and dedication to this important phase of the project.

These project phases foster skills that are essential when dealing with open-ended problems and will be particularly needed when working as engineers (Korte, Sheppard, and Jordan 2008; "The Future of Jobs Report 2020 | World Economic Forum," n.d.). Additionally, we see that students find the problem definition phase particularly challenging. It is not surprising that students encounter difficulties dealing with open-ended problems since many of them never had to practice the required skills before taking the PBL class. This is actually common practice in the current curricula where students face projects for the first time during the capstone project, which limits the improvement of their professional competencies (J. Chen, Kolmos, and Du 2021; Dutson et al. 1997). Beginning to practice professional competencies so late in the curriculum might leave the students totally unprepared for their future jobs. It is therefore important to provide projects to students early on in their studies which allows them to repeatedly face challenges and better prepare them to join the workforce.

REFERENCES

Berbegal Mirabent, Jasmina, Maria Dolors Gil Doménech, and Ines Alegre. 2017. “Where to Locate? A Project-Based Learning Activity for a Graduate-Level Course on Operations Management.” *International Journal of Engineering Education* 33 (5): 1586–97.

Bielefeldt, Angela, Kurt Paterson, and Chris Swan. 2009. “Measuring the Impacts of Project Based Service Learning.” In *2009 Annual Conference & Exposition*, 14–873.

Chen, Cheng-Huan, and Yong-Cih Yang. 2019. “Revisiting the Effects of Project-Based Learning on Students’ Academic Achievement: A Meta-Analysis Investigating Moderators.” *Educational Research Review* 26: 71–81.

Chen, Juebei, Anette Kolmos, and Xiangyun Du. 2021. “Forms of Implementation and Challenges of PBL in Engineering Education: A Review of Literature.” *European Journal of Engineering Education* 46 (1): 90–115.

Dutson, Alan J., Robert H. Todd, Spencer P. Magleby, and Carl D. Sorensen. 1997. “A Review of Literature on Teaching Engineering Design through Project-Oriented Capstone Courses.” *Journal of Engineering Education* 86 (1): 17–28.

English, Mary C., and Anastasia Kitsantas. 2013. “Supporting Student Self-Regulated Learning in Problem-and Project-Based Learning.” *Interdisciplinary Journal of Problem-Based Learning* 7 (2): 6.

Friess, Wilhelm A., and Andrew J. Goupee. 2020. “Using Continuous Peer Evaluation in Team-Based Engineering Capstone Projects: A Case Study.” *IEEE Transactions on Education* 63 (2): 82–87.

Honglin, Liu, and Niu Yifan. 2022. “The Construction of Project-Based Learning Model Based on Design Thinking.” In *2022 4th International Conference on Computer Science and Technologies in Education (CSTE)*, 173–77. IEEE.

Jamison, Cassandra Sue Ellen, Jacob Fuher, Annie Wang, and Aileen Huang-Saad. 2022. “Experiential Learning Implementation in Undergraduate Engineering Education: A Systematic Search and Review.” *European Journal of Engineering Education*, 1–24.

Korte, Russell, Sheri Sheppard, and William Jordan. 2008. “A Qualitative Study of the Early Work Experiences of Recent Graduates in Engineering. Research Brief.” *Center for the Advancement of Engineering Education (NJ1)*.

Mayring, Philipp. 2015. “Qualitative Content Analysis: Theoretical Background and Procedures.” In *Approaches to Qualitative Research in Mathematics Education*, 365–80. Springer.

Nederhof, Anton J. 1985. “Methods of Coping with Social Desirability Bias: A Review.” *European Journal of Social Psychology* 15 (3): 263–80.

Passow, Honor J. 2012. “Which ABET Competencies Do Engineering Graduates Find Most Important in Their Work?” *Journal of Engineering Education* 101 (1): 95–118.

Passow, Honor J., and Christian H. Passow. 2017. “What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review.” *Journal of Engineering Education* 106 (3): 475–526. https://doi.org/10.1002/jee.20171.

Picard, Cyril, Cécile Hardebolle, Roland Tormey, and Jürg Schiffmann. 2022. “Which Professional Skills Do Students Learn in Engineering Team-Based Projects?” *European Journal of Engineering Education* 47 (2): 314–32.

Reis, Ana Carla Bittencourt, Sanderson César Macêdo Barbalho, and Alline Christine Diniz Zanette. 2017. “A Bibliometric and Classification Study of Project-Based Learning in Engineering Education.” *Production* 27.

Stoller, Fredricka. 2006. “Establishing a Theoretical Foundation for Project-Based Learning in Second and Foreign Language Contexts.” *Project-Based Second and Foreign Language Education: Past, Present, and Future*, 19–40.

“The Future of Jobs Report 2020 | World Economic Forum.” n.d. Accessed December 21, 2022. https://www.weforum.org/reports/the-future-of-jobs-report-2020/.

Thomas, John W. 2000. “A Review of Research on Project-Based Learning.” California.

Vogler, Jane S., Penny Thompson, David W. Davis, Blayne E. Mayfield, Patrick M. Finley, and Dar Yasseri. 2018. “The Hard Work of Soft Skills: Augmenting the Project-Based Learning Experience with Interdisciplinary Teamwork.” *Instructional Science* 46 (3): 457–88.

Ward, Thomas A. 2013. “Common Elements of Capstone Projects in the World’s Top-Ranked Engineering Universities.” *European Journal of Engineering Education* 38 (2): 211–18. https://doi.org/10.1080/03043797.2013.766676.

Appendix 1

Table 1. The final codes as well as corresponding examples

Category	Code	Definition	Example
Apply technical foundation	Apply skills and knowledge	Challenge applying theoretical knowledge as well as technical skills.	*I'm still struggling with the Verilog syntax. I think I'm not yet used to the syntax or how to approach problems.*
	Interpret data	Challenges with organizing, analyzing, and interpreting data. Usually encountered during debugging activities, or when making sense of results.	*Interpolating the data and assessing it’s uncertainty.*
	Measure accurately	Challenge with measuring accurately and quantifying errors.	*I didn't know how to start building our own game. It was a bit overwhelming.*

	Solve problems	Challenge identifying, formulating, and solving, engineering problems within defined constraints.	*Get communication to work between Chip and mcu.*
	Expand skills	Challenge expanding skills, and learning new skills.	*learning to parse JSON format with Telegraph.*
Collaborate	Communicate effectively	Challenge with communicating effectively with people that have diverse backgrounds through listening, oral, written, and graphical means.	*Breaking down the content of your thesis such that it can be transmitted within 15mins without having to leave out large parts of what you've done*
	Coordinate efforts	Challenge with collaboration to achieve goals shared with co-workers.	*Me and Sebastian both did the same work on dockerizing the Zephyr OBC project which was disappointing.*
Engineer within constraints	Gather information	Challenge gathering information as needed by searching literature/ the internet.	*look at resources on the subject and understand them; Understand the state-of-the-art time series forecasting models.*
	Think creatively	Challenge thinking creatively when problem-solving and designing solutions.	*Thinking about alternative ways to test some characteristics.*
	Design solutions	Challenge designing a system, component, or process.	*Create layout & routing from schematics.*
	Make decisions	Challenge while making decisions about problem-solving and designing solutions.	*I had to decide which serial protocols are suitable for on board communication.*
Manage own performance	Devise process	Challenge devising and managing one's own process to accomplish a goal. e.g., Estimate time and cost; plan; set and adjust priorities.	*One problem is that I'm involved in another part of the project with higher priority and it's hard to find enough time to work on both.*
	Take responsibility	Challenge taking professional and ethical responsibility for decisions and behavior.	*Getting everything done before the deadline.*
	Regulate emotions	Challenge recognizing and regulating negative emotions	*Was in small motivation slump*

DEVELOPING A BETTER UNDERSTANDING OF IMPACT EVALUATION OF STEM OUTREACH PROGRAMMES – A COMPARATIVE STUDY EXPLORING TEACHERS' AND OUTREACH EVALUATORS' PERSPECTIVE

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ABSTRACT

STEM outreach is a potential route to showcase the engineering discipline in secondary education, in the hope that more young people veer towards the subject in tertiary education and as a career. Impact evaluation of outreach helps determine the success of the programme with respect to its objectives, as well as informing future initiatives. However, impact evaluation of STEM outreach programmes has proven cumbersome and differs across the literature due to the informal space that

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outreach occurs and stakeholders with differing goals. This paper seeks to explore the operational intricacies involved in the STEM outreach landscape that affects impact evaluation. To this end, interviews were conducted with stakeholders involved in STEM outreach, namely teachers and evaluators, to enquire about their experiences regarding outreach evaluation. Interview transcripts were analysed using thematic analysis. Participants' perception of evaluation was generally positive but mentioned several barriers that impeded conducting rigorous evaluation in outreach programmes. It is hoped that this paper can elicit further discussion regarding improving impact evaluation in outreach programmes from a pragmatic perspective.

1 INTRODUCTION

1.1 Background and literature review

Science, Technology, Engineering and Mathematics (STEM) education plays a pivotal role in the modern world. The fact that the United Kingdom (UK) has been facing a STEM skill shortage over the last few decades is of concern to policymakers (Morgan, Kirby, and Stamenkovic 2016). This phenomenon has been fuelled by the fluctuating job market following the coronavirus pandemic (Powell, Francis-Devine, and Foley 2022). Yet engineering, one of the STEM pillars, is almost non-existent in secondary education in the UK – it is not a specifically designated subject in the National Curriculum albeit some of the skills and practices associated with the subject is arguably taught in other subjects such as design & technology (Bonsall, Bianchi, and Hanson 2020).

Outreach, both as ad-hoc activities and long-term programmes, is seen as a potential solution to motivate young people in secondary education towards STEM subjects such as engineering in tertiary education and ultimately as a career (Tillinghast et al. 2020). Outreach exists in the informal education space and as such is an umbrella term that represents a wide range of activities, from industry-led activities such as out of school visits to STEM after school clubs (RAEng 2022). Furthermore, there is a variety of stakeholders involved in outreach with different needs and goals, including facilitators whose main task is to ensure successful delivery of outreach activities, funders whose main concern may be the financial efficiency of an outreach programme on participants and teachers who are keen for their students to develop or enhance their passion for STEM subjects (Appel et al. 2020).

As such, evaluation of outreach programmes has struggled to provide causal evidence of its impact on individuals over an extended timeframe (Banerjee 2017; Robinson and Salvestrini 2020). Whilst recently there have been guidance towards 'best practices' suggested in the literature, this has been limited to theoretical concepts such as methodologies (e.g., suggestions to use validated questionnaires or more broadly encouraging Randomised Controlled Trials (RCTs)) (EngineeringUK 2023; TASO 2020). These best practices tend to be based on the wider evaluation literature, rather than empirical research exploring the STEM outreach landscape. Furthermore, the perpetuation of RCTs may strengthen the narrative of evaluation being a top-down approach which seeks accountability mainly from operational stakeholders (e.g., teachers) against the promise of continuation or reactive change (Kelly 2021). Given teachers are already tasked to fit outreach initiatives within the formal education schedule, often with little help from their school, evaluation of outreach needs to overcome social and practical barriers (Aslam, Adefila, and Bagiya 2018). In other words, evaluators need to cater not only for theoretical best practices but also for operational realities when evaluating outreach. Theoretical best practices (e.g., conducting data collection in multiple instances to increase reliability of results) can be at odds with operational realities (e.g., time constraints) and raises the question of how evaluation of STEM outreach should be conducted.

In this paper, we seek to explore the STEM outreach landscape regarding evaluation, to develop a better understanding of the operational realities where evaluation takes place in. The following research questions are thus proposed:

RQ1: What are the perceptions of teachers and outreach evaluators regarding STEM outreach evaluation?

RQ2: What is the impact of operational challenges on impact evaluation of STEM outreach programmes?

2 METHODOLOGY

2.1 Study Design

This paper is part of a doctoral research project that explores the formulation of a software system to facilitate impact evaluation of STEM outreach. A sequential explanatory study design is used in this instance, whereby quantitative data collection is followed by qualitative data collection. The quantitative element is conducted using a Delphi study, a research method that has previously been used in engineering education and aims to achieve consensus among a panel of experts through a series of rounds of questionnaires (Linstone and Turoff 1975; Rossouw, Hacker, and De Vries 2011). In this study, the Delphi study focussed on impact indicators that are used in STEM outreach evaluation, including aspiration towards STEM educational opportunities, knowledge of STEM opportunities beyond secondary school and attainment in STEM subjects, and was deemed beyond the research questions. On the other hand, qualitative data collection is achieved through phenomenological interviews. This sequential explanatory design allows for further exploration of concepts identified in the Delphi study (Creswell 1999; Johnson and Onwuegbuzie 2004). It has been preferred to a concurrent study design whereby quantitative and qualitative data are collected simultaneously, because:

1. it allows for dissemination of the quantitative data with participants,

2. of practical time constraints - quantitative data will need to be analysed in a short space of time following data collection, as the study involves two rounds of questionnaires (Leech and Onwuegbuzie 2009).

It is worth noting that this paper is solely based on the interview data collected as part of the wider project.

This research was granted ethical approval by the Biomedical and Scientific Research Ethics Committee at the University of Warwick (**BSREC 127/22-23).**

2.2 Sampling Framework

Two groups of STEM outreach stakeholders were identified as participants for this study, namely STEM teachers and STEM outreach evaluators. STEM teachers were previously identified as playing a key role in enabling STEM outreach to occur in schools (Aslam, Adefila and Bagiya 2018). The role of STEM outreach evaluators merit further investigation as despite their involvement in STEM outreach evaluation, they are often unrecognised (Appel et al., 2020). An expansion on the role of evaluators outside the realms of STEM outreach have been beneficial (Rogers, McCoy and Kelly 2019). Purposive sampling was used for the overall research project, whereby the lead author identified participants through the literature and their own professional connections (Etikan, Musa, and Alkassim 2016). Participants were contacted via email or LinkedIn. Inclusion criteria were set for each group of participants, to ensure that participants were familiar with the topic of STEM outreach evaluation:

- STEM teachers: STEM teachers, working in UK secondary education, who identify as being involved in STEM outreach in one or more of the following defined roles: coordinator, evaluator, facilitator, manager or participant, and who is deemed to have substantial involvement in STEM outreach by the lead author. Additional personal information (such as number of STEM outreach programmes an individual is involved in, or length of longest outreach programme they were involved in) was collected to determine substantial involvement in this instance.
- STEM outreach evaluators: Employees of outreach providers OR employees of independent outreach evaluation institution who have conducted evaluation of STEM outreach programmes in the UK.

At the time of writing, interviews have been conducted with five STEM Teachers and four STEM outreach evaluators by the lead author, with an aim of interviewing at least 10 participants from each group of participants in the next three months. A sample size of 10 is regarded as a suitable number for each group of participants for phenomenological interviews (Moser and Korstjens 2018; M. Saunders, Lewis, and Thornhill 2019).

2.3 Research Protocol

The protocol used in this instance is semi-structured interviews, focussing on participants' lived experience regarding STEM outreach. Most of the interviews were conducted using Microsoft Teams with audio recording except for one face to face interview which was conducted in a school. The start of interviews included an introduction of the research from the researcher followed by a brief discussion of participants' occupation, which provided a platform for further questions. The interview spanned participant's involvement and perception regarding:

1. STEM outreach in general, including their aim for facilitating outreach activities and perceived effectiveness of certain activities across different age groups,

2. impact evaluation of STEM outreach programmes, including if evaluation was perceived as part of a programme or a standalone concept and how they envisaged carrying out different stages of evaluation from 'design and implementation' to 'reporting and future changes' (the focus of this paper),

3. impact indicators used in impact evaluation, including discussing results of Round 1 of the Delphi study whereby participants had previously rated various impact indicators in terms of their importance and feasibility of measurement.

The interview guide was informed by various sources including Aslam, Adefila and Bagiya's (2018) exploration of STEM teachers' role in STEM outreach including evaluation, Robinson and Salvestrini's (2020) review of the standard of evidence of outreach evaluation and Tillinghast et al.'s (2020) review of STEM outreach. The interviews' audio recordings were then transcribed by the lead author, with pseudonyms assigned to participants to ensure their anonymity is preserved. Participants were offered the chance to choose their own pseudonym prior to interviews.

2.4 Analysis Method

Thematic analysis was employed in this study to analyse interview transcripts. This involved familiarising oneself with the data, generating initial codes to specific groups of data, searching and subsequent reviewing of themes from similar codes in multiple transcripts that tended to answer the research questions (Braun and Clarke 2006). Those themes were labelled 'emergent' and were then used to inform this section of the paper.

3 PRELIMINARY RESULTS

In this section, we discuss the results from five initial interviewees regarding STEM outreach evaluation. Their profiles are shown below in Table 1 and Table 2 respectively. It is worth noting that this paper does not aim to draw systematic findings across this sample, and the current sample size is unlikely to reach any type of saturation for a qualitative study (B. Saunders et al. 2018). However, the lack of research in this area, as well as the emergence of themes from the current transcripts validates dissemination of preliminary results with the engineering education community.

Table 1. STEM Teachers' profiles

Interview Pseudonym	Involvement in STEM outreach	Occupation	Year in occupation	Number of STEM outreach programmes involved in	Longest involvement in STEM outreach
Ash	Facilitator, Participant	Chemistry teacher and examiner	23	Many	Not sure
Ber	Coordinator, Facilitator, Participant	Engineering lecturer	3	2	5 months
Guy	Coordinator, Facilitator, Participant	Engineering and Construction teacher	20	4	5 years

Laurie	Participant	Design & Technology teacher	10	4	Not sure
Melody*	Coordinator, Facilitator, Participant	Subject lead for science/ Biology, Chemistry and Physics teacher	14	100	3 years

*It is worth noting that Melody's high number of STEM outreach programmes involvement also accounts for her role as a volunteer STEM outreach facilitator at multiple schools, beyond her role as a teacher.

Table 2. STEM outreach evaluators' profiles

Interview Pseudonym	**Involvement in STEM outreach**	**Employer(s)**	**Occupation(s)**	**Year in occupation(s)**
Anne	Coordinator, Evaluator, Manager, Facilitator, Participant	Higher education provider	Manager	6 years in total
Casey	Coordinator, Evaluator, Manager, Facilitator, Participant	STEM outreach provider and higher education provider	Director and senior lecturer	29 years in total
Dana	Coordinator, Evaluator, Manager, Facilitator and related PhD	Various STEM outreach providers including higher education institutions	Various occupations related to outreach including Outreach Manager in Engineering	20+ years in total
Olukọni	Evaluator, Researcher	Higher education provider	Researcher	14 years in total

3.1 Overall perception of evaluation

All participants deemed evaluation an important aspect of STEM outreach programmes, but for various reasons. Amongst teachers, Melody perceived it as a means to an end, primarily for outreach providers to gain more credibility and further funding whereas Guy alluded to evaluation being a chance to sit down and reflect 'in a more formal way' on whether an activity is boosting engagement in engineering and more students are choosing the subject at the end of Key Stage 3 (Year 10). Similarly, Laurie added that evaluation allows you to spot mistake and make appropriate changes.

Certain evaluators also had managerial responsibilities in overseeing outreach programmes but still had an obligation to do evaluation either for external funders or superiors within their respective institutions. Casey as the director of an outreach provider, felt that evaluation was a personal mission above all, in her quest to know if her and her enterprise were having an impact on participants. Similarly, Anne argued that firstly evaluation ensures that an intervention is not having a negative effect on participants. Dana felt that evaluation allowed her to gauge if the knowledge and understanding of STEM subjects amongst participants had changed after being involved in an outreach programme but had mixed feelings regarding evaluation as it was often conducted without any strategic planning of how it will inform a programme post reporting. Dana recalls an occasion in one of her previous roles, where data collected was not used to make any changes,

"*We had one evaluation, it was two A4 sides of questions... we never used the data. We collected it, inputted it [into the system]… we had this data every year and at no point the wider team said, 'What learning can we take from it?', and it just seems pointless."*

This lack of evaluation use is common in non-profit organisations and there is a need to raise evaluation literacy, an individual's understanding and knowledge of evaluation, amongst stakeholders in outreach to enhance evaluation use (Rogers, McCoy and Kelly 2019)

The overall perception of evaluation amongst participants was that it was either beneficial to themselves, students, or outreach providers, with Dana also questioning if evaluation is always appropriate.

3.2 Limited time: evaluation v/s 'more activities'

Time constraints placed on outreach activities is the most common barriers to evaluation (Ruhf 2022). This was a common theme discussed by participants, with several participants highlighting the inevitable consideration of either dedicating more time to an activity or conducting evaluation. Melody admitted that she would prioritise more activities over conducting evaluation, as she felt that benefited the students more. Ash also erred on having more activities, bemoaned lengthy evaluations, and felt other quicker and more enticing media such as taking pictures or 'using props' should be used to capture data. Casey conceded this is a topic her enterprise has to tackle when they visit schools for activities that are time limited (e.g., they might be given 50 minutes in between lessons) and mentioned,

"*So we have to make the decision, is it ethically fair to give them 10 minutes less of content and spend that 10 minutes on getting data?*"

Furthermore, Dana questioned whether finishing an activity with evaluation would taint the memory of an outreach activity amongst participants as they didn't enjoy filling questionnaires. This echoes with a previous study whereby teachers alluded to dialogue as an alternative to questionnaires (Bagiya 2016). However, Ber felt that there was 'no harm' to add on evaluation throughout or at the end of an activity.

3.3 Other challenges to evaluation

There were other challenges explored by participants regarding conducting evaluation in STEM outreach. Casey highlighted that she would like to conduct more academically rigorous evaluation but not only is it time consuming, it is also costly and often funders won't pay her enterprise for the additional costs. Dana agreed that it is unfeasible to do 'adequate' evaluation unless ethical approval has been obtained for a longitudinal research study with a group of participants. Olukọni presented a more theoretical argument, stating that there is a need for a change in mindset amongst stakeholders from short term, which are often superficial (e.g., how many people engaged), to longer term effects.

In terms of the data collection instrument, Casey alluded to digitising paper questionnaires was a tedious and time-consuming process. She hoped that this process would be automated in the future through a dashboard that could display live evaluation data as they are collected. Melody for her part deemed online questionnaires harder for her as a teacher, as she needed to 'book the laptops' prior to the activity for students to fill in 'Google surveys'. It is worth noting in that instance, the activity involved 90 participants. Ber mentioned that there were no such challenges when students who went to a selective activity were then asked to fill in a post-activity survey. Guy went on to add that it was a pleasant experience,

"*We got the students to do Google Forms and they quite liked that because they could go on the computers*."

Melody also revealed that ultimately teachers remain the gatekeeper, not only to evaluation but to the outreach activity reoccurrence itself, by stating that it'll be her decision solely whether 'I'll get them back in'. It is worth noting that what Dana mentioned in section 3.1, in terms of evaluation reports not always being used, can also influence teacher's perception of outreach providers. In this regard, Melody and Guy highlighted that they would like to hear back post-evaluation from outreach providers. Additionally, Anne claimed that communication with teachers was a two-way exchange, and she would often use email exchanges as a form of informal evaluation. Ultimately, good relationship with teachers lead to better outreach provision (Aslam, Adefila and Bagiya 2018).

4 SUMMARY

At this stage, it not fair to draw definitive conclusions. However, we felt a few emerging trends were worth discussing in this section. Whilst both groups of participants acknowledged the importance of evaluation in STEM outreach programmes, participants were divided into whether there are mutual benefits in always conducting evaluation as it is time consuming and a resource intensive task. Melody as the teacher most involved in outreach, felt evaluation had little value to her as a teacher and was more of a favour to the outreach evaluator. In contrast, Guy sought external input to reflect on not only the outreach delivered, but also the wider performance of his team. It will be interesting to see if future participating teachers view evaluation as mutually beneficial or not. Sections 3.2 and 3.3 highlighted there are various challenges, in terms of resources, relationship between stakeholders and time constraints, involved in conducting evaluation in outreach programme, each with their own implications. However, further communication between each group of participants would mitigate some of these challenges and would also be beneficial for the delivery of outreach programmes. For example, teachers would appreciate if outreach providers highlighted that evaluation were not only conducted as a requirement by external funders but rather to improve delivery of the next cycle of outreach activities, and shared some of the findings back to teachers.

4.1 Limitations

The sample size that forms the basis of this paper does not reach any type of saturation for a qualitative study. However, the final sample size of this research project should reach a number deemed appropriate for qualitative research (M. Saunders, Lewis, and Thornhill 2019). Furthermore, non-random sampling was used in this research, which introduces an element of researcher's bias. The researcher used multiple strategies to recruit participants as a mitigation. The results of this study are not generalisable but should depict the complex nature of the STEM and engineering outreach landscape.

4.2 Acknowledgements

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REFERENCES

Appel, D. C., Tillinghast, R. C., Winsor, C., & Mansouri, M. (2020). STEM Outreach: A Stakeholder Analysis. *IEEE Integrated STEM Education Conference (ISEC)*. https://doi.org/10.1109/ISEC49744.2020.9280723

Aslam, F., Adefila, A., & Bagiya, Y. (2018). STEM outreach activities: an approach to teachers' professional development. *Journal of Education for Teaching*, *44*(1), 58–70. https://doi.org/10.1080/02607476.2018.1422618

Bagiya, Y. (2016). A study of evaluation methodologies and impact of STEM (Science, Technology, Engineering and Mathematics) outreach activities. Coventry: Coventry University.

Banerjee, P. A. (2017). Is informal education the answer to increasing and widening participation in STEM education? *Review of Education*, *5*(2), 202–224. https://doi.org/10.1002/REV3.3093

Bonsall, A., Bianchi, L., & Hanson, J. (2020). A scoping literature review of learning progressions of engineering education at primary and secondary school level. *Research in Science & Technological Education*, 1–24. https://doi.org/10.1080/02635143.2020.1799780

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Creswell, J. W. (1999). Mixed-Method Research: Introduction and Application. In *Handbook of Educational Policy* (pp. 455–472). Academic Press. https://doi.org/10.1016/B978-012174698-8/50045-X

EngineeringUK. (2023). *Research & Evaluation - Tomorrow's Engineers*. https://www.tomorrowsengineers.org.uk/improving-practice/research-evaluation/

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied*

Statistics, *5*(1), 1–4. https://www.academia.edu/download/55796997/Comparison_Convenience_and_Purposive_Sampling-2016_4p.pdf

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*, *33*(7), 14–26. https://doi.org/10.3102/0013189X033007014

Kelly, L. M. (2021). A clash of values: Deep-rooted discord between empowering, participatory, community-driven development and results-focused, evidence-based evaluation. *Community Development*, *52*(5), 607–623. https://doi.org/10.1080/15575330.2021.1936101

Leech, N. L., & Onwuegbuzie, A. J. (2009). A typology of mixed methods research designs. *Quality and Quantity*, *43*, 265–275. https://doi.org/10.1007/S11135-007-9105-3/METRICS

Linstone, H. A., & Turoff, M. (1975). *The delphi method*. Addison-Wesley. https://www.researchgate.net/publication/237035943_The_Delphi_Method_Techniques_and_Applications

Morgan, R., Kirby, C., & Stamenkovic, A. (2016). *The UK STEM Education Landscape*. www.raeng.org.uk/stemlandscape

Moser, A., & Korstjens, I. (2018). Series: Practical guidance to qualitative research. Part 3: Sampling, data collection and analysis. *The European Journal of General Practice*, *24*(1), 18. https://doi.org/10.1080/13814788.2017.1375091

Powell, A., Francis-Devine, B., & Foley, N. (2022). Coronavirus: Impact on the labour market Research Briefing. In *UK Parliament* (Issue 8898). https://researchbriefings.files.parliament.uk/documents/CBP-8898/CBP-8898.pdf

RAEng. (2022). *Welsh Valleys Engineering Project Evaluation Report*. https://raeng.org.uk/media/1dddoym3/wvep-evaluation-report-2018-2022.pdf

Robinson, D., & Salvestrini, V. (2020). *The impact of interventions for widening access to higher education: A review of the evidence*. https://epi.org.uk/publications-and-research/impact-of-interventions-for-widening-access-to-he/

Rogers, A., McCoy, A. & Kelly, L. W. (2019). Evaluation Literacy: Perspectives of Internal Evaluators in Non-Government Organizations. *Canadian Journal of Program Evaluation*, 34(1), 1-20. https://doi.org/10.3138/CJPE.42190

Rossouw, A., Hacker, M., & De Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary delphi study. *International Journal of Technology and Design Education*, *21*(4), 409–424. https://doi.org/10.1007/S10798-010-9129-1/TABLES/5

Ruhf, R. J., Williams, C. T., Zelinsky, M. & Becho, L. W. (2022). Barriers to collecting student participation and completion data for a national STEM education grant program in the United States: a multiple case study. *International Journal of STEM Education,* 9(1), 30. https://doi.org/10.1186/s40594-022-00348-w

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H., & Jinks, C. (2018). Saturation in qualitative research: exploring its conceptualization and operationalization. *Quality & Quantity*, *52*(4), 1907. https://doi.org/10.1007/S11135-017-0574-8

Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research Methods for Business Students* (8th ed.). Pearson.

TASO. (2020). *Evidence ratings - TASO*. https://taso.org.uk/evidence/evidence-standards/

Tillinghast, R. C., Appel, D. C., Winsor, C., & Mansouri, M. (2020). STEM Outreach: A Literature Review and Definition. *2020 9th IEEE Integrated STEM Education Conference, ISEC 2020*. https://doi.org/10.1109/ISEC49744.2020.9280745

ENGINEERING COLLABORATION IN PROJECT-BASED LEARNING

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***Keywords**: project-based learning, collaborative Engineering, IT-Tools, product development*

ABSTRACT

In response to the current demands for increased interdisciplinary collaboration, innovation, and sustainability considerations in engineering, this paper discusses a case study conducted at the Department of Industrial Information Technology, Technical University of Berlin. The study employed project-based learning to address these challenges, focusing on the development of sustainable, complex product systems and corresponding business models. The research methodology, including comparisons between start and end of the project, and surveys, is presented along side with the applied teaching concepts, including project structure, deliverables, and methodological support. The analysis includes an overview of the utilized IT tools, an assessment of collaboration efforts, and presentation of survey results. The results highlight the value of methodical collaboration support, emphasizing the targeted collaboration promotion for more structured approaches, enabling faster technical collaboration while acknowledging the persistent challenges of human factors.

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1 INTRODUCTION

Project-based learning (PBL) is a fundamental pedagogical approach in university engineering education. Its aim is to provide students with essential skills that bridge the gap between technical knowledge and practical engineering practice.(Frank, et al. 2003) At the Department of Industrial Information Technology at TU Berlin, PBL courses take on a special form in which interdisciplinary student project teams are entrusted with the challenging task of designing and developing mechatronic products. Collaborative PBL in product development not only emphasises the practical application of theoretical concepts in authentic engineering contexts, but also highlights the collaborative dynamics inherent in engineering projects. Collaboration should always be part of teamwork. However, collaboration must be methodically encouraged. It requires students to communicate effectively, share resources and solve problems not only with and within the teams, but also with the lecturers. Within the project teams, the focus is on developing self-management skills as students need to manage the complexity of product development and improve their ability to plan, organise and execute tasks independently. Collaborative PBL therefore not only teaches technical expertise, but also important soft skills and prepares students for the diverse challenges in the engineering industry.

2 THEORETICAL BACKGROUND

2.1 Learning Method – Project-Based Learning

PBL is a transformative pedagogical approach rooted in progressive educational philosophies that emphasise experiential learning. (Shin 2018)

Students, organised in interdisciplinary teams, engage in practical, collaborative endeavours that mirror real-world problem-solving scenarios. In addition, the lecturer in PBL takes on the role of a facilitator and mentor, guiding students on their learning journey. PBL goes beyond the mere transfer of knowledge and actively promotes problem-solving skills, critical and creative thinking, effective communication and teamwork. (Anazifa and Djukri 2017). By integrating theoretical knowledge and practical application in authentic, project-based settings, PBL cultivates competences that are seen as essential in both academic and professional settings.(Brundiers and Wiek 2013) In engineering, PBL has emerged as a central element of education that fosters essential skills and enhances students' professional maturity. (Kolmos 2017)

2.2 Collaborative Engineering in Product Development

Collaborative engineering in product development is intrinsic and represents the pinnacle of collective human endeavors, fostering collective innovation and shared expertise, surpassing mere cooperation and coordination (Lu et al. 2007). The collaboration life cycle provides a structured approach to address challenges and delineate project-specific aspects. It unfolds in four distinct phases (see Figure 1). Implementing basic collaboration practices within the collaboration lifecycle and technical activities requires a structured approach. The integration of digital tools has changed technical collaboration and enables the exchange of information and collaboration without spatial and temporal restrictions. (Köhler-Schute 2022) It changes processes and supports remote and hybrid work, providing increased flexibility and virtualized collaboration. (Bauer et al. 2021) However, challenges in maintaining social interaction in virtual and hybrid teams needs to be addressed (Balder et al.2024). Yet, effective digital collaboration is crucial for success of product development with IT Tools and systems covering communication, project management, and content creation and sharing.(Deuse et al. 2023) Therefore, providing technical infrastructure and selecting appropriate tools are crucial.

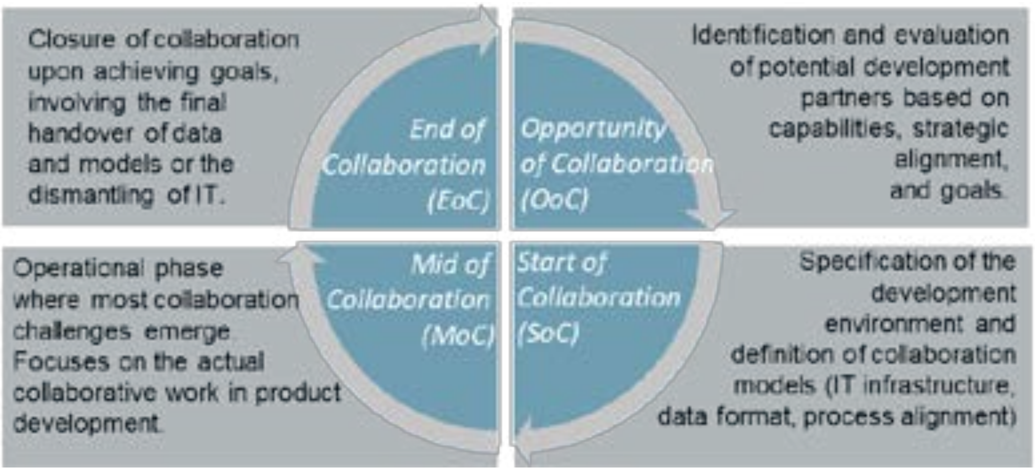

Figure 1 Collaboration life cycle (Wang et al. 2016)

The quality characteristics of collaboration in IT systems and infrastructures include the harmonisation of heterogeneous information systems, compatibility, compliance with standards and adaptability to dynamic cooperation. In addition, clearly defined roles and responsibilities, the commitment and a strategic definition are essential for effective collaboration. Social factors such as trust, conflict management, cultural appreciation and awareness of team members' activities are also crucial. (Randermann et al. 2019)

2.3 Methodical Support for Collaborative Engineering in PBL

Various studies have investigated different approaches to promoting collaboration among students. Du et al. 2020 found a significant relationship between collaboration strategies and team performance, emphasising the importance of strategic planning. Their findings emphasise the importance of planning and structured approaches to improve team outcomes. Mosgaard and Spliid 2011 emphasise reflection and experimentation in the development of process skills and highlight the value of iterative learning. Sumino et al. 2017 found that cross-institutional PBL improves communication skills and students benefit from diverse collaborative experiences. Alves et al. 2021 point out that teachers' collaborative practices serve as role models for students and have a positive impact on their teamwork behaviour. Santoro, et al. 2005 emphasise the importance of planning collaborative processes to foster group engagement and indicate that a well-structured framework for collaboration can lead to more effective teamwork. Hagedorn et al. 2023)investigated into the development of digital twins in PBL setting in a hybrid teaching concept demonstrating the use of IT Tools in PBL.

Despite these findings, there is a notable gap in the literature regarding the methodological support of collaborative engineering using IT tools.

3 METHODOLOGY

3.1 Research Question

The primary research question guiding this study is: *How does task-specific methodological support especially through IT Tools impact engineering collaboration in PBL environments*? The research aims to investigate the role of tailored methodological support in enhancing collaboration skills, focusing on the specific challenges such as communication, time management, resource allocation.

3.2 Presentation of Research Teams

The project analysed for this study took place during the winter semester of 2023/24, spanning from October 2023 to February 2024. Two master project-courses were subjected to the analysis. "Development and Management of Digital Product Creation Processes" (EMP) and "Applications of Industrial Information Technology" (AIIT) modules, further named as AIIT/EMP. In the project AIIT/EMP, each team comprised 2-3 EMP students collaborating with 6-7 AIIT students, creating a dynamic mix of skills and expertise. A total of 44 students, with 11 from EMP and 22 from AIIT, formed 4 project teams with 8-9 students.

3.3 Surveys

The students participated in two surveys conducted at the beginning and end of the project. The surveys contained standardised questions that ensured consistency between the teams and explored key project concepts and collaboration dynamics. By comparing the questions, the study captures the transformation journey of each team and assesses the impact of collaboration.

The first survey focuses on demographic questions that capture the characteristics of the participants, as well as an assessment of prior knowledge and experience in collaboration. Participants are asked to provide insights into any challenges they have experienced in collaboration. This survey aims to gain a basic understanding of the participants' background, experiences, and perceived difficulties in collaboration.

The second survey focuses on participants' current knowledge of collaboration. It aims to gather information on the applied methods, lessons learned and the actual use of collaboration tools and platforms. Participants will be asked to identify the challenges they faced in the project and make suggestions for improvement. This survey should enable a more differentiated and timely assessment of participants' cooperation skills and potential areas for the development of the project itself.

The surveys contained qualitative and quantitative questions. For most quantitative the 5-point Likert scale was used.

3.4 Methodological Support for Student to Facilitate Collaboration

The students were supplied by targeted methodological support aimed at enhancing collaboration within the project. E.g., a specialized seminar was conducted, emphasizing the pivotal role of collaboration in product development. Key principles for successful collaboration, conflict management, and cultivating a culture that embraces failure were elucidated. The seminar also featured a comprehensive presentation on various IT tools and processes designed to bolster collaborative efforts. To streamline collaboration, project roles were thoughtfully assigned, ensuring a clear delineation of responsibilities within the team.

A structured approach was implemented through the formulation of tasks and deliverables, as outlined in Table 1. This served as a roadmap for the teams, guiding them through the intricacies of collaborative product development. The culmination of this support was observed through the meticulous evaluation of team collaboration and working methods during designated design reviews (DRs). DRs are review situations in which decisions can be made and actual results will be interactively discussed (‘Design-Review | KVP Institut GmbH’, n.d.).

4 USE CASES

4.1 Structure of the Semester Projects

The primary objective is to display the product development process from the initial idea to the implementation of a real prototype. All modules were accompanied by lectures on project-relevant topics held by the professor or other experts as well as practical seminars that help the students with the implementation of the projects. Further consultation for individual questions and feedback are offered by the lecturers (see Figure 2). Finaly, the exam performance are deliverables, two DRs and a final presentation.

Figure 2 Structure of the semester project

In total, the academic focus is directed towards equipping students with theoretical and practical engineering knowledge, fostering collaboration in real-world product development projects among students from diverse technical backgrounds. Further, the project is conducted hybrid. Seminars, DRs, and the final presentation are primarily set physical, while the teamwork was left to the individual teams and mainly carried out virtually.

Table 1 Overview of collaboration phase and tasks

No.	Collab. Phase	Short Description
1	OoC	Project Kick-Off
2	SoC	Project plan with task distribution, resource allocation and tool list
3	SoC	Development of a collaboration concept with the other teams based on the collaboration life cycle
4	SoC	Requirement list and solution concept
5	SoC	System design diagrams including technical overlaps with other teams
6	MoC	Operationalisation of the ability to collaborate
7	MoC	Working in digital transformation
8	MoC	Cross-team CAD model and joint physical prototype

9	EoC	Evaluation of the IT tools used for collaboration
10	EoC	Lessons learned on the teamwork and collaboration
11	EoC	Visualisation of the collaboration process throughout the project with the help of the collaboration life cycle

4.2 Tasks and Assessment of Submissions

The product development within the projects is systematically divided into four distinct phases divided by the two DRs and the final presentation.

Phase 1: Idea and Concept Generation (Ooc and SoC) - Teams engage in the initial phase of ideation, exploring creative solutions and conceptualizing their projects.

Phase 2: Design (MoC)- The teams leverage tools such as CAD-Modelling to translate their concepts into tangible designs.

Phase 3: Prototyping and Validation (MoC) – This phase focuses on prototyping and validation, where teams bring their designs to life and test them.

Phase 4: Reflection (EoC) - The team reflect the task and writes a final report.

The two DRs are strategically positioned within this developmental timeline, with specific deliverables and tasks associated with them. These reviews serve as crucial milestones, allowing teams to showcase their progress, receive constructive feedback, and refine their approaches.

In the project, the teams are tasked with developing a smart rollator collaboratively. The project uniquely assigns subsystems (pavement overcoming, obstacle detection, automatic height adjustment, and chassis damping) to individual teams. To add a layer of real-world constraints, conditions for the prototype are stipulated, including a budget of 100€ per team, a requirement for a minimum of 50% reused materials, and the incorporation of mechatronic components.

4.3 Project Results

In the AIIT/EMP project, a fully integrated prototype was successfully developed, showcasing all subsystems, as illustrated in Figure 3.

Figure 3 Final prototype

5 RESULTS

5.1 Presentation of the survey results

The first survey included 34 participants, with an average age of 24. The majority of students studies production technology or mechanical engineering and have an average of 11 semesters of study. Qualitative questions are analysed interpretatively, while quantitative questions are analysed statistically.

The key aspects of collaboration, as the students defined it, included different competences (27%), several participants (57%), common goal (37%), conflict resolution (17%), distribution of structure/tasks (30%), and communication

(27%). 29% had already 1-2 other teamwork, 44% 3-4 and 26% more than 5. The assessment of prior knowledge in various collaboration-related areas can be seen in Table 2. 24% stated that they had a project in which there were guidelines on how to work together. 76% denied being so far supported in the teamwork.

The main challenges on collaboration included coordinating/resource allocation (41%), unequal workload distribution (21%), communication within the team (32%), decision making (12%), different motivation (32%), different skill sets (18%), time management (26%), and planning/structure of the project (44%).

In the second survey, 20 participants revisited their perspectives on collaboration. Collaboration definition included the key aspect of different competences (10%), several participants (80%), a shared common goal (75%), structured task distribution (20%), and effective communication (20%).

The survey also encompassed a comprehensive review and feedback segment focusing on methodological support:

- Survey results indicated that methodological support had proven beneficial for the majority of students, with a notable 60% expressing appreciation for its assistance. However, a significant portion (30%) considered it a helpful addition but not always necessary.
- Seminars received a positive response from 70% of participants, yet constructive feedback suggested a desire for increased practicality and task-specific focus in future sessions.
- DRs were recognized as constructive tools, aiding participants in better task implementation and addressing comprehension problems (60%).

Table 2 Results of the prior knowledge of the students

Prior knowledge	**1**	**2**	**3**	**4**
Collaboration & teamwork area	0%	12%	29%	59%
Use of collaborative tools and platforms	15%	15%	47%	24%
IT tools in product development	6%	47%	35%	12%
Development in interdisciplinary teams	9%	35%	44%	12%
Sustainability	9%	50%	38%	3%
Product development	9%	18%	59%	15%
User-centred development	21%	13%	29%	12%

1= no experience; 2= heard it before;3= first experience gained; 4= experienced

Collectively, the project yielded positive outcomes for the participants. The findings suggested that the students' enhanced understanding of roles and responsibilities in project work reached 53%, and they reported performing collaborative engineering activities more methodically and effortlessly, encompassing collaborative design, knowledge exchange, review, concept development, etc. (60%).

The average feedback on each collaborative task presented in Chapter 3.3 was remarkably positive. This average score underlines the generally positive response from participants, suggesting that the collaborative tasks were well received and contributed effectively to the overall learning experience (see Table 3).

5.2 . Presentation of Employed IT Tools

The utilization of IT tools within the project is categorized into four main domains: Communication, Product Design, Data and Knowledge Management, and Project Management. In each of these categories, predominantly Software as a Service (SaaS) solutions have been employed, characterized by their collaborative features that facilitate effective teamwork (see Table 3).

Table 3 Overview of Employed IT Tools and Used Functions

Team/ Tool	Communi-cation		Product Design		Data and Knowledge Management					Projekt mgmt
1	Whats-App	ZOOM	Fusion 360	Adruino IDE	Microsoft Office	Over-leaf	TUB-Cloud	Trello		
2	Whats-App	ZOOM	Fusion 360	Adruino IDE	Microsoft Office		TUB-Cloud	Microsoft Visio		
3	Whats-App	ZOOM	Fusion 360	Adruino IDE	Microsoft Office	Over-leaf	TUB-Cloud	yED live	Miro	Notion
4	Whats-App	ZOOM	Fusion 360	Adruino IDE	Microsoft Office		Share-point	Lucid-chart		MS Planer

Notably, within the realm of Product Design, similarities are observed among the tools chosen by various teams. This consistency can be attributed to the task descriptions, indicating a standardized approach to product design requirements. Additionally, it is noteworthy that most teams have adopted similar functions within these tools, further emphasizing a shared understanding.

6 Discussion

The survey shows a notable shift in the understanding of collaboration among students over time. There is a clear focus on understanding a common purpose, which emphasises the importance of aligning efforts towards common goals. Students involved demonstrate a deep understanding of their roles and responsibilities within the team.

To promote cross-team collaboration, additional structural guidance from lecturers is critical. This can be achieved through more explicit recommendations for tools to ensure seamless interfaces, scheduled meetings to facilitate coordination and increased methodological support in framing internal discussions.

Furthermore, it is considered necessary to move away from the free choice of team members. Instead, the focus should be on putting together teams with a balanced skills profile. This strategic approach aims to optimise collaboration by utilising different skills within each team, which contributes to a more effective and harmonious learning environment.

Compared to previous studies this study demonstrates a needed methodical support not only in theory but also in the deployment of IT tools in students collaboration.

7 SUMMARY AND ACKNOWLEDGEMENTS

To summarise, the results of this study highlight the importance of methodological support for improving collaboration in projects. While master's students generally demonstrate high levels of collaboration skills, the study emphasises the importance of task-specific methodological support through IT tools to effectively address nuanced challenges. In particular, the delivery of PBL varies significantly across the university, suggesting a need for standardised approaches to improve collaboration consistently.

The realisation that collaboration in both interpersonal interaction and the methodical use of IT tools and building processes is a critical skill for the future underlines the need for a structured approach in degree programmes. This study argues in favour of the introduction of systematic strategies to promote cooperation skills that are geared towards the changing demands of the professional world. It was also intended to investigate the extent to which the perception of collaboration in methodologically supported projects differs from non-supported projects.

The study has its limitations, as the findings were obtained from a sample of 60 students, which does not represent the all students and only covers a period of one semester. Nonetheless, these findings offer valuable perspectives and insights into the collaborative landscape at the university and pave the way for future research and programme improvements. Future research should focus on expanding the sample size and extending the study duration to validate and build upon these findings. Moreover, there is a need to explore the integration of advanced digital tools such as simulation, Digital Mock-Up (DMU), and Virtual Reality/Augmented Reality (VR/AR) technologies in PBL environments. These tools can facilitate virtual prototyping and early-stage collaboration. The chair of IIT should play a pivotal role as a digital integrator. For further exploration of these concepts, readers are recommended to (Stark 2022).

REFERENCES

Alves, Anabela C., Natascha van Hattum-Janssen, and Sandra Fernandes. 2021. ‘Teacher Collaboration in PBL: Setting the Example for the Students’, July. https://doi.org/10.5281/ZENODO.5093791.

Anazifa, R. D., and D. Djukri. 2017. ‘Project- Based Learning and Problem-Based Learning: Are They Effective to Improve Student’s Thinking Skills?’ *Jurnal Pendidikan IPA Indonesia* 6 (2): 346. https://doi.org/10.15294/jpii.v6i2.11100.

Balder, Juliane; Porst, Marius; Stark Rainer. 2024. ‘Digital and Agile Collaboration in New Work SME Product Development’, June.

Bauer, Wilhelm, Susanne Mütze-Niewöhner, Sascha Stowasser, Claus Zanker, and Nadine Müller, eds. 2021. *Arbeit in der digitalisierten Welt: Praxisbeispiele und Gestaltungslösungen aus dem BMBF-Förderschwerpunkt*. Open Access. Berlin [Heidelberg]: Springer Vieweg. https://doi.org/10.1007/978-3-662-62215-5.

Brundiers, Katja, and Arnim Wiek. 2013. ‘Do We Teach What We Preach? An International Comparison of Problem- and Project-Based Learning Courses in

Sustainability’. *Sustainability* 5 (4): 1725–46. https://doi.org/10.3390/su5041725.

‘Design-Review | KVP Institut GmbH’. n.d. Accessed 12 March 2024. https://www.kvp.de/lexikon/design-review/.

Deuse, Jochen, René Wöstmann, Vanessa Weßkamp, David Wagstyl, and Christoph Rieger. 2023. ‘Digital Work in Smart Production Systems: Changes and Challenges in Manufacturing Planning and Operations’. In *New Digital Work*, edited by Alexandra Shajek and Ernst Andreas Hartmann, 31–50. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-26490-0_3.

Frank, Moti, Ilana Lavy, and David Elata. 2003. ‘Implementing the Project-Based Learning Approach in an Academic Engineering Course’. *International Journal of Technology and Design Education* 13 (3): 273–88. https://doi.org/10.1023/A:1026192113732.

Hagedorn, Lisa, Theresa Riedelsheimer, and Rainer Stark. 2023. ‘PROJECT-BASED LEARNING IN ENGINEERING EDUCATION – DEVELOPING DIGITAL TWINS IN A CASE STUDY’. *Proceedings of the Design Society* 3 (July):2975–84. https://doi.org/10.1017/pds.2023.298.

Hannam University, and Myeong-Hee Shin. 2018. ‘Effects of Project-Based Learning on Students’ Motivation and Self-Efficacy’. *English Teaching* 73 (1): 95–114. https://doi.org/10.15858/engtea.73.1.201803.95.

Köhler-Schute, Christiana, ed. 2022. *Homeoffice und hybride Arbeitsformen: Organisation, Technologie und juristische Aspekte: Homeoffice in Zeiten der Pandemie - und was wir daraus lernen können*. Berlin: KS-Energy-Verlag.

Kolmos, Anette. 2017. ‘PBL Curriculum Strategies: From Course Based PBL to a Systemic PBL Approach’. In *PBL in Engineering Education*, edited by Aida Guerra, Ronald Ulseth, and Anette Kolmos, 1–12. Rotterdam: SensePublishers. https://doi.org/10.1007/978-94-6300-905-8_1.

Lu, S.C-Y., W. Elmaraghy, G. Schuh, and R. Wilhelm. 2007. ‘A SCIENTIFIC FOUNDATION OF COLLABORATIVE ENGINEERING’. *CIRP Annals* 56 (2): 605–34. https://doi.org/10.1016/j.cirp.2007.10.010.

Mosgaard, Mette, and Claus Monrad Spliid. 2011. ‘Evaluating the Impact of a PBL-Course for First-Year Engineering Students Learning through PBL-Projects’. In *2011 2nd International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE)*, 1–6. Chennai, India: IEEE. https://doi.org/10.1109/WIRELESSVITAE.2011.5940927.

Randermann, Marcel, Till Blüher, Roland Jochem, and Rainer Stark. 2019. ‘Reifegradmodelle in Der Produktentwicklung: Eine Literaturanalyse’. *Zeitschrift Für Wirtschaftlichen Fabrikbetrieb* 114 (4): 184–86. https://doi.org/10.3139/104.112070.

Santoro, Flávia Maria, Marcos R. S. Borges, and Neide Santos. 2005. ‘Learning to Plan the Collaborative Design Process’. In *Computer Supported Cooperative Work in Design I*, edited by Weiming Shen, Zongkai Lin, Jean-Paul A.

Barthès, and Tangqiu Li, 3168:33–44. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/11568421_4.

Stark, Rainer. 2022. *Virtual Product Creation in Industry: The Difficult Transformation from IT Enabler Technology to Core Engineering Competence*. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-64301-3.

Sumino, Haruhiko, Mai Aoki, Takeshi Yamada, Shuji Kawakami, Tsuyoshi Yamaguchi, Toshiyuki Takahashi, and Masayoshi Yamada. 2017. 'ATTEMPT OF A MULTI-INSTITUTIONAL PBL USING ICT AND COOPERATIVE EXPERIMENT'. *Journal of Japan Society of Civil Engineers, Ser. H (Engineering Education and Practice)* 73 (1): 34–42. https://doi.org/10.2208/jscejeep.73.34.

Wang, Wei Min, Pascal Lünnemann, Sebastian Neumeyer, Haygazun Hayka, and Rainer Stark. 2016. 'Product Development in Collaborative Networks – An Expert View on Current Challenges and Future Trends'. In *Collaboration in a Hyperconnected World*, edited by Hamideh Afsarmanesh, Luis M. Camarinha-Matos, and António Lucas Soares, 480:302–12. IFIP Advances in Information and Communication Technology. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-45390-3_26.

Xiangyun Du, Khalid Kamal Naji, Saeed Salah, Usama Ebead. 2020. 'Engineering Students' Conceptions of Collaboration, Group-Based Strategy Use, and Perceptions of Assessment in PBL'. In *The International Journal of Engineering Education*, 296–308. Vol. 36, No. Extra 1.

Exploring the Education and Training of Nuclear Engineers in Australia

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ABSTRACT

The Australian Nuclear Science and Technology Organisation (ANSTO) is the largest concentration of nuclear expertise in Australia and OTJ learning contributes to the development of a highly skilled nuclear workforce. Through a DYD workshop, this paper reports on the OTJ learning and Knowledge, Skills, and Attributes (KSAs) development of a cohort of individuals either whose role has been defined as a nuclear engineer or expected to develop expertise in nuclear engineering at ANSTO.

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The OTJ learning revealed the technical tasks including research planning, experimental work, modelling and data analysis form a crucial part of their roles. Non-technical tasks associated with their roles included administration and communication tasks. Analysis of the KSAs associated with each activity demonstrates the importance of experiential and self-directed learning to master nuclear competencies. We find that within this subset of the workforce at ANSTO, specifically nuclear competency predominantly resides in the knowledge domain. As a result, an effective strategy to training could involve a more structured approach to nuclear knowledge development, thereby fast-tracking competency, without compromising overall proficiency.

1 INTRODUCTION

Nuclear engineers conduct research and development activities related to the release, control, and use of energy from nuclear reactions, applicable to nuclear power, nuclear medicine, nuclear waste management, (O*Net, 2024; US Bureau of Labor Statistics, 2022; Townsend et al., 2022). Johnston (2009) affirms that nuclear engineers require expertise in reactor analysis and design, radiation effects analysis, shielding design, radiation utilisation, radioactive materials control and processing, and nuclear energy systems design for constructing nuclear reactors.

There is a growing demand for nuclear skills and expertise in Australia (Commonwealth of Australia, 2006). A nuclear engineer in Australia, could be involved in a wide range of activities, including nuclear fusion, medical applications, health physics, and materials research. The learning of nuclear engineering in Australia takes place both at university and in the workplace (Baradaran et al.,2023). Learning arrangements can be formal, non-formal or informal. Formal learning relates to earning qualifications, certificate training and degrees whereas non-formal and informal learning relates to on-the-job (OTJ) training, mentorships and continuous learning activities (Crouse et al., 2011). Formal, non-formal and informal workplace methods of learning are equally important and complementary.

The University of New South Wales (UNSW, Sydney) offers a formal qualification in nuclear engineering - a Master of Engineering Science in Nuclear Engineering. The Australian Nuclear Science and Technology Organisation (ANSTO) provides OTJ training and professional development opportunities for nuclear engineers and other professionals in the nuclear sector. ANSTO has over 1,300 staff, working in nuclear engineering and reactor operation, safety and radiation protection, waste management, nuclear security and safeguards, materials science, and education and communications (ANSTO, 2022). The workplace clearly plays a fundamental role in educating and training professionals in nuclear engineering in Australia.

Competency, in terms of Knowledge, Skill, and Ability refers to the integrated application of these attributes by professionals in specific contexts to achieve high performance and meet quality standards required by their roles (Warier, 2014).

1. Knowledge –the understanding of technical information necessary to adequately perform job function (Valdez et. al, 2008).
2. Skill – either a demonstration of procedural knowledge or the capability to demonstrate procedural knowledge. Such procedural knowledge usually results from training, i.e. a process of learning and acquisition of proficiencies, including training that may be self-directed (Hlavac, 2023). A skill is something that is

almost always observable and measurable and usually involves a person's interaction with stimuli and/or other people (Hlavac, 2023). Skills can be acquired across various domains and transferred between different contexts.
3. Ability – sometimes called attribute – the power or capacity to act or do certain things in a particular way. In some ways similar to a skill, it encompasses the capacity to do things that are not the result of formal training or instruction (Dweck, 2002). As such, an ability can refer to personal attributes and innate talents that contribute to an effectiveness in performing tasks or roles. These include creativity, adaptability and honesty (Verduyn, 2023).

To meet the needs of the nascent nuclear sector in Australia, the next generation of nuclear engineers must be trained in a timely and efficient manner. ANSTO's current and future engineering capabilities were mapped in the Engineering Capability Framework (ANSTO, 2022) which identified the gaps in capabilities in the workforce and the need to train more nuclear personnel. A thorough understanding of the informal learning and OTJ training at ANSTO is needed to better integrate workplace learning with university programs, and thereby accelerate the training of nuclear engineers.

This research paper aims to uncover the OTJ learning and KSA development of a cohort of people at ANSTO whose role has been defined as a nuclear engineer and, matched to an expectation that they will develop this expertise in the coming years. Through the Define Your Discipline (DYD) process (Dowling and Hadgraft, 2011, 2013), the cohort communicated the tasks and the competencies that constitute their nuclear engineering expertise. By deconstructing this competency into KSA, and comparing with the entry qualifications of this group, we answer how this cohort of people conceptualize their role as a current (or future) nuclear engineer, and how their OTJ training contributes to their KSA development in this discipline.

2 METHODOLOGY

The participants were selected from the Nuclear Fuel Cycle (NFC) Group at ANSTO. ANSTO utilised the US-developed Occupational Information Network (O*Net) online database (US O*Net, 2024), along with its internal specialised knowledge and expertise to categorise roles which correspond to 'Nuclear Science' or 'Nuclear Engineering'. The participants selected from the NFC group were identified in the strategic workforce plan, as nuclear engineers. The group consisted of 9 individuals at various stages of their career, from early career graduates to senior engineers.

During the workshop (Dowling and Hadgraft, 2011, 2013), each participant was asked to write 5-10 technical nuclear engineering tasks and 5-10 non-technical nuclear engineering tasks that they perform in their role on separate Post-it notes. This activity provided information on OTJ learning and the key tasks that participants engage in at work. Participants were then asked to write the Knowledge, Skills and Attributes (KSAs), needed to perform each task, behind each Post-it note. This provides the competency underpinning the activities of the participants at work.

After the participants had written their tasks, they began the second stage of the DYD process, the convergent phase, by performing a cluster analysis. This involved pasting all the Post-it notes with the tasks on the whiteboard and looking for commonalities. The tasks were then grouped into clusters that were named during the workshop.

The workshop concluded when all the tasks were grouped into the clusters and all the KSAs had been recorded. This process ensured that contributions from each individual participant was captured. After the DYD workshop, the clusters were analysed again by the research group to ensure consistency. The KSAs were tabulated, and specific nuclear competencies were isolated from others based on the researcher's knowledge. The competency results (i.e. KSAs) of the DYD analysis were compared to background information for the entry qualification of the cohort at the time of commencing ANSTO employment. This research has adhered to ethical guidelines for conducting qualitative research (HRECS, 2024).

3 RESULTS

The initial data for the cohort of 9 participants working in the NFC group is shown in the Ecosystem Map (Fig.1). This shows the starting level of education and field of qualification of an employee and the upskilling process employees go through in a nuclear organisation.

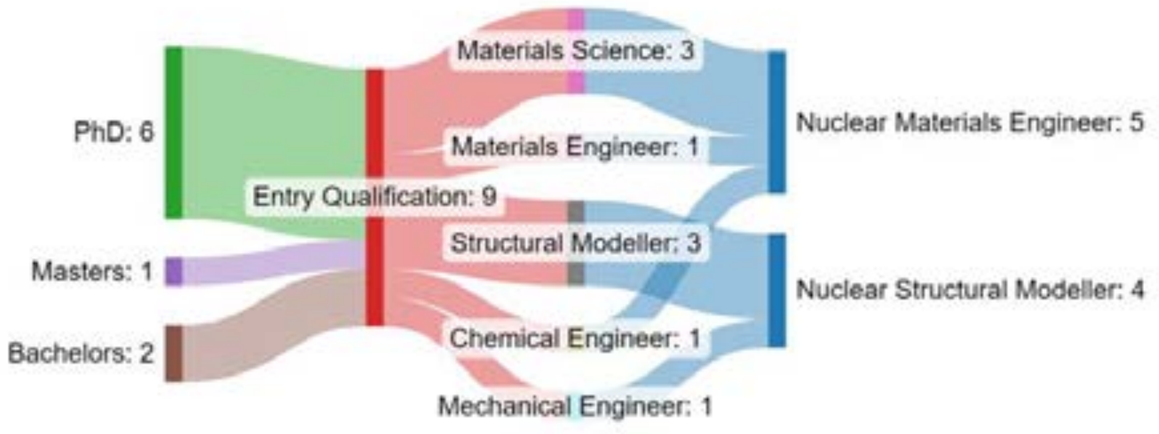

Fig 1. Ecosystem map of DYD workshop participants; people move from left to right.

The workshop comprised of eight males and one female, aged between 24 and 64 years. Among them, two of the participants had a tenure of more than 12 years at ANSTO, while the remaining seven had less than 12 years of tenure.

Table 1. shows the technical and non-technical tasks reported by the DYD workshop participants in the NFC group. Technical tasks are clustered into four main activities: research planning, experimental work, modelling, and data analysis. Non-technical tasks are clustered into two main activities: administration and communication.

Table 1. Technical and non-technical tasks from DYD workshop participants in the NFC group at ANSTO

Activity	Specific activities
Research Planning	1.Conduct literature review of research topic. 2.Contextualise the literature review to determine specific gaps in knowledge and ways to bridge the gaps. 3.Acquire online data on nuclear materials.

	4.Review ASTM standards for nuclear materials testing and simulations.
Experimental work	1.Conduct specific experiments to generate experimental data for testing assumptions and validating the models for nuclear engineering structures of materials used in simulations, including: 2. Conduct corrosion, radiation damage test on materials. 3. Conduct creep, creep-fatigue, tensile and other mechanical testing on various samples. 4. Investigate the structure of materials under TEM or SEM and relate it to properties.
Modelling	1. Generate code in open-source software to build nuclear materials models. 2. Design a model on CAD software of nuclear reactor structures (e.g. pressure vessel, pipe, cooling pipe). 3. Create FEM models to study fracture and plastic behaviour of nuclear materials and engineering systems. 4. Model solid state phase transformations to predict the effect of microstructure changes on stresses in nuclear materials.
Data Analysis	1.Analyse data from mechanical testing of nuclear materials for material models in FEM. 2. Analyse data from mechanical testing to evaluate the performance of nuclear materials in extreme reactor conditions. 3. Analyse data from DIC technique to obtain strain fields of tested nuclear materials. 4. Analyse data of nuclear materials testing, using python to develop figures and plots that can convey information to the appropriate audience
Administration	1. Conduct lab inspections 2.Supervise university students projects. 3.Setup regular meetings for reporting on progress and objectives. 4.Offer internal and external advice on nuclear materials.
Communication	1.Write reports and papers on results of experiments to clients and for publication. 2.Present scientific findings to supervisors, stakeholders, etc. 3.Communicate results to team members. 4.Develop collaborations with external stakeholders (industries, universities and national labs).

Table 2. shows the Knowledge, Skills, and Attributes (KSAs) reported from the participants in the DYD workshop.

Table 2. Key Competencies (KSAs) reported from the DYD workshop participants in the NFC group at ANSTO

Knowledge (nuclear/non-nuclear)	Skill	Attribute

Nuclear: 1.Nuclear fuel cycle process 2.Reactor processes and technologies 3.Nuclear legal frameworks ***Non-nuclear:*** *1.Research methods* *2.Materials science* *3.Mechanical testing* *4.Chemistry* *5.Physics* *6.Numerical techniques* *7.FEM principles* *8.Organisational processes* *9.Economics*	1.Data processing 2.Interpreting information 3.Problem-solving 4.Teamwork 5.Safety awareness 6.Mathematical skills 7.Computer skills 8.Programming skills 9.Analytical skills 10.MS Office 11.Leadership skills 12.People management 13.Interpersonal skills 14.Scientific writing skills 15.Verbal communication skills	1. Perseverance 2. Critical thinking 3. Adaptability 4. Diligence 5.Time management 6. Attention to detail 7. Work ethics 8. Responsibility 9. Team player 10. Strategic thinking

The technical activities related to nuclear engineering include research planning, experimental work, modelling and data analysis. Workshop participants highlighted the specific activities that nuclear engineering research planning involves, underlying the need for knowledge of the nuclear fuel cycle, reactor processes and associated technologies (Table 2, Nuclear Knowledge 1 and 2). Participants emphasised the importance of proficiency in various research methodologies, particularly the importance literature review (Table 1, Research Planning 1), to grasp the current state of knowledge and identify gaps for exploration. As seen in Table 2. participants underscored critical skills in data processing and interpretation for undertaking research (Table 2, Skills 1 and 2). Problem-solving and teamwork skills were emphasised as necessary for persistence with research activities (Table 2, Skills 3 and 4). Key attributes like perseverance, critical thinking and adaptability play a pivotal role in defining research methodologies and outlining experimental and theoretical approaches to address specific research objectives in the organisation (Table 2, Attributes 1-3).

Conducting experiments in this group demands knowledge in materials science, particularly in understanding material behaviour under radiation and familiarity with mechanical testing techniques including micro-tensile sample fabrication testing, electron backscatter diffraction imaging, and mechanical testing of structures of materials under Transmission Electron Microscope (TEM) or Scanning Electron Microscope (SEM) (Table 1, Experimental Work 4). As presented in Table 2, participants mentioned problem-solving skills as essential for troubleshooting issues that may arise during experiments (Table 2, Skill 3). Skills in data processing are essential for analysing experimental data and extracting meaningful insights (Table 2, Skill 1). Furthermore, attributes like diligence and attention to detail are indispensable for the rigorous experimental work (Table 2, Attributes 4 and 6). Effective time management is also essential for balancing the various tasks involved in experimental research, from sample preparation to data collection, ensuring efficient progress and timely completion of projects (Table 2, Attribute 5).

For analysing experimental data in nuclear engineering research workshop participants reported needing knowledge of materials science, mechanical testing, physics and chemistry (Table 2, Non-nuclear Knowledge 2-5). Mathematics, computer and programming skills are essential for data analysis (Table 2, Skills 6-8). Analytical and problem-solving skills are also needed for data analysis (Table 2, Skills 3 and 9). Attributes such as critical thinking and attention to detail come into play when determining the most appropriate statistical and analytical techniques to apply to experimental data, ensuring the validity and reliability of results (Table 2, Attributes 2, 6). Additionally, effective time management is crucial for prioritising data analysis tasks and meeting project deadlines (Table 2, Attribute 5).

Other operational duties form a crucial part of their responsibilities, such as project management, supervision, and compliance with regulatory standards. Participants reported administrative tasks and communication tasks to be a regular part of their jobs (Table 1). Given the highly regulated nature of nuclear activities, ensuring proper documentation, reporting and adherence to safety protocols are paramount (Table 1, Administration 1-4). The participants often find themselves engaging in administrative tasks related to compliance (Table 1, Administration 1-4). Effective communication requires knowledge of nuclear materials and regulatory matters (Table 1, Communication 4), for communicating with colleagues, management, regulatory authorities and the public. This may involve tasks such as writing technical reports, delivering presentations, participating in meetings and engaging with media inquiries (Table 1, Communication 2).

4 DISCUSSION

The data collected from the participants in the NFC group at ANSTO shows the process in action as employees become nuclearized or acquire nuclear knowledge and expertise in the workplace. The Ecosystem Map (Fig. 1) shows three of participants in the workshop came to ANSTO with a PhD in materials science, one with PhD in materials engineering, and two with a PhD in structural modelling. There was one participant with a masters in structural modelling and one with a bachelor's in chemical engineering and one participant with a bachelor's in mechanical engineering. Since the starting qualification of the participants were not nuclear disciplines, the competencies (KSAs) in the nuclear field were acquired through OTJ training at ANSTO.

The results in Table 2. shows the nuclear and non-nuclear knowledge required by these 9 professionals at ANSTO. Elsevier's Dictionary of Nuclear Science and Technology defines nuclear engineering as a branch of engineering focused on research and development related to the construction and practical utilisation of nuclear reactors and their products (Clason, 1970). During the DYD workshop, participants reported technical activities in nuclear engineering shown in Table 1. Including research planning, experimental work, modelling, and data analysis, all of which align with the Elsevier definition (Clason, 1970).

Johnston (2009) delineates the expertise expected of nuclear engineers, including knowledge of reactor analysis and design, radiation effects analysis, shielding design, radiation utilisation, radioactive materials control and processing, and nuclear energy systems design for constructing nuclear reactors. The participants in the DYD workshop had knowledge of the nuclear fuel cycle, reactor processes and technologies aligning with Johnston's definition (Johnston, 2009). The participants also noted that non-technical activities in nuclear engineering require knowledge of nuclear legal frameworks, considering the highly regulated nature of nuclear activities. However, these researchers do not have complete expertise in all the aforementioned areas and are therefore more narrowly specialised in materials research than overall nuclear engineering, as outlined by Johnston (2009).

Comparing KSAs reported in the DYD workshop, and the entry qualifications in Fig. 1, it is evident that the cohort must be engaged in experiential and self-directed learning to learn the nuclear component of the competencies in their professional activities. Kolb's experiential learning theory includes engaging in direct experiences to extract meaning and insights and then applying or acting upon what has been learned in practice (Kolb, 1984). Self-directed learning is where the individuals have taken responsibility for their own learning (Knowles, 1968), which is evident in the specific activities reported.

The results from this pilot DYD workshop represent only a very small portion of the organisation, and further data collection is needed to validate the learning process and KSA development. Based on these initial findings, it is evident that the nuclear competencies within this subset of the workforce at ANSTO are primarily concentrated in the knowledge domain. This implies that formal, accelerated instruction in nuclear knowledge could expedite the development of this and similar groups, without compromising overall competency.

5 Conclusion

Through the DYD process, this study uncovered the technical and non-technical activities crucial for OTJ learning in nuclear engineering. Technical activities encompassed research planning, experimental work, modelling, and data analysis, while non-technical tasks involved administrative and communication duties. The analysis of KSAs for each activity affirms that this cohort is engaged in experiential and self-directed learning to learn the nuclear component of their competencies. The results show the nuclear complexities within this subset of the workforce at ANSTO are primarily concentrated in the knowledge domain. This implies a viable approach to expedite their OTJ learning experience could involve intensive, structured instruction approach to nuclear knowledge development, without comprising the overall competency of this group.

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REFERENCES

Australian Nuclear Science and Technology Organisation (ANSTO), Corporate Plan, 2022.

Baradaran, T., J. Stansby, M. Ionescu, C. Saint, I. Koskinen, and E. Obbard. "Learning Nuclear Engineering in the Workplace: Developing an Understanding of On-the-Job Training of Nuclear Engineers in Australia." In *2023 IEEE ASEE Frontiers in Education Conference*. IEEE, College Station, Texas, 2023. http://dx.doi.org/10.26190/wnsf-hg38.

Clason, W. E. *Elsevier's Dictionary of Nuclear Science and Technology*. Second Edition. Elsevier,1970.

Crouse, P., Doyle, W., & Young, J. D. "Workplace learning strategies, barriers, facilitators and outcomes: a qualitative study among human resource management practitioners." Human Resource Development International, 14(1), 39–55., 2011. https://doi.org/10.1080/13678868.2011.542897

Commonwealth of Australia, Department of Prime Minister and Cabinet, *Uranium Mining, Processing and Nuclear Energy — Opportunities for Australia?* Report to the Prime Minister by the Uranium Mining, Processing and Nuclear Energy Review Taskforce, December 2006.

Dowling, D.G., and. Hadgraft R. G. "A systematic consultation process to define graduate outcomes for engineering disciplines." In *Proceedings of the Research in Engineering Education Symposium (REES)*. University of Southern Queensland, 2011.

Dowling, D.G, and Hadgraft, R. G. "The DYD Stakeholder Consultation Process: a user guide." 2013.

Hlavac, J., Knowledge, skills and abilities (KSAs) as a metric to

re-conceptualise aptitude: a multi-stakeholder perspective, The Interpreter and Translator Trainer, 17:1, 29-53, 2023. DOI: 10.1080/1750399X.2023.2170052

Johnston, S.F. "Implanting a Discipline: The Academic Trajectory of Nuclear Engineering in the USA and UK." *Minerva 47*, 51–73, 2009. https://doi.org/10.1007/s11024-009-9114-6

Knowles, Malcolm S. "Andragogy, Not Pedagogy." *Adult Leadership*, 16(10), 350–352, 1968.

Kolb, D. A., The Process of Experiential Learning." *In Experiential learning: Experience as the source of learning and development*, pp. 20-38, 1984.

Townsend LW, Brady L, Lindegard J, Hall HL, McAndrew-Benavides E, Poston JW. "Nuclear engineering workforce in the United States." J Appl Clin Med Phys. 2022. doi: 10.1002/acm2.13808

US Bureau of Labor Statistics. Occupational Outlook Handbook.U.S. Bureau of Labor Statistics. 2022. Accessed 4th March 2024. https://www.bls.gov/ooh/architecture-and-engineering/nuclear-engineers.htm

US Department of Energy. *Employment in Nuclear Energy Activities: A Highlights Report,* 1979.

US focused Occupational Information Network (O*Net), "Nuclear Engineers 17-2161.00", 2024 17-2161.00 - Nuclear Engineers (onetonline.org)

University of New South Wales (UNSW) Human Research Ethics Procedure, 2024.

Valdez, B., Svolou, A., and Valdez, F., "A Holistic Approach to Process Improvement Using the People CMM and the CMMI-DEV: Technology Process, People, & Culture, The Holistic Quadripartite", Software Engineering Information Repository. SEI and CMU, 2008; https://seir.sei.cmu.edu/seir/

Verduyn, M. "23 KSA (Knowledge, Skills & Abilities) Examples + How to Use KSAS." AIHR. 2023. Available at: https://www.aihr.com/blog/knowledge-skills-abilities-ksa-examples/

Warier, S. *Competency & Competency Management – The Practitioner's Handbook*. Cognitio Knowledge Services, 2014.

FRAMEWORK CONDITIONS AND STRATEGIES FOR ATTRACTING YOUNG WOMEN TO ENGINEERING IN TIMES OF DIGITAL AND GLOBAL TRANSFORMATION

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ABSTRACT

Tackling the issues of the future will increasingly depend on the dedicated work and creativity of engineers. In addition to the general shortage of skilled workers in the engineering sector, there is a structural under-representation of women in particular, which is reflected in the choice of STEM studies by young women. In addition, the professional fields for future engineers are changing due to global change processes and steadily increasing digitalisation. In order to increase the proportion of female students, motivational projects for the study orientation are seen as a possibility to inspire young women for engineering. With a view to digital and global transformation processes, a central question is: *How should a motivation project for the transition between school and university be designed under today's conditions?*

This paper explores this question in a theory-based manner. After presenting theoretical findings on influencing factors in study orientation, current framework

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conditions and requirements are worked out in a two-stage study. First, there is a systematic literature review (SLR) on the state of research in STEM study orientation. Based on this, a qualitative interview study was conducted and evaluated with 25 young women, which identifies the framework conditions for motivational projects to attract young female engineers in today's world. As a result, concrete recommendations for action are given for the design of suitable concepts. In this way, this research work contributes to increasing the efforts of universities to attract young women to study engineering and to strengthen their motivation, self-efficacy and an engineering identity.

1 INTRODUCTION: WOMEN IN ENGINEERING

The engineering sciences have long had to deal with a growing problem of young talent, particularly among young women. This paper aims to make an evidence-based contribution to identifying the challenges, framework conditions and possible intervention strategies. To this end, this section analyses the current framework conditions and theoretical findings on influencing factors in study orientation.

1.1 Lack of young female engineers

The data situation regarding the proportion of women in engineering degree programmes is sobering. The initial situation in Germany is an example: there are currently a total of 300,000 open STEM positions (Anger et al. 2023). Another challenge is the continuing underrepresentation of women in engineering studies. Current statistics show that women currently make up 20% of the engineering professions in Germany (Federal Employment Agency 2023), while only 17.5% of first-semester students in the field of electrical engineering are female (destatis 2019). A variety of projects and initiatives have tackled this problem in the past. There has been a slight increase in the number of young female engineers, but a joint effort is still required from all stakeholders involved to motivate more women to study engineering. In view of digital and global transformation processes (e.g. sustainability), a core question is: How should a motivation project for the transition between school and university be designed under today's conditions? This **research question about framework conditions and strategies for attracting young women to engineering in times of digital and global transformation** is explored in this article in a theory-based manner.

1.2 Theoretical foundation for gender-specific study orientation

The current situation regarding first-year female STEM students points to challenges in study orientation. Evidence-based, gender-specific study choice programmes need to be developed for the engineering sector in particular. In order to analyse the (complex) correlations and answer the research question, theoretical approaches from the various scientific fields are required (e.g. linking the theories of teaching-learning research EER and gender and diversity research). A SLR has revealed the state of research in STEM study orientation, which will be outlined here. In addition to gender, **findings from gender research** point to other factors influencing young women's choice of study and their retention in STEM fields, e.g. (Taskinen and Lazarides 2020, Moote et al. 2020). A large number of research studies on the underrepresentation of women see the prevailing STEM image as well as professional and gender stereotypes as a reason for this, cf. (Hannover and Wolter

2019, Dreisiebner 2019). Prevailing attitudes and images and the "professional image" appear to be of particular importance for young women and may lead to them turning away from a STEM degree programme. This is often due to the fact that young women have little idea of specific STEM fields of activity and the fact that young adults often see STEM activities as "isolated" work with no relevance to their lives, see (Jeanrenaud 2020, Sept et al. 2019). Further studies on the connection between study choice and gender show the great importance of a lack of role models in the STEM field, cf. (Ihsen 2013 and 2019, Makarova et al. 2016) as well as social structural influencing factors, cf. (Jeanrenaud 2020, Makarova and Herzog 2020). The positive effect of role models on the attractiveness of STEM degree programmes has been empirically proven several times, for example (Battistini 2015, Wentzel and Funk 2015). In particular, the research findings that point to the need for "achievable" and "realistic" role models, including (Battistini 2015, Ihsen 2019, Greusing 2018), must form the central theoretical basis of programme concepts. **Educational sociology, psychology and motivation research** see study choice factors in close connection with self-efficacy, cf. (Bandura 1997, Schwarzer and Jerusalem 2010). The particular importance of the theoretical approaches of motivation and self-determination in the STEM context is referred to several times, cf. (Morgenroth et al. 2015, Deci and Ryan 1993, Jerusalem and Hopf 2010). Both theoretical constructs must play a central role in the programme design of motivation projects.

A STEM studies motivation programme should primarily address the causes of the underrepresentation of women in the engineering sector. To this end, theoretical findings on influencing factors in study orientation are presented. These include changes in attitude (e.g. increasing interest in the STEM field, increasing self-efficacy, reducing gender stereotypes) and long-term effective behavioural change, e.g. the intention to take up STEM studies (Brenning and Wolf 2021). Three fundamental factors are identified:

- ***Motivation*** is a significant factor influencing the choice of study. Motivation to choose a course of study is understood to be the force that drives one to choose a subject of study [Janke et al. 2023]. The different facets of study choice motivation are based on the self-determination theory of motivation, (Deci and Ryan 1993),
- ***Self-efficacy*** as personal confidence in one's own abilities, (Goodwin 2016), and
- ***Engineering identity*** as the self-perception of a person as an engineer, (Bandura 1994).

2 METHODOLOGY

2.1 Research on the empowerment of women in STEM fields

The methodological design of the analysis on the framework conditions and strategies for the study orientation of female pupils is carried out in two stages. As a *first step*, a SLR was conducted. The objective was to determine the current state of the art in research on the framework conditions for motivational projects for female students in the STEM sector. In addition to the theoretical findings from Sec. 1, publications from Scopus were selected. The PRISMA statement (Preferred

Reporting Items for Systematic Reviews and Meta-Analyses) was used as a method of systematic literature research (Moher et al., 2009; Page et al., 2021). In particular, the five aspects *Engineering, Motivation, Women, School* and *Programme* should appear as keywords within the title, abstracts or in the keywords of the articles; the document type is limited to scientific articles and conference papers in German and English. Following, the methodology of the analysis is presented in detail. Fig. 1 shows the complete search strings used in the SLR and the inclusion/exclusion criteria. Based on the selection of keywords, 244 contributions were initially identified.

ID	Search	Results
#1	engineering	19.705.099
#2	#1 AND motivation	17.751
#3	female	9.474.629
#4	women	1.504.660
#5	#2 AND (#3 OR #4)	938
#6	#5 AND (student OR school)	625
#7	#7 AND program	244
Search conducted on the 20.06.2023		

Fig. 1. Search strings used in the SLR and the inclusion/exclusion criteria

In the further procedure of literature selection according to the PRISMA statement, the selection of publications suitable for the research question was narrowed down to 18. These publications focus on STEM-related programmes for students at different grade levels and evaluate them with a focus on motivation, self-efficacy and identity. Fig. 2 presents the the data extraction process by using the PRISMA method.

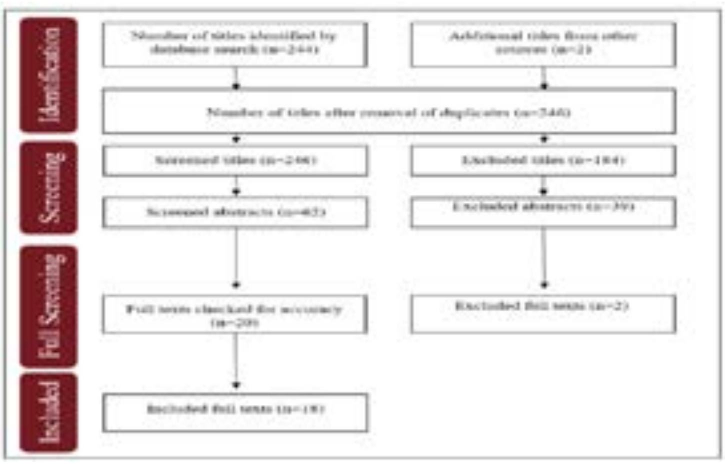
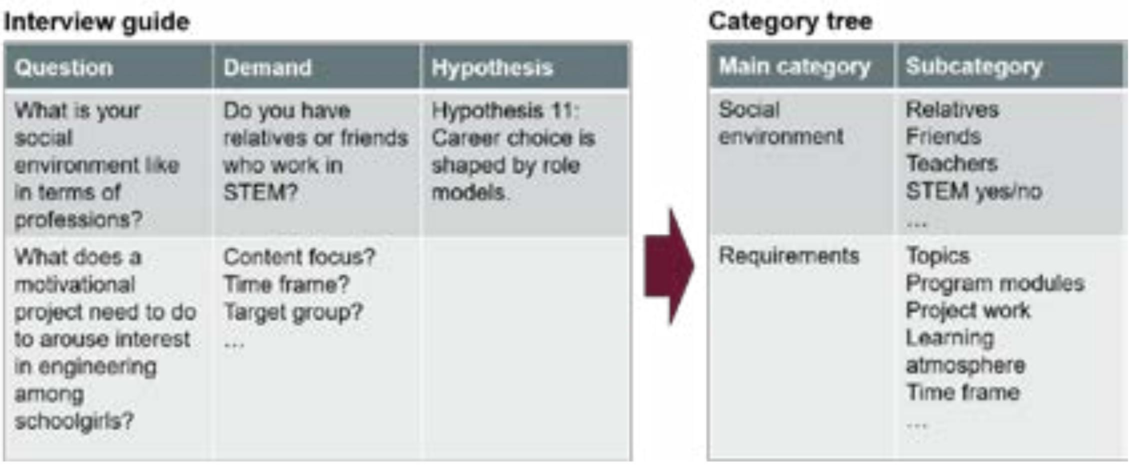


Fig. 2. Further procedure of literature selection according to the PRISMA method, according to (Moher et al., 2009; Page et al., 2021)

After clustering and inductive categorisation, the following categories were derived from the systematic literature analysis and the theoretical approaches from Sec. 1: *Target group; Topics; Time frame; Programme modules; Project work; Learning atmosphere; Role models*. These approaches form the theoretical basis for the qualitative survey and were incorporated into the development of the theory-based guidelines in Sec. 3. For this paper, the focus is on the qualitative study, as this provided valuable research findings on the fundamental decision-making process for women to study STEM in general and engineering in particular. The reasons for this are analysed qualitatively and barriers and support conditions in this decision-making process are identified based on evidence, see Sec. 3.1. These findings from the qualitative study are formulated as requirements for concepts in Sec. 3.2, which should address the causes of the underrepresentation of women.

2.2 Qualitative Study

As a *second step*, a *qualitative interview study* was conducted. This served to test the hypotheses on study and career orientation in the STEM field and to develop framework conditions for motivational projects for schoolgirls in engineering. Using a theory-based interview guide, 25 young women were interviewed, 14 high school students and 11 students in the initial phase of their engineering studies. Examples from the list of questions included: What is your social environment like in terms of careers? What does a motivational project have to fulfil in order to arouse interest in engineering among schoolgirls? Fig. 3 shows an example of the methodological design of the interview guide and category tree. The interviews were analysed and evaluated on the basis of hypotheses using qualitative content analysis according to (Mayring 2022, Kuckartz and Rädiker 2022). Intersubjective validation was used to increase the quality of the research process.


Interview guide

Question	Demand	Hypothesis
What is your social environment like in terms of professions?	Do you have relatives or friends who work in STEM?	Hypothesis 11: Career choice is shaped by role models.
What does a motivational project need to do to arouse interest in engineering among schoolgirls?	Content focus? Time frame? Target group? ...	

Category tree

Main category	Subcategory
Social environment	Relatives Friends Teachers STEM yes/no ...
Requirements	Topics Program modules Project work Learning atmosphere Time frame ...

Fig. 3. Interview guide and category tree - example of the methodological design

Research findings on the framework conditions and requirements for motivational programmes for young women in engineering have been explored through clustering and categorisation and are presented in Sec. 3.

2.3 Discussion of validity and limitations

At this point, the threats to the validity of the previously presented analysis of the framework conditions and strategies of study orientation programmes for female pupils will be discussed. The main limitation of the systematic literature search is that only one database (Scopus) was used as a source of scientific literature. This could not be realised otherwise for reasons of research economy. This narrow selection may lead to a weakening of the generalisability of the statements. The interview study has a reliably large sample. Nevertheless, limitations can also be identified here that may affect the generalisability of the results. The interviews were conducted and categorised by different people. Subjective categorisations can occur, particularly in the categorisation process, despite intensive discussion within the research team about the categories and their meaning. Another limitation is the selection of the interviewees. On the one hand, the time at which they left school varied and, on the other, all of the selected student interviewees came from the same university.

As the results from two different parts of the analysis were combined in the overall analysis using a mix of methods, the authors assume that the findings are robust.

For this reason, the findings have been adopted for the design of the STEM study orientation programme. A further step in validating the research results will be taken once the orientation programme has been carried out several times and evaluated with regard to the framework conditions and success. It is planned to share these evaluation results in the EER community after three rounds of the programme.

3 RESULTS

3.1 Research findings on the framework conditions of motivation programmes

The interview study shows that female students are aware of the importance of study orientation programmes. The study orientation programmes offered at schools is diverse, but nevertheless insufficient and non-transparent. Furthermore, results show that female students have low self-confidence in the technical field and that the use of role models in motivational projects is of particular importance. By clustering and categorising, findings on the following aspects of general framework conditions have been explored:

- *Focus on content* (e.g. career planning and training paths, future-oriented topics, diverse job profile and gender diversity, awareness of the role of engineering in sustainability, work-life balance),
- *Methodical-didactical design* (e.g. target group, learning atmosphere, type of programme modules, time frame),
- *Incorporating of (female) role models*,
- *Embedding into the school system*.

To assess the effectiveness of motivation projects, the impact of support measures for female pupils in STEM subjects can be assessed in two ways, based on (Brenning and Wolf 2021). As shown in Fig. 4, on the one hand, *short-term effects* can be achieved, which involve changes in attitude and settings. These include an increase in interest in the STEM field, support in finding a study programme and career, an increase in self-efficacy and a reduction in gender stereotypes (Brenning and Wolf 2021). A link can be made here to the theoretical findings from Sec. 1.2, as increasing interest in the STEM field is part of intrinsic motivation (Janke et al. 2023), increasing self-efficacy is described as such (Bandura 1994) and reducing stereotypes favours the development of an engineering identity (Godwin et al. 2023). Measurable indicators can include acceptance of the study orientation programme as a basic prerequisite for effectiveness, satisfaction with the programme, evaluation of the content of the programme and the people involved, as well as potential recommendation or renewed participation (Brenning and Wolf 2021: 115). In addition, *long-term effects* can be achieved, which are reflected in the changed behaviour of the female pupils. These can be determined based on the intention or actual STEM study or career choice, see Fig. 4.

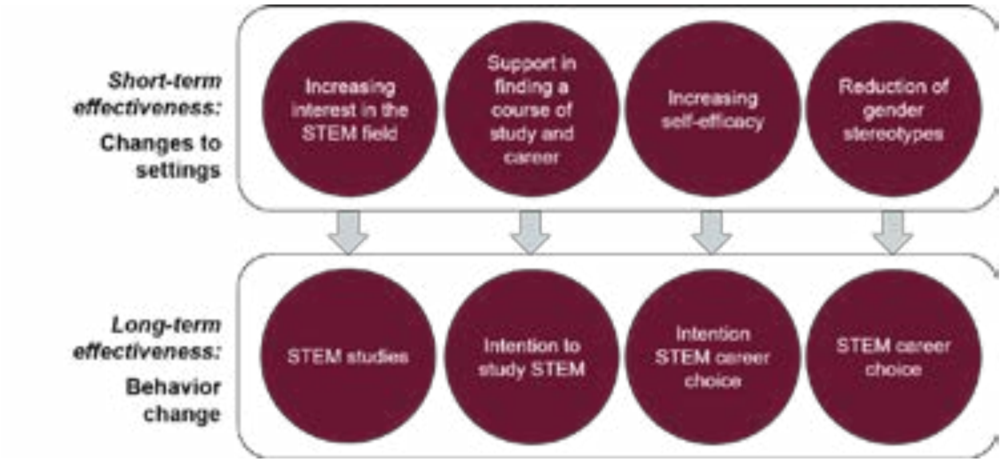


Fig. 4. Impact of measures for the study orientation of female pupils, based on (Brenning and Wolf 2021)

Suitable study orientation programmes for female students in the engineering sciences must therefore strengthen the influencing factors of motivation, self-efficacy and identity in order to have a short-term effect. The long-term effect of such a programme then determines the actual STEM study or career choice of the schoolgirls. The evaluation of the qualitative study has provided valuable insights into the design of a suitable and contemporary orientation programme, excerpts of which are presented next.

3.2 Theory-based recommendations for action for a motivation programme for young women in the engineering sciences

From the interview study, recommendations for action on the following aspects have been explored through clustering and categorising (Fig. 5).

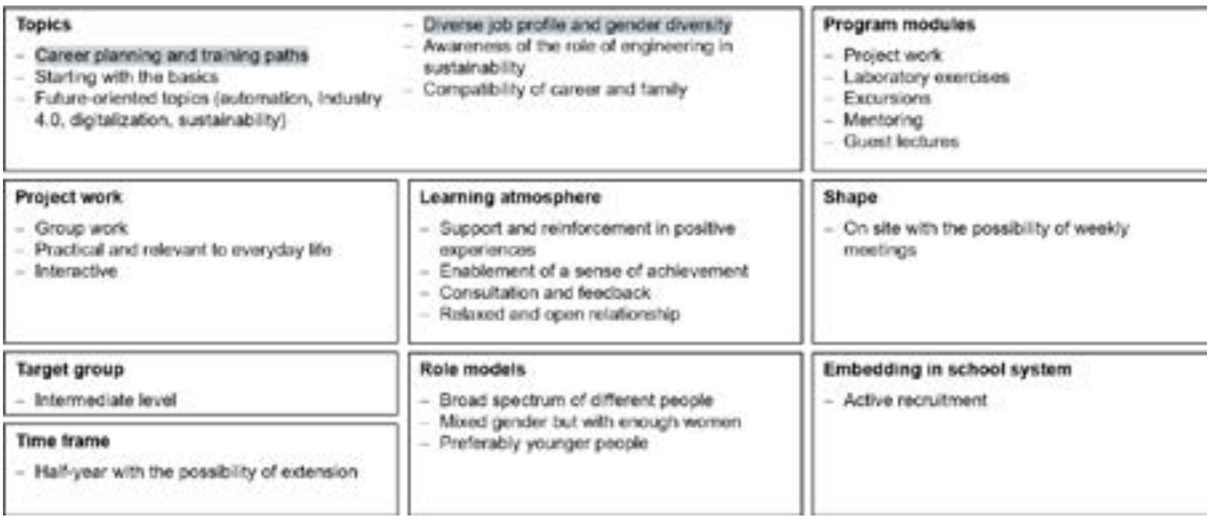


Fig. 5. Overview of recommendations for action

Evidence-based results on all aspects have been obtained from the qualitative study. Statements are listed as examples in this paper. The selected categories are colour-coded in Fig. 5. In the category *"Career planning and training paths to engineering"*, 5 out of 11 female students emphasise that different training paths and career opportunities should be addressed:

“It should be said that you can study there and that there are these and these opportunities, because I don't think anyone knows what opportunities there are in the STEM subjects.” Female student 2

Results in the category *"Diverse job profile and gender diversity"* indicate a diffuse job profile based on gender stereotypes:

“Just talking a bit against this 'women have nothing to do in technical professions' [...], I think that would have helped me a lot.” Female student 6

“So my father also has a technical profession, but because I am the girl, he had shown things to my brother rather than to me.” Female student 2

As outlined in the previous sections, the programmes should also include future-oriented topics such as automation, Industry 4.0, digitalisation and sustainability. The students' statements suggest that modern technology in particular can arouse interest.

4 SUMMARY AND OUTLOOK

The aim of this paper is to provide evidence-based findings on framework conditions and strategies for attracting young women to engineering in times of digital and global transformations.

A SLR on the state of research in general STEM study orientation is first carried out to provide a theoretical foundation. Based on this, a qualitative interview study with 25 female pupils and students in the initial phase of their engineering studies identifies the framework conditions for motivational projects to attract young female engineers today. The results are discussed in relation to the theoretical findings. As a result, concrete recommendations for action are given for the design of suitable concepts at universities.

As a validation approach of the presented study, a project for engineering study choice orientation for schoolgirls was developed as a regional STEM education measure based on the recommendations for action (see sec. 3.2). The aim of the project is to increase the proportion of women in STEM fields through the framework conditions and strategies outlined in this paper (strengthening the self-efficacy, initiative and creativity of female pupils, overcoming stereotypes and prejudices, creating a network of role models for female pupils). The study presented here is therefore to be further validated in practice. To this end, the first round of the project was successfully implemented in January 2024. The next planned steps are further project runs and the review of the effectiveness of the framework conditions presented in this paper by means of the pilot project. In addition, the long-term impact of the motivation project and the influence of the framework conditions on the actual study choices of female pupils will be investigated.

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REFERENCES

Anger, C., Betz, J., & Axel, P. (2023): MINT-Frühjahrsreport 2023: MINT-Bildung stärken, Potenziale von Frauen, Älteren und Zuwandernden heben. Strengthening STEM education, realising the potential of women, older people and immigrants. (Institut der deutschen Wirtschaft Köln e. V, Eds..). https://www.nationalesmintforum.de/fileadmin/medienablage/user_upload/MINT-Fruehjahrsreport_2023.pdf

Bandura, A. (1994): Self-efficacy. Encyclopedia of human behavior, (4), 71–81.

Battistini, Martina (2015): Ganz normale Exotinnen. [Quite normal exotic women. In: Sandra Augustin-Dittmann and Helga Gotzmann (eds.): MINT gewinnt Schülerinnen. [MINT wins schoolgirls.] Wiesbaden: Springer Fachmedien Wiesbaden, S. 93–110.

Brenning, S., & Wolf, E. (2021): MINT-Projekte für Schülerinnen an Hochschulen. Analyse des Wirkungsmechanismus und Meta-Evaluation der empirischen Evidenz. [STEM projects for female students at universities. Analysis of the impact mechanism and meta-evaluation of the empirical evidence] ZeHf – Zeitschrift für empirische Hochschulforschung, 4(2), 111–129. https://doi.org/10.3224/zehf.v4i2.02

Deci, E., & Ryan, R. M. (1993): Die Selbstbestimmungstheorie der Motivation und ihre Bedeutung für die Pädagogik.[The self-determination theory of motivation and its significance for pedagogy.] Zeitschrift für Pädagogik, 39(2), 223–238.

Destatis (2019): Berechnungen des Kompetenzzentrums Technik-Diversity-Chancengleichheit e. V. (2020) und des Statistisches Bundesamt für 2019, [Calculations by the Kompetenzzentrum Technik-Diversity-Chancengleichheit e. V. (2020) and the Federal Statistical Office () for 2019], https://www.komm-mach-mint.de/service/mint-datentool.

Dreisiebner, Gernot (2019): Berufsfindungsprozesse von Jugendlichen. [Career choice processes of young people], Springer Fachmedien Wiesbaden.

Federal Employment Agency / Bundes Agentur für Arbeit (2023): Berufe auf einen Blick (Alle Berufe, MINT und Ingenieurberufe). Professions at a glance (all professions, STEM and engineering professions). https://statistik.arbeitsagentur.de/DE/Navigation/Statistiken/Interaktive-Statistiken/Berufe-auf-einen-Blick/Berufe-auf-einen-Blick-Anwendung-Nav.html

Godwin, A. (2016): The Development of a Measure of Engineering Identity. 2016 ASEE Annual Conference & Exposition. https://doi.org/10.18260/p.26122.

Greusing, Inka (2018): „Wir haben ja jetzt auch ein paar Damen bei uns“. Symbolische Grenzziehungen und Heteronormativität in den Ingenieurwissenschaften. ["We've got a few ladies with us now too". Symbolic boundaries and heteronormativity in the engineering sciences.], Dissertation.

Hannover, Bettina; Wolter, Ilka (2019): Geschlechtsstereotype: wie sie entstehen und sich auswirken. [Gender stereotypes: how they arise and have an impact.] In: Beate Kortendiek, Birgit Riegraf und Katja Sabisch (Eds.): Handbuch Interdisziplinäre Geschlechterforschung, Bd. 65. Wiesbaden: Springer, S. 201–210.

Ihsen, Susanne (2013): Gender and Diversity in Engineering Education. In: Françoise Côme, Xavier Fouger, Kamel Hawwash und Wim Van Petegem (Eds.): SEFI@40 Driving Engineering Education to Meet Future Challenges. Brüssel, S. 65–67.

Ihsen, Susanne (2019): Zwei Schritte vor und einen zurück? Wirksame Strategien und nachhaltige Maßnahmen für mehr Frauen in MINT. [Two steps forward and one step back? Effective strategies and sustainable measures for more women in STEM.] In: Yvonne Haffner und Lena Loge (Eds.): Frauen in Technik und Naturwissenschaft: eine Frage der Passung. Aktuelle Erkenntnisse und Einblicke in Orientierungsprojekte. Opladen, Berlin, Toronto: Verlag Barbara Budrich.

Janke, S., Messerer, L. A. S., Merkle, B., & Krille, C. (2023): *STUWA: Ein multifaktorielles Inventar zur Erfassung von Studienwahlmotivation.* [STUWA: A multifactorial inventory for recording motivation to choose a degree programme.] Zeitschrift für Pädagogische Psychologie, 37(3), 215–231. https://doi.org/10.1024/1010-0652/a000298 Janke et al. 2023).

Jeanrenaud, Yves (2020): MINT. Warum nicht? Zur Unterrepräsentation von Frauen in MINT, speziell IKT, deren Ursachen, Wirksamkeit bestehender Maßnahmen und Handlungsempfehlungen. [MINT. Why not? On the underrepresentation of women in STEM], Expertise für den Dritten Gleichstellungsbericht der Bundesregierung.

Jerusalem, Matthias; Hopf, Diether (Eds.) (2010): Selbstwirksamkeit und Motivationsprozesse in Bildungsinstitutionen. [Self-efficacy and motivational processes in educational institutions].Weinheim: Beltz (Zeitschrift für PädagogikBeiheft, 44).

Kuckartz, U., Rädiker, S. (2022): Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung. [Qualitative content analysis: methods, practice, computer support]: Beltz Juventa

Makarova, E.; Herzog, W. (2020): Geschlechtersegregation bei der Berufs- und Studienwahl von Jugendlichen. [Gender segregation in the career and study choices of young people]. In: Tim Brüggemann und Sylvia Rahn (Eds.): Berufsorientierung. Ein Lehr- und Arbeitsbuch. Münster, New York: Waxmann (utb, 5249), S. 271–278.

Makarova, E., Aeschlimann, B., Herzog, W. (2016): Wenn Frauen in MINT-Studiengängen fehlen: Mathematisch-naturwissenschaftlicher Unterricht und die Studienwahl junger Frauen. [When women are missing from STEM degree programmes: Maths and science education and young women's study choices.] In: Hannelore Faulstich-Wieland (Eds.): Berufsorientierung und Geschlecht. Weinheim, Basel: Beltz Juventa, Band 50, S. 39–57.

Mayring, P. (2022): Qualitative Inhaltsanalyse: Grundlagen und Techniken. [Qualitative content analysis: basics and techniques.] Beltz.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009): Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Annals of Internal Medicine, 151(4), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

Moote, Julie; Archer, Louise; DeWitt, Jennifer; MacLeod, Emily (2020): Science capital or STEM capital? Exploring relationships between science capital and technology, engineering, and maths aspirations and attitudes among young people aged 17/18. In: J Res Sci Teach 57 (8), S. 1228–1249. DOI: 10.1002/tea.21628.

Morgenroth, Thekla; Ryan, Michelle K.; Peters, Kim (2015): The Motivational Theory of Role Modeling: How Role Models Influence Role Aspirants' Goals. In: Review of General Psychology 19 (4), S. 465–483. DOI: 10.1037/gpr0000059.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow,C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021): The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Journal of Clinical Epidemiology, 134, 178–189. https://doi.org/10.1016/j.jclinepi.2021.03.001

Schwarzer, R., & Jerusalem, M. (2002): Das Konzept der Selbstwirksamkeit. [The concept of self-efficacy]. In M. Jerusalem & D. Hopf (Eds..), Selbstwirksamkeit und Motivationsprozesse in Bildungsinstitutionen (S. 28–53). Beltz.

Sept, Alexandra; Jeanrenaud, Yves; Ihsen, Susanne (2019): Gender aspects of study decisions, entrance and academic success in STEM. Journal of Global Education and Research (JGER)3(1).

Taskinen, P. H. and Lazarides (2020): Berufs- und Studienorientierung in MINT-Berufen. [Career and study guidance in STEM professions]. In T. Brüggemann & S. Rahn (Eds..), Berufsorientierung (S. 337–342). Waxmann.

Wentzel, Wenka; Funk, Lore (2015): „Als ich selbst an der Maschine war, war ich erstaunt wie leicht es ging" – Kriterien zur Gestaltung von Berufsorientierungsveranstaltungen für Mädchen. ["When I was at the machine myself, I was amazed at how easy it was" - criteria for organising career orientation events for girls]. In: Micus-Loos, C./Plößer, M. (Eds..): Des eigenen Glückes Schmied_in!? Geschlechterreflektierende Perspektiven auf berufliche Orientierungen und Lebensplanungen von Jugendlichen. Wiesbaden: Springer VS, S. 135–153.

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How Experienced Teachers Teach Lifelong Learners

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Conference Key Areas: *Continuing education and life-long learning. Building the capacity and strengthening the educational competences of engineering educators.*
Keywords: *Upskilling teachers, teaching approaches*

ABSTRACT

Educating professionals in continuing higher education significantly differs from educating students in traditional university programs. This study aims to investigate the pedagogical approaches of experienced teachers. The insights gained are intended to inform the development of an upskilling program for novice teachers in lifelong higher education, thereby enhancing their didactical skills in this unique educational setting.

This research employed six semi-structured interviews with experienced teachers within a Diploma of Leadership Program, analyzed through a grounded theory approach. The study presents two principal findings: First, teachers who pay close attention to their students' practices often use more experimental teaching methods. Second, the analysis revealed three distinct teaching roles adopted by teachers: Facilitator, Coach, and Challenger. These roles underscore the multifaceted nature of teaching in continuing higher education. While all teachers act as facilitators, coaches, and challengers, they do so to varying degrees.

The conclusions suggest that developing a program to support teachers in lifelong learning contexts should focus on expanding their awareness of educational impacts and outcomes, incorporating experiential learning techniques, and recognizing the value of a diverse learning community.

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1 INTRODUCTION

Educating professionals in formal continuing higher education is distinct from teaching students in conventional university programs. Exceptional teaching combines self-awareness, relational skills, and subject expertise to foster critical thinking and problem-solving within a dynamic, supportive learning environment (Cohen et al 2010, Sherman et al 1987). This study aims to explore the teaching methodologies that contribute to becoming an exceptional teacher.

The research question is: How do skilled teachers teach, and what is their reasoning behind their approaches? And assuming the teachers are not all exceptional, looking for differences might help us identify possible lines of progression: What differences do we observe among the teachers?

The findings from this study are intended to guide the creation of an upskilling program for new teachers in continuing higher education, enhancing their teaching capabilities in this specialized educational context.

The study involved teachers from the Diploma of Leadership program, which awards 60 ECTS. To be admitted to the program, students must have an educational background at least equivalent to that of a business academy degree, in addition to two years of relevant work experience. The participants are professionals for whom the integration of practice and theory constitutes the core of the program. The analysis indicates that teachers who successfully blend theory with practice through experiential learning also demonstrate a profound understanding of how to align their teaching with the professional practices of their students.

1.1 The professionals

In the evolving landscape of continuing higher education, the adult learner emerges with distinct characteristics that set them apart from students in regular higher education. These adults, as lifelong learners, come with a rich background of experiences, responsibilities, and goals. They seek education not just for the sake of learning but for practical uses that can boost their careers and professional growth. They participate in different social practices simultaneously, as learners in continuing education and as professionals at work. For them, learning is more than just academic success; it's about improving their practical skills and how they perform in their jobs (Knowles et al. 2020; Knowles 1978, Purwata et al 2022, Illeris 2017).

To join the Diploma of Leadership Program, candidates need at least two years of work experience in their field, along with the necessary academic background. The knowledge and real-world experience these learners bring into the classroom play several vital roles: It deepens theoretical discussions, form a concrete foundation for hands-on learning activities, and demonstrates how theoretical ideas are relevant and useful in real-world practice. Thus, emphasizing the connection between theory and practice is crucial for ensuring that what is learned in the classroom can be effectively applied in professional contexts (Hajian 2019).

1.2 Transformative learning

Transformative learning turns training into a powerful tool for change, opening new ways of seeing one’s work, increasing self-awareness, and broadening the scope of possible actions. Illeris defines transformative learning as "all forms of learning that result in changes in the learner’s identity." (Illeris 2013 pp.67). This perspective shifts the focus towards critically evaluating traditional teaching methods to ensure that learning experiences are relevant and can be directly applied in real-life situations (Mezirow 1997, Kitchenham 2008, Illeris 2013).

Transformative learning involves making tacit knowledge and assumptions explicit, subjecting them to critical scrutiny within theoretical frameworks. It is the teacher's role to foster a learning environment that encourages the exploration and questioning of these underlying beliefs and knowledge.

For adult learners in continuing higher education, collaborative and experiential learning methods are particularly effective. They connect theory with practice and improve the application of classroom learning in professional settings. These methods utilize the vast experiences of adult learners, prompting them to share their insights, question their preconceptions, and collaboratively build knowledge with peers. Experiential learning allows learners to test new ideas and methods in a supportive, reflective space. This practical approach not only deepens their understanding of the subject but also boosts their ability to use this knowledge effectively in their work (Deslauriers et al. 2019, Kolb et al. 2001, Hansman 2001, Wenger-Trayner et al 2014, Mezirow 1990, Gokhale 1995; Kim and Pak 2002).

1.3 Teaching for transformation

Teaching adult learners in continuing higher education presents unique challenges for teachers. While they may design learning activities and possess a deep understanding of the theoretical aspects of a course, less experienced instructors might struggle to establish credibility and authority in classrooms filled with experienced professionals (Holton et al. 2001, Kugel 1993, Eschenbacher 2020, Gravett 2004, Foote 2015, Hatlevik 2018).

A key issue is whether teachers, especially those with limited practical experience in a specific area, can create an environment that supports transformative learning. I argue that these educators can do so. As learning professionals, they can organize collaborative and experiential learning activities that draw on the learners' own experiences and knowledge, fostering a group exploration of practices.

2 METHODOLOGY

2.1 Interviews

To explore how skilled teachers teach, and their reasoning behind, semi-structured interviews were conducted with six teachers from the Diploma of Leadership Program. The head of studies compiled a list of six teachers, representing a diverse mix across the program, and all were invited to participate in the interviews, which they accepted. The group consisted of four women and two men, a blend of both external and internal hires. Their teaching experience ranged widely, from three to over fifteen years, and besides teaching the Diploma of Leadership Program, their professional activities spanned research, teaching in other areas, and consultancy.

The interviews were conducted in a random sequence and analyzed accordingly. The semi-structured format allowed for an in-depth exploration of the teachers' viewpoints, following their train of thought naturally. An interview guide served as a comprehensive checklist, ensuring that by the end of each session, all relevant topics pertaining to the study were discussed. The questions were crafted to shed light on their teaching practices, and were as follows:

- Who typically participates in your teaching sessions?
- If I were to open the door to your classroom on a random day, what would I observe?
- In what ways do the students rely on you?
- How do you prepare for your teaching sessions?
- Could you briefly discuss your teaching career?
- How have you yourself acquired competences to teach lifelong learners?
- If you were mentoring a new teacher in lifelong learning, how would you approach it?

Interviews were recorded on a mobile device and subsequently transcribed using the transcription feature in Microsoft software. The transcriptions were carefully read, coded, and analyzed. To ensure a thorough understanding, the recordings were listened to again, with additional notes taken to enhance the initial analysis as needed.

2.2. Analyzing interviews

The analytical process adhered to the principles of grounded theory (Corbin and Strauss 1990, Corbin and Strauss 1996), ensuring a rigorous examination of the data. To keep a detailed record of each interview, quotes were systematically organized into a program theory matrix (Dahler-Larsen 2018, Frye and Hemmer 2012). This approach provided a structured and comprehensive overview of each interview.

In this study, program theory was utilized to organize and analyze quotes and insights from each interview, with the goal of clearly demonstrating what teachers do and the reasons behind their actions. First, each interview was analyzed separately to treat them as unique stories, ensuring they were understood on their own before comparing them. This step provided a clear picture of each teacher, including how they plan and execute their teaching and the reasoning behind, as shown in table 1. To answer the second half of the research question, 'What differences do we observe among teachers?' the interviews were compared. First, common themes were identified, and then fundamental differences among the teachers were examined based on patterns.

I… (activity)	In order to… (Intention)	The effect in classroom is…	Outcome
Collect, develop and tell stories that illustrate theory	Help the students to understand theory and connect it to practice	Theories become mental tools that the students find meaningful and useful	In practice, the manager must make decisions on a reflected basis

Table 1: A section of a program theory matrix based on an interview with a teacher

3 Presentation and Discussion

How do skilled teachers teach? Initially, data from the various interviews were compiled to outline the teachers' actions in preparing for and conducting their teaching. The data presented in this section, and illustrated in figure 1, details the teachers' activities in both the preparation and execution of their teaching.

The Interviews were coded and condensed. Across interviews, activities fell within four overarching categories:

- Activities to foster a safe and fruitful learning environment
- Activities to link theory and practice
- Activities to facilitate students learning process
- Activities to manage classroom

In addition to these categories, the interviews revealed insights into how teachers prepare, perspectives on teaching roles and how they would mentor new teachers entering the field of teaching lifelong learners.

Fig. 1. Overview of activities teachers carry out related to teaching

Figure 1 represents a comprehensive summary of all the activities discussed individually by the teachers. It depicts the activities conducted by teachers, as identified across interviews, to a) establish a learning environment and define roles, b) ensure student engagement with the content, and c) prepare and evolve their teaching. These activities are arranged according to an intuitive understanding of complexity, increasing from the centre outward.

Differences among teachers manifest in their actions and motivations. The following discussion includes a quantitative analysis of their teaching rationale and a qualitative examination of the differences among teachers.

3.2 Diverse approaches to teaching, quantitative differences

The interviews revealed that teachers have unique traits and engage in various activities, prompting an exploration of these differences. Revisiting the program theories pinpointed variations in activities and revealed an unexpected trend in teachers' views on effects and outcomes (program theories' columns 3 and 4 as in table 1).

All teachers described numerous activities linked to the four main themes identified in the program theory. However, there was a clear distinction in how they discussed the immediate effect of these activities in the classroom and the expected outcomes in students' professional practice.

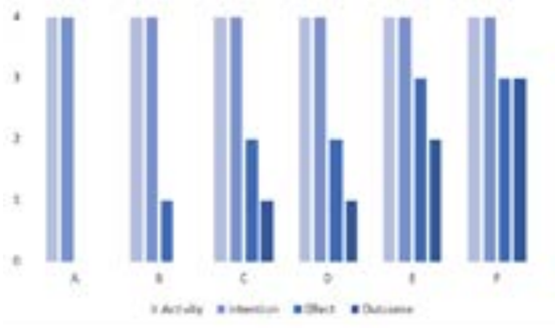

Fig. 2. A numerical representation of the six program theories for each of the teachers A–F.

The chart shows that teachers, labeled A through F, each discussed the four main themes (y-axis). Teachers B, C, D, E, and F talked about the classroom effects to different degrees. Additionally, Teachers C, D, E, and F shared their thoughts on how these activities could influence the students' professional practices.

When comparing the information from Figure 1, Figure 2, and the records from each teacher, it became clear that teachers who focused more on the effects and outcomes tended to use more advanced teaching methods, such as storylines, sociodramas, and action learning.

This analysis suggests that three distinct teaching practices emerge from the data: facilitator, coach, and challenger. The challenger role is observed more frequently among educators who emphasize student outcomes in their practice.

3.3 Characterizing teaching practices –qualitative differences

The six teachers exhibit variations in their approaches, as shown by their activities, how they link theory with practice, the role they assume as teachers, and the value they place on the learning community. These differences are discussed in section 3.3 - 3.6 and summarized in table 2.

All teachers used dialogue and group work in their teaching strategies. However, experiential learning methods like storyline, sociodrama, and case-based teaching were mainly used by teachers C, D, E, and F.

Experiential learning allows learners to gain knowledge and skills through direct experiences. It emphasizes active involvement, tackling real-world problems, and reflecting on these experiences to deepen understanding. This process encourages learners to act, reflect, learn, and apply, thereby building vital skills. Storyline and sociodrama enable participants to engage with real issues in an interactive way, enhancing problem-solving, critical thinking, and adaptability. These methods also help link theory to practice, uncover tacit knowledge, and experiment with new ways of thinking and acting in a safe space (Kolb et al 2001, Lewis and Williams 1994).

While all teachers introduced trial actions, they vary in execution. Teachers A and B ask participants to share their experiences. In contrast, Teachers E and F prompt reflection with questions like "What happened? Did it change anything?"

There is a noticeable difference in how teachers use these learning activities. Although all teachers incorporate elements of the three approaches, the extent and manner of their usage vary greatly. This suggests a link between a teacher's approach to learning and their choice of activities.

3.4 Linking theory and practice

Teachers A and B frequently use a deductive approach, beginning with theory and then inviting students to provide practical examples to illustrate the theory. In contrast, teachers C, D, E, and F prefer an inductive approach in their classrooms. For example, one of them organizes a role-play that immerses students in scenarios related to their leadership practices. This activity helps students see how different strategies can result in varied outcomes and approaches. At times, the teacher steps in as a challenger, pushing students to consider and assess different ways of acting.

The shift from deductive to inductive teaching enables students to not only understand and apply theories but also to address real-life challenges using theoretical knowledge. This method transforms theories into practical tools for making well-informed decisions. As one teacher put it: "Theories become valuable mental tools for students, guiding their decisions in leadership."

Thus, while some teachers focus more on theory, others emphasize the practical application of theoretical concepts.

3.5 The role of the teacher and the learning community

A teacher mentioned: "I sometimes teach very small classes and feel that I can't provide the same quality as when teaching slightly larger classes." This comment sheds light on the difficulties of teaching very small groups. It underscores an inherent understanding of the advantages that arise when students share their knowledge, experiences, and viewpoints in class.

Teachers universally value the input students bring to the learning environment. The diversity of perspectives enriches classroom discussions, serving either as conversation partners in small groups or as a mini society that helps delve into various dilemmas, ideas, and responses. Not surprisingly, teachers who utilize interactive methods like sociodrama and case studies particularly cherish and recognize the significance of a dynamic learning community.

3.6. Classroom management

Teachers have distinct teaching styles, which extends to their approach towards classroom management. All teachers recognize their duty to foster a safe and engaging learning space. They set up a clear didactical contract, define the learning objectives, and establish rules for teamwork and communication.

Some teachers focus more on asserting their credibility and control, while others strive to ensure that every student has equal opportunity to delve into both theory and practice, valuing the varied perspectives and experiences of all students.

Teachers E and F, in particular, face challenges when students struggle to work together or when some students dominate the discussions. They share concerns like "He takes up too much space" and "I mentally keep track of participation to make sure I involve everyone equally." For these teachers, it is crucial to bring into play the diverse perspectives and experiences of all students, acting as a sort of playmaker.

All the interviewed teachers use elements of facilitating, coaching and challenging. However, the reasons, extent, and ways they do it, differ greatly. The three teaching practices as facilitator, coach and challenger are summarized in the table below.

	Teacher as facilitator	Teacher as coach	Teacher as challenger
Focus	Ensure students meet the course objective	Foster the development of each student	Empower students as active practitioners
Teaching approach	Deductive lectures, dialogue-based, group work and time for reflection.	Inductive case studies, storylines, sociodramas, and mirroring exercises.	Experiential Action learning activities
Learning community	Students are viewed as a uniform group.	Each student is addressed individually.	Release of the learning community potential
Classroom management	Establish legitimacy	Clarify didactical contract	Bring diverse perspectives forward

Table 2. Overview of differences between teaching practices.

Table 2 summarizes differences in how teachers approach the students, the content, and the classroom.

4 CONCLUSIONS

Teaching lifelong learners in continuing education demands an approach that takes the participants' professional mindset and applicative perspective into account. This study aimed to answer the questions: How do skilled teachers teach, and what is their reasoning behind their methods? What differences do we observe among teachers?

We have observed quantitative and qualitative differences among the interviewed teachers and identified three distinct approaches where teachers take on the roles of facilitator, coach, or challenger, respectively. While all teachers exhibited elements of these roles, they varied in the extent and way they implemented them. Teachers who are attentive to the participants' practices also challenge participants and leverage the knowledge and experience of the learning community.

The study aims to inform the next phase in creating a training program for new teachers within continuing higher education at an engineering university. Teachers were asked not only about their teaching methods but also how they would guide a newcomer to continuing education. One experienced teacher suggested: "You need to first thoroughly understand yourself and your content." Beyond this, all participants highlighted the importance of watching peers, experimenting, providing mentorship, and building a professional community among teachers. Based on this study's findings, a training program could include expanding understanding of the effects and outcomes of teaching, incorporating experiential learning, and leveraging the benefits of a diverse learning community.

REFERENCES

Corbin, J.M., and Strauss, A. "Grounded theory research: Procedures, canons, and evaluative criteria." Qualitative Sociology 13, no. 1 (1990): 3-21. https://doi.org/10.1007/BF00988593

Corbin, J., and Strauss, A. "Analytic ordering for theoretical purposes." Qualitative Inquiry 2, no. 2 (1996): 139-150. https://doi.org/10.1177/107780049600200201

Cohen, A. and Porath, M. “Exceptional educators: Investigating Dimensions of their practice.” Transformative Dialogues: Teaching & Learning Journal 4, no 2 (2010).

Dahler-Larsen P. ”Evaluering af Projekter - og andre ting, som ikke er ting”. 2 ed. Odense: Syddansk Universitetsforlag, 2018.

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., and Kestin, G. "Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom." Proceedings of the National Academy of Sciences of the United States of America 116, no. 39 (2019): 19251-19257. https://doi.org/10.1073/pnas.1821936116

Eschenbacher, S. "Transformative learning and the hidden dynamics of transformation." Reflective Practice 21, no. 6 (2020): 759-772. https://doi.org/10.1080/14623943.2020.1821631

Foote, L. S. "Transformational Learning: Reflections of an Adult Learning Story." Adult Learning 26, no. 2 (2015): 84-86. https://doi.org/10.1177/1045159515573017

Frye, A. W. & Hemmer, P.A. “Program evaluation models and related theories: AMEE Guide No. 67”. Medical Teacher” 34 no.5 (2012): 288-299. https://doi.org/10.3109/0142159X.2012.668637

Gokhale, A. "Collaborative Learning Enhances Critical Thinking." Journal of Technology Education 7, no. 1 (1995). https://doi.org/10.21061/jte.v7i1.a.2

Gravett, S. "Action research and transformative learning in teaching development." Educational Action Research 12, no. 2 (2004): 259-272. https://doi.org/10.1080/09650790400200248

Hajian, S. “Transfer of Learning and Teaching: A Review of Transfer Theories and Effective Instructional Practices.” IAFOR Journal of Education 7, no.1 (2019): 93-111. https://doi.org/10.22492/ije.7.1.06

Hansman, C. A. "Context-Based Adult Learning." New Directions for Adult and Continuing Education 2001 no 89 (2001): 43-52. https://doi.org/10.1002/ace.7

Hatlevik, I.K. R. "Transformativ læring. Hva er det, og hva kan det bidra med i lærerstudenters kompetanseutvikling?" Uniped 41, no. 4 (2018): 384-400. https://doi.org/10.18261/issn.1893-8981-2018-04-02

Holton, E.F., Swanson, R.A. and Naquin, S.S. “Andragogy in Practice: Clarifying the Andragogical Model of Adult Learning.” Performance Improvement Quarterly 14 no. 1. (2001): 118-143. https://doi.org/10.1111/j.1937-8327.2001.tb00204.x

Illeris, K. ”Transformativ Læring og Identitet”. Frederiksberg: Samfundslitteratur, 2013

Illeris, K. "Peter Jarvis and the understanding of adult learning." International Journal of Lifelong Education 36, no. 1-2 (2017): 35-44. https://doi.org/10.1080/02601370.2016.1252226

Kim, E. and Pak, S.. "Students do not overcome conceptual difficulties after solving 1000 traditional problems." American Journal of Physics 70, no. 7 (2002): 759–765. https://doi.org/10.1119/1.1484151

Kitchenham, A. "The Evolution of John Mezirow's Transformative Learning Theory." Journal of Transformative Education 6, no. 2 (2008): 104-123. https://doi.org/10.1177/1541344608322678

Knowles, M. S. "Andragogy: Adult Learning Theory in Perspective." Community College Review 5, no. 3 (1978): 9-20. https://doi.org/10.1177/009155217800500302

Knowles, M.S., Holton III, E.F., Swanson, R.A., SWANSON, R., & Robinson, P.A. "The Adult Learner: The Definitive Classic in Adult Education and Human Resource Development." 9th ed.. London: Routledge, 2020.

Kolb, D. A. Boyatzis, R.E. and Mainemelis, C.. "Experiential Learning Theory: Previous Research and New Directions." In Perspectives on Thinking, Learning, and Cognitive Styles. 1st Ed London: Routledge, 2001.

Kugel, P. "How professors develop as teachers." Studies in Higher Education 18, no. 3 (1993): 315-328. https://doi.org/10.1080/03075079312331382241

Lewis, L.H. and Williams, C.J.. "Experiential learning: Past and present." New Directions for Adult and Continuing Education 1994 no. 62 (1994): 5-16. https://doi.org/10.1002/ace.36719946203

Mezirow, J. "How critical reflection triggers transformative learning." In J. Mezirow & Associates (Eds.), Fostering critical reflection in adulthood: A guide to transformative and emancipatory learning (pp. 1–20). San Francisco: Jossey-Bass, 1990.

Mezirow, J. "Transformative Learning: Theory to Practice." New Directions for Adult and Continuing Education 1997, no 74 (1997): 5-12. https://doi.org/10.1002/ace.7401

Purwati, D., Mardhiah, A., Nurhasanah, E. and Ramli, R. "The Six Characteristics of Andragogy and Future Research Directions in EFL: A Literature Review." Elsya: Journal of English Language Studies 4, no. 1 (2022): 86-95. https://doi.org/10.31849/elsya.v4i1.7473

Sherman, T. M., Armistead, L. P., Fowler, F., Barksdale, M. A. and Reif, G. "The Quest for Excellence in University Teaching". The Journal of Higher Education 58 no.1 (1987): 66–84. https://doi-org.proxy.findit.cvt.dk/10.1080/00221546.1987.11778228

Wenger-Trayner, E., Fenton-O'Creevy, M., Hutchinson, S., Kubiak, C. and Wenger-Trayner, B. (Eds.). "Learning in Landscapes of Practice: Boundaries, identity, and knowledgeability in practice-based learning." (1st ed.). London, Routledge, 2014.

EVALUATING IDEA GENERATION HEURISTICS BY MEANS OF SCHEMATA AND SEARCH

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ABSTRACT

The significance of cognitive skills, particularly creativity, for the workforce of today, has been widely acknowledged, with engineering educators and accreditation bodies alike underlining the necessity for integrating and developing creative problem-solving skills in engineering students. Simple ideation techniques have been previously explored to enhance creative problem-solving among students, however measuring their effectiveness is partially masked by whether students employed schema-driven or search-based strategies. Schema-driven strategies, utilising specialised memory structures developed through acquiring expertise are highly effective, while search-based strategies, typically employed by students who do not have a wealth of expertise, are inefficient but can be enhanced through the use of idea generation heuristics. This research evaluates the influence of a particular heuristic, the Eight Fields of MATCEMIB, on idea generation in first-year engineering students through an experiment constructed to separate schema-driven and search-based ideas. Students were exposed to open-ended problems with different prompts and stimuli and assessed on the number, breadth and creativity of the ideas generated. The control group, without any prompting, showed less effective idea generation compared to experimental groups guided by such prompts, indicating the

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heuristic’s effectiveness in improving search-based idea generation for engineering students. No difference was observed in idea generation whether hints were offered as words or images, nor in the sequence of hints provided. By understanding the impact of these heuristics on idea generation, educators can better utilise such techniques to foster creativity in design and project-based subjects.

1 INTRODUCTION

Over the past decade, various entities including governments, technological associations, engineering firms, and global business leaders have recognised the importance of cognitive skills, particularly creativity, for professionals in the 21st century (Deloitte 2017; Aggarwal 2021). For instance, the World Economic Forum surveyed Chief Human Resources Officers and strategy executives from 371 companies, revealing that five out of the top ten essential skills for employment were cognitive: (1) complex problem solving, (2) critical thinking, (3) creativity, (7) judgement and decision making, and (10) cognitive flexibility (World Economic Forum 2016). Engineering educators and accreditation bodies have also strongly advocated for a focus on creative problem-solving skills in engineering education (National Academy of Engineering 2005; Cropley 2015; Valentine et al. 2019). As a result, today’s engineering students often engage in multiple design projects throughout their degree to help develop these skills in preparation for the modern workforce, underscoring the need for effective heuristics to enhance problem-solving approaches and creativity skills (Deckert 2018; Belski et al. 2019).

Problem-solving approaches can be categorised into schema-driven and search-based strategies (Gick 1986). The former are developed through acquiring expertise, while the latter involve following idea generation heuristics. During problem-solving, relevant information is typically retrieved in response to specific cues, which are stored in (limited) short-term memory. These cues are then used to search long-term memory for related information and subsequently retrieved back to short-term memory to be presented as potential solution ideas (Ericsson et al. 1995; Belski et al. 2008).

Over years of extensive professional practice, experts develop special memory structures (schemata) that integrate their specific knowledge. These schemata allow experts to rapidly (and often automatically) search their long-term memory for information and actions that are the most appropriate for the given problem-solving situation (Gobet et al. 1996). In essence, these schemata substantially enhance the operations of their short-term memory (Egan et al. 1979) and reduce its limitations (Kirschner et al. 2006), leading to better performance in recognition and recall. On the other hand, first-year undergraduate students, who can be considered ‘novices’, have not yet built up a sufficient base of expert knowledge and experience and thus have not developed expert schemata, relying on inefficient search strategies (Gobet 1998). Most of the students are likely to develop schemata that are related to their day-to-day experiences (e.g. washing dishes, simple cooking, cleaning shoes).

Previous research has investigated whether several simple ideation techniques (processes of generating and developing new ideas), can enhance students’ creative problem-solving ability and provide insight into simple and effective means to enhance it (Belski et al. 2014; Belski et al. 2015). In these studies, creative problem-solving ability was measured by the total number of ideas generated, the breadth of ideas, and an assessment of their creativity in addressing a given problem. Research established a statistically significant improvement in the numbers and the breadth of ideas generated by students when they were exposed to the Eight Fields of MATCEMIB heuristic through prompts (Buskes et al. 2017, 2018). A true comparison of the influence of these types of heuristics is difficult to achieve, however, due to some of the ideas generated by the students being created by means of schemata. In light of this, the research presented in this paper extends past work to separate schema-driven (developed by acquiring expertise) and search-based (using idea generation heuristics) ideas in order to more accurately evaluate the influence of a heuristic alone on idea generation. The influence on the idea search of changing the sequence of prompting as well as replacing a word prompt by an image was investigated and differences in performance between subgroups of students was explored.

2 METHODOLOGY

Two hundred and thirty-eight students that have just enrolled in a first-year Engineering course in the Bachelor of Science degree at an Australian university participated in this study on a voluntary basis. Seventy-three percent of the participants graduated from secondary school in Australia; 26% were international school students; just one percent of participants did not reveal their country of graduation.

This study utilised the idea generation experiment that was originally conducted by Belski et al. (Belski et al. 2014). Students from five tutorial groups were randomly assigned to five conditions: one control and four experimental. All participants were given 18 minutes of tutorial time to individually generate as many ideas as possible for the same open-ended problem (to remove the lime build-up in water pipes). Participants were shown 26-minute videos that were specifically created for each group. The first eight minutes of the videos were the same for all groups. During these eight minutes participants were introduced to the experiment, entered information on the country of graduation from secondary school as well as information on mathematical and science courses that they studied at school. Australian students were asked to provide their Australian Tertiary Admission Rank (ATAR), a number between 0.00 and 99.95 that indicates a student’s position relative to all the students in their age group. For example, an ATAR of 90 indicates that the high school performance of a student was above 90 percent of all students that graduated in the same year. After this, the problem was introduced to students in a video as an image that contained the problem statement and a photo of a cross-section of a pipe, half of which was covered with lime deposit. This image can be comprehended from Figure 1a if the word “Mechanical” is removed from it. All participants were asked to work individually and to record as many ideas as possible to remove the lime build-up from the pipes. They were asked to record their ideas starting at the top of a page and to draw a line under the ideas they had recorded when prompted to do so. Participants from the four experimental groups were also told that during their idea generation session some additional words or images will be shown on a screen and that they will be told when a new word or image is shown. No explanation of what these words or images would be and what to do with them was given.

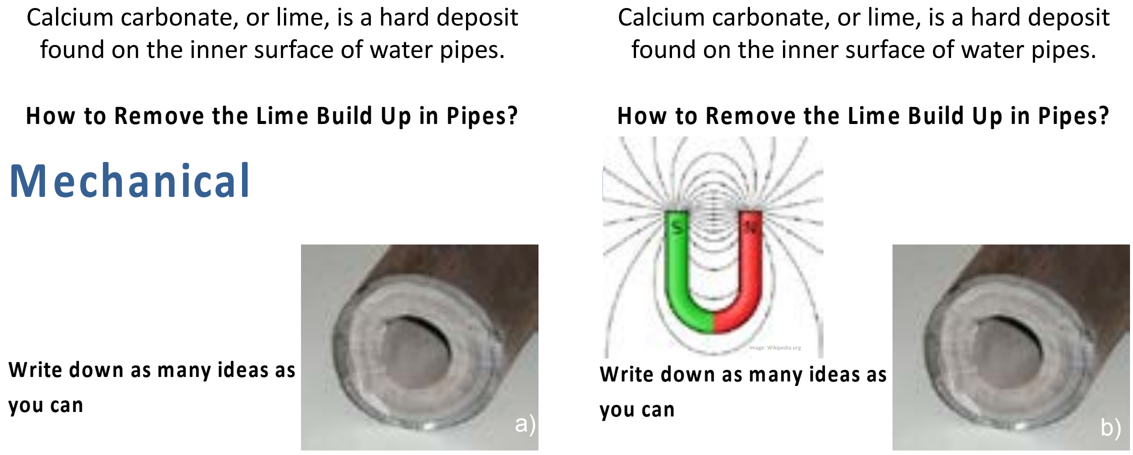

Fig. 1. Screenshots of a video presented to students: a) Word and Reversed Word groups; b) Image and Reversed Image groups.

After the problem introduction, the videos that were shown to groups differed. For the remaining 18 minutes, Control group participants were shown the same 'introductory' image and were prompted to draw a line under the ideas that they recorded every two minutes. Experimental groups were also asked to draw a line under the ideas recorded every two minutes but, after the announcement to draw a line, they were shown a new word or an image and were notified verbally of the change. It is important to note that for the first two minutes of idea generation, students from the experimental groups have not been shown any hints. In essence, for two minutes they generated ideas under the same conditions as the Control group. It was expected that during this time students would use the schema-driven strategies that they have acquired over their day-to-day activities.

Participants from the Word (W) group were shown the names of the Eight Fields of MATCEMIB (i.e. Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular and Biological). The Reversed Word (RW) group were shown the same names of the eight fields of MATCEMIB, but in the reverse order (i.e. Biological, Intermolecular, Magnetic, Electric, Chemical, Thermal, Acoustic and Mechanical). Similarly, participants from the Image (I) and the Reverse Image (RI) groups were shown images that were expected to represent appropriate fields of MATCEMIB in an original order for the former group and in a reverse order for the latter. Figure 1 depicts one of the eight screenshots that were shown to participants from different groups: Figure 1a – the Word (W) and the Reverse Word (RW) groups; Figure 1b – the Image (I) and the Reverse Image (RI) groups.

Two independent assessors were trained to evaluate the student idea generation forms using the criteria that were developed for the original idea generation experiment (Belski et al. 2014). To do that, assessors watched a video that explained the assessment criteria and showed the evaluation of ideas proposed by three students. They also evaluated performance of 10 students as an assessment exercise. The inter-rater reliability of their assessment was evaluated with SPSS by establishing the Cronbach's Alpha for the number of independent ideas proposed by each individual student. The Cronbach's Alpha was over 0.9, which suggested excellent internal consistency of assessment of the two assessors. After that, the assessors evaluated all student idea generation forms. Among other items, assessors counted the *number* of distinct (independent) ideas proposed by each student during each of the nine two-minute intervals without necessarily assessing their practicality. Only the ideas to remove the lime build-up were counted, with the number of ideas to prevent build-up or to replace the pipe recorded separately. To judge how broad the independent ideas to remove the lime build-up were, each idea was assigned to a field of MATCEMIB that most closely matched the proposed principle of removing the lime build-up. The number of fields of MATCEMIB present in the ideas proposed by each student during each of the nine two-minute intervals (*breadth* of ideas) was also counted.

Evaluation of internal consistency of assessment of the two assessors for all 238 participants showed that the collected data can be statistically explored: Cronbach's Alphas were 0.948 for the number of ideas and 0.945 for the breadth of ideas. Four participants left their idea generation forms empty and were excluded from statistical analysis. The following statistical analysis was conducted after both the number of ideas and the breadth of ideas generated by each individual participant in each time interval was averaged (sum of numbers by each assessor divided by two).

3 RESULTS

IBM SPSS (28) statistical software was used for the analysis. Table 1 depicts basic information about the groups: group composition (number of Australian students shown in parenthesis), the average number of mathematics and science courses studied by the participants, and average ATAR scores of the Australian students.

Table 1. General Information on Groups of Participants

Group	N(AU)	Mean/SD	ATAR	Math	Science
C(ontrol)	48(37)	Mean	**95.22**	**1.96**	**2.13**
		SD	4.44	0.74	0.87
W(ord)	51(43)	Mean	**88.63**	**1.75**	**1.88**
		SD	20.90	0.80	0.71
RW(ord)	40(27)	Mean	**95.15**	**1.97**	**1.88**
		SD	4.48	0.53	0.72
RI(mage)	56(34)	Mean	**89.33**	**1.86**	**2.04**
		SD	23.10	0.80	0.71
I(mage)	39(29)	Mean	**91.47**	**1.59**	**1.87**
		SD	17.75	0.60	0.86

Table 2 presents the results for the average numbers of independent ideas proposed by the participants in each group during: (i) the first two minutes of the experiment (NB2), (ii) from the third minute until the end of the experiment (NA2) and (iii) the total number of ideas (NAll). It also presents the average values of breadth of these ideas in a similar notation: BB2, BA2 and BAll. Furthermore, it shows the average number of ideas to prevent build-up that were proposed by the participants in each group during the first two minutes of the experiment (PB2) and from the third minute until the end of the experiment (PA2).

Table 2 also contains information on the Standard Deviations (SD) related to the number ideas to clean and prevent build-up as well as to the breadth of ideas generated during the above-mentioned time intervals. It must be noted that when the breadth of ideas proposed by a participant after the first two-minute interval (BA2) was calculated, the fields that were counted towards ideas during the first two-minute interval (BB2) were not counted (e.g. if a participant proposed Mechanical and Chemical ideas during the first two-minute interval (BB2=2) and later on suggested ideas that exploit Mechanical, Chemical, Thermal and Biological fields, only the last two were counted for the breadth during the remaining 16 minutes (BA2=2)). Counting the breadth of ideas in this way ensured that the total breadth of ideas (BAll) will correctly represent the fields of MATCEMIB considered by a participant as ways of removing the lime build-up.

Table 2. Number (Mean) and Breadth of distinct ideas generated by students.

Group	Mean/SD	NB2	NA2	NAll	BB2	BA2	BAll	PB2	PA2
C	Mean	**1.71**	**3.92**	**5.63**	**1.47**	**1.55**	**3.02**	**0.34**	**1.03**
	SD	1.40	3.13	4.00	0.84	1.18	1.42	0.53	1.42
W	Mean	**1.71**	**5.94**	**7.65**	**1.49**	**3.81**	**5.30**	**0.27**	**0.88**
	SD	1.11	2.87	3.27	0.68	1.70	1.71	0.48	1.53
RW	Mean	**1.64**	**6.13**	**7.76**	**1.44**	**3.96**	**5.40**	**0.19**	**0.30**
	SD	1.10	3.00	3.61	0.74	1.67	1.73	0.39	0.83
RI	Mean	**1.90**	**6.05**	**7.96**	**1.68**	**3.67**	**5.35**	**0.12**	**0.18**
	SD	0.90	2.71	2.98	0.70	1.31	1.33	0.38	0.51
I	Mean	**1.89**	**5.78**	**7.67**	**1.59**	**3.90**	**5.49**	**0.14**	**0.18**
	SD	1.04	1.96	2.30	0.77	1.33	1.29	0.30	0.35

The Shapiro-Wilk test identified that the distributions of the number of ideas and the breadth of ideas shown in Table 2 were not normal for all five groups. Therefore, the Independent Kruskal–Wallis 1-Way ANOVA test with Bonferroni adjustment was used to evaluate differences in performance of students from the five groups during different time intervals. The Kruskal–Wallis test showed that the distribution of the number and breadth of ideas during the first two minutes (NB2 and BB2) was the same across the groups (NB2: N=234, Z=5.825, p=0.213; BB2: N=234, Z=3.714, p=0.446). The difference in performance of the participants from the Control group and the other four groups during other time intervals (adjusted by the Bonferroni correction) were statistically significant for the number of ideas (CA2 vs WA2: Z=-50.710, p=0.002; CA2 vs RWA2: Z=-56.877, p=0.001; CA2 vs RIA2: Z=-53.007, p=0.001; CA2 vs IA2: Z=-52.675, p=0.001; CAll vs WAll: Z=-44.834, p=0.010; CAll vs RWAll: Z=-45.973, p=0.015; CAll vs RIAll: Z=-52.180, p=0.001; CAll vs IAll: Z=-50.357, p=0.006). Similarly, the difference in performance of the participants from the Control group and the other four groups during other time intervals (adjusted by the Bonferroni correction) were also statistically significant for the breadth of ideas (CA2 vs WA2: Z=-87.068, p=0.000; CA2 vs RWA2: Z=-91.710, p=0.000; CA2 vs RIA2: Z=-81.689 p=0.000; CA2 vs IA2: Z=-90.720, p=0.000; CAll vs WAll: Z=-83.298, p=0.000; CAll vs RWAll: Z=-87.417, p=0.000; CAll vs RIAll: Z=-84.024, p=0.000; CAll vs IAll: Z=-90.139, p=0.000).

No correlation was discovered between the number and breadth of ideas generated at all time intervals and ATAR, as well as between the number and breadth of ideas and number of mathematics and science courses studied. When groups were considered separately, only a correlation between the number of ideas generated after the first two-minute interval (NA2) and the number of science courses studied for students from the Reverse Image (RI) group (r=0.375, p=0.38) was discovered.

A statistical analysis showed that Australian school students from all five experimental groups generated more ideas than their international counterparts.

The Shapiro-Wilk test identified that the distributions of the number of ideas and the breadth of ideas were not normal for all five groups for both populations. Therefore, Independent Kruskal–Wallis 1-Way ANOVA tests with Bonferroni adjustment were used to evaluate differences in performance of local and international students separately. The results of the Kruskal–Wallis tests were practically the same for local and international students as they were when groups were considered without subdivision (local and international together): no statistical differences in performance were found between the groups during the first two minutes of idea generation and statistically significant differences between the Control (C) group and the other four groups were discovered for other time intervals.

The Mann-Whitney U test was used to more accurately evaluate differences in performance of local and international students for three cases: (i) difference in performance of all local and international students during the first two-minute interval, (ii) difference in performance of local and international students from the Control group after the first two-minute interval and (iii) difference in performance of local and international students from all four experimental groups together (excluding the Control group) after the first two-minute interval. It was established that during the first two-minute interval only the difference in number of ideas to prevent a lime build-up (NP2) was statistically significant (170 vs 62, Z=-2.794, p=0.005) – international students proposed more prevention ideas than their local counterparts. No statistical difference in performance was discovered between local and international students from the Control group after the first two-minute interval. When performance of local and international students from the four experimental groups were compared after the first two-minute interval, their performance differed statistically for both the numbers of ideas to remove and to prevent the lime build-up: NA2: (133 vs 52, Z=-2.237, p=0.025), PA2: (133 vs 52, Z=-2.324, p=0.020).

The number of ideas and the breadth of ideas proposed by local and international students from all groups excluding the Reverse Words (RW) group did not differ statistically. For the Reverse Words (RW) statistical significance was found for NB2 (Z=-2.173, p=0.030), NAll (Z=-1.982, p=0.047) and BB2 (Z=-2.122, p=0.034). It also needs to be noted that local students on average generated more ideas for preventing lime build-up and for removing it than their international counterparts.

4 DISCUSSION

It can be seen from the results of the experiment that the students have not yet developed expert schemata. Most students in the first two minutes proposed mechanical and chemical ideas, which were related to their schemata and were therefore proposed quickly. These schemata have likely developed due to

their day-to-day experiences (for example, schema of cleaning mechanically or with chemicals). Subsequent minutes of idea generation showed that an idea search by students from the Control group was not very effective. At the same time, students from the other groups that were ‘guided’ by hints were able to conduct much more effective searches for ideas, in terms of the number generated and their breadth. The results prove that the Eight Fields of MATCEMIB heuristic, delivered via prompts, is effective in improving idea generation in engineering students by improving their search-based problem-solving methods to generate ideas. It also appears to be unimportant whether the hints are offered as words or images, or the sequence of hints provided.

The fact that there is no practical difference between the number/breadth of ideas generated in the first two minutes between all the five groups is proof that the groups can be considered identical. In previous research, an assumption that the groups were ‘identical’ was based upon random choice of the groups and a similarity in their ATAR. This time there is much more solid proof that the groups can be considered identical in a sense of their ability to initially generate ideas. Although this study did not find any correlation of number and breadth of ideas with ATAR, it is possible that such a correlation exists. The range of ATAR in this study was rather limited, with most students at the upper end of the scale.

Interestingly, there was no correlation found between idea generation performance and number of science subjects studied. This could be possible due to those students having studied, for instance, chemistry in high school, understanding that a chemical removal of a build-up is hardly realistic; consequently, they may not have entered many ‘chemical’ ideas. This may result in a negative correlation between studying chemistry and ideas related to chemical removal. When the data were averaged for all science subjects, this could no correlation to be seen. A further analysis of the data to look for a correlation between ‘subject’ and ‘number of ideas related to this subject matter’ would need to be performed. In this case, it will be necessary to decide which ideas are likely to be related to each subject to then perform a further statistical analysis.

5 SUMMARY

The importance of cognitive skills, especially creativity, in today's workforce is widely recognised, and consequently a focus of development through engineering education. In this research, an experiment evaluating the Eight Fields of MATCEMIB heuristic on first-year engineering students demonstrated its effectiveness in improving idea generation through enhancing search-based strategies. Both the number and breadth of ideas generated by students who were introduced to the heuristic were statistically significantly higher than the control group, which was not provided with anything to assist in idea generation. The heuristic employed also showed effectiveness in not being sensitive to being word- or image-based or to the sequence in which the prompts were shown to the students. Engineering educators can therefore apply this heuristic to support students in idea generation in a broad range of contexts, for example when devising solutions to design problems.

REFERENCES

Aggarwal, Ashwani. 2021. *Global framework on core skills for life and work in the 21st century*. ILO Geneva, Switzerland.

Belski, Iouri, Anne Belski, Victor Berdonosov, Bohuslav Busov, Milada Bartlova, Elena Malashevskaya, Tuomo Kässie, Antero Kutvonene, and Nina Tervonene. 2015. "Can simple ideation techniques influence idea generation: comparing results from Australia, Czech Republic, Finland and Russian Federation." In *Proceedings of the 26th Annual Conference of the Australasian Association for Engineering Education – AAEE2015*, edited by Aman Oo, Arun Patel, Tim Hilditch and Siva Chandran, 474-483. Geelong, Victoria, Australia: School of Engineering, Deakin University, Victoria, Australia.

Belski, Iouri, and Ianina Belski. 2008. "Cognitive Foundations of TRIZ Problem-Solving Tools." Proceedings of the TRIZ-future conference.

Belski, Iouri, Akram Hourani, Andrew Valentine, and Anne Belski. 2014. "Can Simple Ideation Techniques Enhance Idea Generation?" In *Proceedings of the 25th Annual Conference of the Australasian Association for Engineering Education*, edited by Andrew Bainbridge-Smith, Ziming Tom Qi and Gourab Sen Gupta, 1C, 1-9. Wellington, NZ: School of Engineering & Advanced Technology, Massey University.

Belski, Iouri, Anne Skiadopoulos, and Chi Tin Stephenb Yang. 2019. "TRIZ Heuristics improve creative problem solving self-efficacy of engineering students." Proceedings of the 30th Annual Conference of the Australasian Association for Engineering Education-AAEE2019.

Buskes, Gavin, and Iouri Belski. 2017. "Prior knowledge and student performance in idea generation." Proceedings of the 28th Annual Conference of the Australasian Association for Engineering Education (AAEE 2017).

Buskes, Gavin, and Iouri Belski. 2018. "ATAR, prior knowledge and performance in idea generation." 29th Annual Conference of the Australasian Association for Engineering Education (AAEE 2018).

Cropley, David H. 2015. "Promoting creativity and innovation in engineering education." *Psychology of Aesthetics, Creativity, and the Arts* 9 (2): 161.

Deckert, Carsten. 2018. "Creative heuristics in engineering education." Proc., 46th SEFI Annual Conf. in Copenhagen. Brussels, Belgium: European Society for Engineering Education.

Deloitte. 17 May 2017 2017. *Soft skills for business success.* (Sydney, Australia: Deloitte Australia). https://www2.deloitte.com/au/en/pages/economics/articles/soft-skills-business-success.html.

Egan, Dennis E, and Barry J Schwartz. 1979. "Chunking in recall of symbolic drawings." *Memory & cognition* 7: 149-158.

Ericsson, K Anders, and Walter Kintsch. 1995. "Long-term working memory." *Psychological review* 102 (2): 211.

Gick, Mary L. 1986. "Problem-solving strategies." *Educational psychologist* 21 (1-2): 99-120.

Gobet, Fernand. 1998. "Expert memory: A comparison of four theories." *Cognition* 66 (2): 115-152.

Gobet, Fernand, and Herbert A Simon. 1996. "The roles of recognition processes and look-ahead search in time-constrained expert problem solving: Evidence from grand-master-level chess." *Psychological science* 7 (1): 52-55.

Kirschner, Paul A, John Sweller, and Richard E Clark. 2006. "Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching." *Educational psychologist* 41 (2): 75-86.

National Academy of Engineering. 2005. *Educating the engineer of 2020: adapting engineering education to the new century.* New York: National Academies Press.

Valentine, A., I. Belski, M. Hamilton, and S. Adams. 2019. "Creativity in Electrical Engineering Degree Programs: Where Is the Content?" *IEEE Transactions on Education* 62 (4): 288-296. https://doi.org/10.1109/TE.2019.2912834.

World Economic Forum 2016. *The future of jobs: employment, skills and workforce strategy for the Fourth Industrial Revolution.* World Economic Forum (Geneva). http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf.

Perceived characteristics of innovative engineering mathematics courses in the Netherlands and China

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***Conference Key Areas**:* Teaching foundational disciplines of Mathematics and Physics in engineering education, Teaching technical knowledge in and across engineering disciplines, Curriculum development, and emerging curriculum models in engineering
***Keywords**: engineering mathematics, innovative pedagogies, student-centered learning, Project-based learning, Challenge-based learning*

ABSTRACT

In this study a comparative analysis of innovative engineering mathematics courses at TU/e, Netherlands, and HKUST(GZ), China, was conducted to explore distinct educational philosophies and pedagogical approaches that foster unique learning environments. Using a student centered approach, both institutions incorporate a dual focus on knowledge growth and problem-solving skills, employing

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comprehensive evaluation frameworks that integrate peer reviews, assignments, and presentations for a holistic assessment of student learning. [Institution]'s challenge-based learning model in this context emphasizes specific scientific disciplines, while [Institution] focuses on project-based, methodological learning, particularly around design thinking. Despite their common prioritization of student autonomy and engagement, differences emerge in mathematical application, problem themes, student support, and resource allocation. The study highlights the dynamic nature of engineering education, underscoring the need for pedagogical strategies that align with educational objectives and student needs.

1 INTRODUCTION

1.1 Background

Over-consumption, driven by a growing population, climate change, and globalization, necessitates innovative solutions, particularly through engineering education (e.g. Gaskins et al. 2015; Lönngren et al. 2017; Membrillo-Hernández et al. 2021). Mathematics is vital for engineering students' success, with proficiency in mathematics correlating to better engineering outcomes (e.g. Agoestanto and Masitoh 2021; Tsui and Khan 2023). Consequently, there is a push for innovative teaching approaches in engineering mathematics, moving from traditional teacher-centred approaches to student-centred learning. The latter emphasizes active engagement, critical thinking, and application of knowledge (e.g. Baeten et al. 2010; Tangney 2014), unlike the passive lecture-based teacher-centred methods (Emaliana 2017). Innovative pedagogies like flipped classrooms, active learning, problem-based learning (PBL), inquiry-based learning (IBL), and challenge-based learning (CBL) are characterized by student ownership, interdisciplinary learning, collaboration, and real-world relevance (e.g. Hayward et al. 2016; Kock et al. 2021; Van der Wal et al. 2019). This shift also sparks interest in comparing innovative curricular features between different countries, like China and the Netherlands.

This study explores the question: what are the characteristics of innovative engineering mathematics courses in the Netherlands and China from the perspective of the educators involved, including both teachers and teaching assistants?

1.2 Literature review

Mathematics is crucial in higher education, particularly in engineering and STEM, where it supports innovation and technology integration. Mathematics is not only a core academic subject but also a practical tool across various fields, underpinning innovative engineering courses (e.g. Dahl 2018; Liu and Pásztor 2022). The adoption of Problem-Based Learning (PBL) and blended learning highlights the effectiveness of active, hands-on approaches in advancing mathematical understanding relevant to societal and professional needs (Maass et al. 2019). Innovations in mathematics education encompass also technological advancements in curriculum design and novel pedagogical methods, aiming for a deep exploration of these elements.
The integration of technology in engineering mathematics education has revolutionized traditional teaching, with tools like MATLAB enhancing interactive learning and problem-solving skills (Aruvee & Vintere 2022; Soares et al. 2019). Meanwhile, pedagogical innovations, shifting from teacher-centred to student-

centred approaches, promote active learning, critical thinking, and the practical application of knowledge (Elen et al. 2007; Baeten et al. 2010). Methods such as flipped classrooms and PBL emphasize student engagement and real-world relevance, reflecting an educational shift towards student autonomy and interdisciplinary application (Karabulut-Ilgu et al. 2017).
Innovative pedagogical approaches are often characterized by a student-centered orientation. Student-centered learning contrasts significantly with teacher-centered approaches in educational settings. (Elen et al., 2007). In student-centered learning, the focus shifts from the teacher imparting knowledge to students actively engaging in their learning process. This approach emphasizes critical thinking, problem-solving, and the application of knowledge in various contexts, promoting a deeper understanding and retention of material (e.g. Baeten et al., 2010; Tangney, 2014).

A focus on PBL and CBL in engineering education reveals their widespread adoption and effectiveness in addressing socio-technical challenges and enhancing collaboration with industry (e.g. Chen et al. 2021; Gallagher and Savage 2020). Notably, institutions in the Netherlands and Mexico, such as the Tecnológico de Monterrey and institutions in the 4TU Center of Engineering Education, have been pioneers in implementing these models (e.g. Doulougeri et al. 2022; Van den Beemt et al. 2022). In China, the transition from "Made in China" to "Created in China" highlights the importance of innovative skills in national development strategies, with higher education playing a pivotal role in fostering innovation through updated knowledge, innovative skills, and pedagogies (Zhou 2019). Universities are introducing courses like SPOC-based flip classrooms and CBL to address real-world challenges, aiming to enhance student participation and learning outcomes (Yilmaz, 2016). However, despite these efforts, the quality and impact of China's engineering education still lags behind some developed countries, like the Netherlands.

This comparative study aims to identify features of engineering mathematics education in both China and the Netherlands to provide insights into ways to improve the quality of education in China and further contribute to research in this area. Teachers' perceptions of their work and the programs supporting their learning can significantly impact the educational system they operate within (Liu & Goh, 2016). Therefore, examining teachers' and teaching assistants' perspectives can provide valuable insights into the characteristics of courses and the experiences of both students and teachers themselves. However, a review of the existing literature reveals a gap in research specifically addressing this area. Consequently, this study focuses on the teacher's and teaching assistants' perspective of innovative approaches where engineering mathematics is taught or applied.

2 METHODOLOGY

2.1 Learning Settings

The comparative study focuses on engineering education at TU/e in the Netherlands and HKUST(GZ) in China. The primary criteria for selecting schools and courses in China and the Netherlands were the following: 1. Preference for universities that emphasize innovation in science and technology. 2. Engineering courses that involve mathematical content or concepts and apply mathematical knowledge to problem-solving. 3. Courses aimed at engineering students. 4. Student-centered, problem-solving-oriented innovative engineering courses.

The courses considered here were the following:

TU/e, Netherlands

- Sociophysics (SP): This 8-week course is a challenge-based learning (CBL) course facilitated by applied physics faculty. It engages students in addressing real-world problems through teamwork, guided by a teaching assistant. Teams formulate an Essential Question (EQ) and navigate the project with Guiding Questions (GQs), Guiding Activities (GAs), and Guiding Resources (GRs), promoting interaction with lecturers in physics, psychology, and ethics. This is an elective course for students taking programs in applied physics.
- Data Challenge 3 (DC3): This 8-week course is a challenge-based learning (CBL) course. DC3 is the third in a series of Data Challenge courses designed to incrementally introduce students to working with real or semi-real data. Unlike the more structured assignments of DC1 and DC2, DC3 offers greater freedom in applying mathematical techniques, encouraging independent problem-solving. This is a compulsory course for students taking programs in data science.

HKUST(GZ), China

- Cross-disciplinary Design Thinking: This 3-month project-based learning (PBL) course focuses on user-collaborative design methods to create inclusive product solutions, covering design thinking, stakeholder research, and concept development through recursive user feedback. The course utilizes the Canvas platform for distributing lecture notes and materials, emphasizing a varied grading scheme that includes participation, assignments, a final presentation, and peer reviews instead of traditional examinations. This is a university wide course taken by students in different STEM disciplines.

Both courses at TU/e and the program at HKUST(GZ) demonstrate a commitment to fostering innovative thinking, interdisciplinary collaboration, and real-world problem-solving skills among engineering students.

2.2 Methods

Data collection

The research adopted a qualitative approach to data collection and analysis strategies. The study has been granted ethical approval by the Ethics Review Board at TU/e in July 2023. Participants in the study were teachers and teaching assistants involved in the courses described above as follows;

- Five teaching assistants (TAs) (three in TU/e, two in HKUST(GZ)): the graduate or upper-level students who support the lead teacher by assisting with instructional responsibilities, such as facilitating discussions and grading assignments.
- Three teachers (two in TU/e, one in HKUST(GZ)): the educational professional responsible for planning, implementing, and assessing lessons to facilitate students' learning and academic development.

Semi-structure interviews with teachers and tutors were conducted at the end of the courses in 2023. The same interview protocol was used for both institutions. The purpose of the interviews was to provide data to investigate the research questions on student experience and innovative courses from the teacher/tutor perspective. Each interviewee participated in an interview lasting at least one hour. The questions for teachers and TAs covered not only their perspectives on the course and their personal experiences within it but also their views on student and the students' learning experiences. The dataset generated from both institutions helps to build a general perspective of student learning in innovative engineering mathematics settings where both commonalities and differences are evident.

Data analysis

We employed thematic analysis (Braun & Clarke,2006) for data analysis of the orthographic transcription of participant's interviews. The steps followed in the analysis included the following: (1) familiarization with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes (5) defining and naming themes, and (6) producing the report. In coding the data results of a previous literature review (e.g. Doulougeri et al. 2022; Kock et al. 2021) were used as concept-driven codes, and through an inductive process also new codes have been identified (marked with an asterisk) as presented in Table 1.

In the analytical phase, we systematically classified the dataset in alignment with the principal categories identified based on the research question and conceptual codes. This classification involved a meticulous coding process, whereby data were organized into predefined categories from the literature, leading to the identification of nuanced subcategories. Subsequently, an iterative examination of the dataset, guided by these categories and subcategories, facilitated the identification of interrelations among them. In addition, an inductive approach enabled the identification of data-driven categories not initially considered in the literature. This iterative analytical process not only underscored the dynamism inherent in the data but also significantly contributed to a theoretical elucidation of the findings, as mentioned by Walker & Myrick (2006).

3 RESULTS

Table 1 presents the result of the coding scheme and framework used to formulate the themes, including examples of instances where such code and category appear in the data set for each of the learning settings (identified with T for the Netherlands and H for China).

Table 1. Codes, categories, and examples identified in the data corpus. Examples coded starting with T refer to the Netherlands while examples starting with H refer to China.

Codes Category/-Subcategory	Codes Definition	Examples (Quotations are from interviewees)
1. Learning Objectives/Course Design		

- Knowledge growth	Development of interdisciplinary knowledge and application of mathematical knowledge	"…the course encourages students to venture beyond their current knowledge boundaries…" (TSP1-1) "This requires students to have broad knowledge and deep thinking abilities when approaching problems …"(HK2-1)
- Problem-solving and skills goals	Aspiration that students solve real-world and complex problems, personal growth, teamwork,…	"Witnessing students' creativity and their approach to problem-solving not only validates the collaborative effort but also…"(HK3-1) " The training primarily focused on general guidelines and specific problem-solving techniques, particularly for addressing conflicts or issues within team dynamics."(TDC2-1)
2. Feedback and Guidance/Course Design		
- Assessment	Types of assessments used e.g. peer assessment, presentation, prototyping, and grading by TAs and Teachers.	"Our assessments focus on the entire journey from problem comprehension to solution implementation…"(TDC1-1) " The evaluation criteria are shared at the beginning of the course, covering assignments, participation, and peer reviews, among others, to ensure transparency and understanding of expectations."(HK1-1)
- Support for Students	Different human resources of support for students i.e. Teachers, Teaching Assistants, Stakeholders	"… we facilitate additional funding, ensuring that students have access to the necessary resources for their projects…"(HK1-2)
- Organizer Role	Different actors take organizational roles i.e. course designer, external stakeholder, teacher, and monitors (teaching assistant).	" Facilitating and observing were the key aspects of my TA role, ensuring students progressed effectively while maintaining their autonomy. "(TDC2-2) " I see my role as a bridge for communication between teachers and students."(HK3-2)
3. Student Learning Experience		
- Transaction of the Problem by Students	Related to the process that students follow to solve a problem, starting with the definition of the problem and subsequently how they tackle the problem and including how they work together.	"… This diversity not only enhances the problem-solving process but also prepares students for the multifaceted nature of solving societal issues..."(TSP2-1)
- Resources Used for Problem-Solving	Physical resources supporting students problem-solving e.g. course materials, equipment (e.g. 3D printers), project budget, and also online resources.	"…if prototyping was needed, students would utilize resources like the school's 3D printing lab." (HK2-3)

- Students' Preparedness	Student academic background and prior knowledge of mathematics or other knowledge and skills.	" The absence of background in these areas is not seen as a hindrance but rather as an opportunity for growth…"(TSP1-3)
- Students' Performance	Associated to results of assessments e.g. grades, achievement of learning outcomes	"…motivation significantly influences one's engagement and appreciation of the course." (TDC2-3)
- Collaboration with Team Members/ Tutors/ Problem Owners	Students working together as a team including communication with others	" … foster a more inclusive and supportive group atmosphere, encouraging participation and collaboration from all members." (TSP2-2) " … this course emphasizes teamwork more strongly."(HK2-3)
- Learning Environment*	Course setting and use of the physical classroom including meeting rooms.	"… as a positive and supportive environment can foster collaboration, creativity, and open communication among students.(HK2-4)
- Challenges in the Learning Process*	Difficulties that students face when working in groups e.g. different levels of motivation, organization, and students from different backgrounds.	"…another group initially struggled with collaboration but improved as they became more accustomed to the course tools."(TSP2-3)

3.1 Comparative analysis between the Netherlands and China

In the comparative analysis of innovative engineering mathematics courses in two countries, the study delineates the overarching characteristics derived from interviews, coding, and textual analysis. The findings are structured into two main themes, reflecting the nuanced aspects of course design and student experience. For the case of TU/e, Netherlands we found the following:
Course Design:

1. Learning Objectives: Emphasis on integrating knowledge growth with problem-solving skills, specifically targeting complex problems within disciplinary contexts. Presents specific, detailed challenges within a disciplinary scope, necessitating a deep engagement with mathematical content.
2. Feedback and Guidance: Utilizes a holistic evaluation framework combining peer reviews, written assignments, teacher evaluations, and final presentations, supported by well-defined roles for teaching assistants and stakeholders. Teaching assistants play a critical role in guiding students through discussions and project work, with responsibility for specific groups.

Student Learning Experience:
Focuses on student autonomy in defining and tackling complex problems, supported by diverse and flexible resources. The learning environment promotes critical thinking, team collaboration, and iterative learning processes.

For the case of HKUST(GZ), China we found;
Course Design:

1. Learning Objectives: Favors a project-based, methodological learning approach across the university, particularly emphasizing design thinking. Focuses on broader, exploratory projects allowing for a wide range of mathematical applications and interdisciplinary integration
2. Feedback and Guidance: Employs a similar multifaceted evaluation strategy but with a broader scope for external collaboration and stakeholder engagement. Focuses on broader, exploratory projects allowing for a wide range of mathematical applications and interdisciplinary integration.

Student Learning Experience:
Encourages broad exploration and discovery, leveraging a "smart campus" for open-ended problem-solving with greater flexibility and autonomy. It's worth noting that the course offers project funding to facilitate the development of prototypes and other project outcomes within a budget.

In this analysis we observe that both institutions, in China and the Netherlands, prioritize innovative pedagogies that encourage autonomous knowledge growth (example TSP1-1 & HK2-1), and problem-solving skills (example HK3-1 & TDC2-1). Likewise, each institution employs a comprehensive evaluation framework that integrates various forms of feedback and guidance to holistically assess student learning (for example TDC1-1 & HK1-1). The importance of student autonomy and engagement is emphasized in both locations, with educational strategies tailored to foster a deep engagement with resources and collaborative problem-solving (for example TSP2-2 & HK2-3).

However, we also noticed differences in both themes. TU/e in the Netherlands adopts a challenge-based learning model with a focus on specific scientific disciplines, requiring deep mathematical engagement and presenting detailed challenges. In contrast, HKUST(GZ) in China utilizes a project-based learning framework, emphasizing design thinking and methodological learning with broader, more open-ended projects (see example HK2-5).

"*Smart campus" is a broad theme, but specific projects require students to focus and expand on their own.*" (HK2-5)

In addition, the role of teaching assistants varies significantly, with TU/e having TAs more involved in direct student guidance and project monitoring, whereas in HKUST(GZ) TAs provide broader, as-needed support (for example TDC2-2 & HK3-2). Finally, resource allocation and provision also differ between the two institutions, with HKUST(GZ) providing specific project funding, in contrast to TU/e, where direct funding for projects is not available (example HK1-2). Despite selected differences in the courses offered by the two universities, likely to be influenced by institutional settings, educational cultures, and backgrounds, there are still valuable lessons to be learned, in particular in relation to TA- approaches and project funding.

4 DISCUSSION

This comparative analysis of innovative engineering mathematics courses in the Netherlands and China demonstrates distinct educational approaches. The study contrasts TU/e's CBL, which emphasizes scientific discipline, with HKUST(GZ)'s PBL focused on design thinking. The findings underscore the importance of diverse teaching strategies, comprehensive assessment frameworks, and adaptable support systems to enhance student learning experiences in engineering education. While the study provides valuable insights into the flexibility and innovation within the field, its conclusions are specific to the unique contexts of TU/e and HKUST(GZ), indicating the difficulty of applying these findings universally across different educational cultures. Similarly, the findings here report only on the teacher perspective which is strongly linked to intended course design and delivery but do not reflect the enacted delivery as experienced by the students. This is an aspect that is important to investigate further to provide a broader picture of the use of these innovative approaches.

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REFERENCES

Agoestanto, A., & Masitoh, S. (2021). Mathematical creative thinking ability viewed from students' learning interest and adversity quotient through creative problem-solving learning model. *Journal Of Physics: Conference Series*, 1918(4), 042074. https://doi.org/10.1088/1742-6596/1918/4/042074

Aruvee, Eve, and Anna Vintere. 2022. "Use of Ict in Mathematics Studies to Develop Digital Skills of Undergraduate Engineering Students." *Engineering for Rural Development (Print)*, May. https://doi.org/10.22616/erdev.2022.21.tf291.

Baeten, Marlies, Eva Kyndt, Katrien Struyven, & Filip Dochy. (2010). Using student-centred learning environments to stimulate deep approaches to learning: Factors encouraging or discouraging their effectiveness. *Educational Research Review*, 5, 243-260. https://doi.org/10.1016/j.edurev.2010.06.001.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa.

Chen, J., Kolmos, A., & Du, X. (2020). Forms of implementation and challenges of PBL in engineering education: a review of literature. *European Journal Of Engineering Education*, 46(1), 90-115. https://doi.org/10.1080/03043797.2020.1718615.

Dahl, B. (2017). What is the problem in problem-based learning in higher education mathematics. *European Journal Of Engineering Education*, 43(1), 112-125. https://doi.org/10.1080/03043797.2017.1320354.

Doulougeri, K., Bombaerts, G., Martin, D., Watkins, A., Bots, M., & Vermunt, J. D. (2022). Exploring the factors influencing students' experience with challenge-based learning: a case study. *Proceedings of the 2022 IEEE Global Engineering Education Conference, EDUCON 2022,* 981-988. Article 9766574. https://doi.org/10.1109/EDUCON52537.2022.9766574.

Elen, Jan, Geraldine Clarebout, Rebecca Léonard, & Joost Lowyck. (2007). Student-Centred and Teacher-Centred Learning Environments: What Students Think.

Teaching in Higher Education, 12(1), 105–117. https://doi.org/10.1080/13562510601102339.

Gallagher, S. E., & Savage, T. (2020). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education*, 1-23. https://doi.org/10.1080/13562517.2020.1863354.

Gaskins, W., Johnson, J., Maltbie, C., & Kukreti, A. (2015). Changing the Learning Environment in the College of Engineering and Applied Science Using Challenge Based Learning. *International Journal Of Engineering Pedagogy (Ijep)*, 5(1), 33. https://doi.org/10.3991/ijep.v5i1.4138.

Hayward, D., Bungay, V., Wolff, A.C., & MacDonald, V. (2016), A qualitative study of experienced nurses' voluntary turnover: learning from their perspectives. *J Clin Nurs*, 25, 1336-1345. https://doi.org/10.1111/jocn.13210.

Karabulut-Ilgu, Aliye, Nadia Jaramillo Cherrez, & Charles T. Jahren. (2018). A systematic review of research on the flipped learning method in engineering education. *British Journal of Educational Technology*, 49(3), 398-411. https://doi.org/10.1111/bjet.12548.

Kock, Z., Saeli, M., & Pepin, B. E. U. (2021). Participation of mathematics and physics students in multidisciplinary challenge-based education at the end of a bachelor program. In H.-U. Heiss, H.-M. Jarvinen, A. Mayer, & A. Schulz (Eds.), *Proceedings - SEFI 49th Annual Conference: Blended Learning in Engineering Education: Challenging, Enlightening - and Lasting?* (pp. 303-311). European Society for Engineering Education (SEFI)

Liu, Yong, & Attila Pásztor. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis. *Thinking Skills and Creativity*, 45, 101069. https://doi.org/10.1016/j.tsc.2022.101069.

Lönngren, J., Adawi, T., & Svanström, M. (2017). Scaffolding strategies in a rubric-based intervention to promote engineering students’ ability to address wicked problems. *European Journal Of Engineering Education*, 44(1-2), 196-221. https://doi.org/10.1080/03043797.2017.1404010.

Maass, K., Geiger, V., Ariza, M., & Goos, M. (2019). The Role of Mathematics in interdisciplinary STEM education. *ZDM*, 51(6), 869-884. https://doi.org/10.1007/s11858-019-01100-5.

Membrillo-Hernández, J., de Jesús Ramírez-Cadena, M., Ramírez-Medrano, A., García-Castelán, R., & García-García, R. (2021). Implementation of the challenge-based learning approach in Academic Engineering Programs. *International Journal On Interactive Design And Manufacturing (Ijidem)*, 15(2-3), 287-298. https://doi.org/10.1007/s12008-021-00755-3.

Pepin, B. E. U., & Kock, Z.-J. D. Q. P. (2021). Students’ use of resources in a challenge-based learning context involving mathematics. *International Journal of Research in Undergraduate Mathematics Education*, 7(2), 306-327. https://doi.org/10.1007/s40753-020-00138-4)

Tangney, S. (2014). Student-centred learning: a humanist perspective. *Teaching in Higher Education*, 19(3), 266–275. https://doi.org/10.1080/13562517.2013.860099.

Tsui, T., & Khan, R. N. (2023). Is mathematics a barrier for engineering? *International Journal of Mathematical Education in Science and Technology*, 54(9), 1853–1873. https://doi.org/10.1080/0020739X.2023.2256319.

van den Beemt, A. A. J., van de Watering, G., & Bots, M. (2023). Conceptualising variety in challenge-based learning in higher education: the CBL-compass. *European Journal of Engineering Education*, 48(1), 24-41. https://doi.org/10.1080/03043797.2022.2078181.

van der Wal, N., Bakker, A., & Drijvers, P. (2017). Which Techno-mathematical Literacies Are Essential for Future Engineers?. *International Journal Of Science And Mathematics Education*, 15(S1), 87-104. https://doi.org/10.1007/s10763-017-9810-x.

Yilmaz, Rabia M. (2016). Educational magic toys developed with augmented reality technology for early childhood education. *Computers in Human Behavior*, 54, 240-248. https://doi.org/10.1016/j.chb.2015.07.040.

Zhou, C. (2019). Developing engineering creativity in STEM programs in Chinese universities. *Global Perspectives on Fostering Problem-Based Learning in Chinese Universities*, 273-293. https://doi.org/10.4018/978-1-5225-9961-6.

CULTIVATING A PRO-DIVERSITY MINDSET: AN INTERVENTION AMONG FIRST-YEAR ENGINEERING STUDENTS

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***Keywords**: Diversity and Inclusion, Pro-diversity Mindset, Intervention, Engineering, First-year students*

ABSTRACT

To foster a more inclusive learning environment, this study implements a quasi-experimental intervention at a university campus of KU Leuven in Belgium. Targeting first-year engineering students (N=88), the intervention aimed to stimulate students' pro-diversity mindset through a brief explanation and reflective assignment. Our hypothesis was that students exposed to this intervention would exhibit a higher pro-diversity mindset. Analysis of pre- and post-tests supported this hypothesis, revealing small, but significant differences in personal attitudes towards - and comfort levels with diversity between the experimental and control group. The findings highlight the importance of integrating diversity topics into engineering education to create a more inclusive learning environment and to emphasize education's role in promoting diversity and inclusivity within the engineering profession.

1 INTRODUCTION

Our rapidly evolving society is heavily influenced by the work of engineers, underscoring the critical importance of diversity in this field. A more diverse representation in engineering teams brings more individual perspectives and experiences together. This does not only enhance inclusivity in developing and implementing innovative solution to society's problems, but also improved problem-solving skills, and enhanced creative thinking, resulting in more ingenious solutions (Page 2017; Herring 2009). However, despite numerous efforts, the engineering field in Western society is still dominated by white men (Charles and Bradley 2009).

If we wish to stimulate a more diverse workforce, it is important to start with the engineering educational programmes. Underrepresented groups in engineering education, such as women and ethnic minorities, often struggle with a lack of sense of belonging, which can lead to higher dropout rates or different study choices in engineering and other educational fields in which women and minorities are underrepresented (Diekman, Clark, and Belanger 2019; Villa et al. 2020; González-Pérez et al. 2022). Previous efforts to overcome this lack of belonging, often include interventions targeting changes in minority groups themselves (Ong, Smith, and Ko 2018; Blosser 2020; Campbell-Montalvo et al. 2022). However, students belonging to a minority group should not bear sole responsibility for fitting in, rather, it is upon the educational system to foster an inclusive environment (Atadero et al. 2018; Moreu, Isenberg, and Brauer 2021).

A mindset that welcomes diversity will foster a more inclusive environment, benefiting the sense of belonging, and by extension the retention, of underrepresented groups, ultimately leading to a more creative workforce (Page 2017; Isaac, Kotluk, and Tormey 2023; Palid et al. 2023). Hence, a quasi-experimental study was set up at a campus of KU Leuven in Belgium, to stimulate first-year engineering technology students' pro-diversity mindset. An intervention was designed to cultivate an inclusive attitude, now, but also for their future careers. We hypothesized that students who are exposed to a brief lecture on the importance of diversity and inclusion in engineering, coupled with a reflective activity related to this, will have a higher pro-diversity mindset than students who are not exposed to this intervention.

This paper first explores the theoretical framework guiding the development of the pro-diversity mindset scale that we generated, followed by a method section detailing the development of the survey and the implementation of the intervention. The results demonstrate the impact of the intervention on participants' pro-diversity mindset. We conclude with a discussion on the implications and limitations of the study, and suggestions for future research on stimulating a pro-diversity mindset in engineering education and beyond.

2 THEORETICAL FRAMEWORK: THE PRO-DIVERSITY MINDSET SCALE

Although several studies address stimulating more positive attitudes, behaviour, or beliefs in the context of diversity, few studies use similar scales, as there is no established standardized scale on this topic (Kauff et al. 2019). However, the Miville-Guzman Universality Diversity Scale (M-GUDS) contributed significantly to assessing pro-diversity attitudes. This scale measures "*an attitude that recognizes and accepts the differences and similarities*" (Miville et al. 1999, 303), and encompasses three subscales: diversity of contact, relativistic appreciation, and sense of connection/comfort with differences (Kottke 2011).

While the M-GUDS is focussed on contact with people and cultures that are different than themselves, the Attitudes Toward Diverse Workgroup Scale (ADWS), is focused on working in diverse teams (Nakui, Paulus, and Van der Zee 2011). The study of Nakui, Paulus, and Van der Zee (2011) found that positive attitudes towards diversity were associated with enhanced creativity and qualitative outputs in diverse team settings. Additionally, the affective dimension of attitudes towards diversity contributed to improved psychological reactions within diverse group dynamics. Studies such as Maestas, Vaquera, and Zehr (2007) also found that supporting affirmative-action goals positively impact students' sense of belonging in diverse academic settings.

Interventions that are focussed on diversity attitudes, beliefs, or behaviours, are often linked to influencing social norms. For example, both Murrar, Campbell, and Brauer (2020), and Bennett and Sekaquaptewa (2014), tried to improve the inclusive social climate, by exposing students to pro-diversity attitudes of their peers at the university, or the university itself. This exposure led to a more positive attitude towards outgroups for non-minority students, while minority students reported an increased sense of belonging and had improved grades.

Several of these studies show the importance of a positive attitude towards diversity when it comes to creating a welcoming environment for minority students. However, many of the existing scales predominantly focus on the specific dimensions of diversity in terms of ethnicity or culture, thereby neglecting other identity dimensions such as gender, age, sexual orientation, or disability. Additionally, it is worth mentioning that most of these studies were conducted in the United States. This indicates a notable gap in European-based research, and even more so for research beyond western contexts, highlighting the need for additional research on this subject matter.

The current study aims to raise awareness among students about the importance of diversity and the consequences of its absence in a demographically relatively homogenous field such as engineering. By focussing on diversity in a broader sense, and recognizing the importance of diversity, we aim to create an environment that embraces differences.

3 METHODOLOGY

3.1 Study design

Context

The intervention took place at a campus of KU Leuven in Belgium and was integrated in a regular course entitled 'Enterprises and Ethics' (3 ECTS). The course consists of three subparts: lectures on enterprises and management (1.2 ECTS); lectures on ethics in engineering (1.2 ECTS); and a practical assignment called ‘day with an engineer’, including an introduction and two workshops (0.6 ECTS). The intervention was integrated in the subpart ‘day with an engineer’, as part of the assignment and first workshop. For their ‘day with an engineer’, the students were tasked with contacting an engineer to plan a day of job observation. Afterwards, students discussed their experiences in small self-organized groups and wrote a group paper about these experiences. The paper consisted of three parts: (1) an individual part, describing and reflecting on their job observation experience; (2) an ethics part, based on a group interview with one of the engineers; (3) a group conclusion, based on the group discussion and reflection.

The intervention

The goal of the current study was to develop an intervention by employing a quasi-experimental study design, using a cluster randomized controlled intervention. Self-organized teams were randomly assigned to the experimental or control group. The intervention was integrated in the subpart ‘day with an engineer’, where both the experimental group and control group received slightly different guidelines for the job observation assignment, as well as different information during the first workshop:

(1) The experimental group focused on the diversity within the engineer’s team and were tasked with checking whether the engineer’s company had inclusive policies. Additionally, the students were tasked with formulating some personal ideas on how they, as future engineers, could contribute to the diversity and inclusivity in the engineering field. During the first preparatory workshop, the students received instructions on the group paper, including a ten-minute explanation on diversity and inclusion. The explanation covered the meaning of diversity and inclusion, why these concepts are important, and what some examples are of the consequences of a lack of diversity in engineering (e.g., women are more likely to die in a car crash, and face recognition software is less likely to work properly for people with darker skin tones).

(2) The control group focused on the influence of external stakeholders on the work of the engineer and the company. They were tasked with formulating personal ideas on how to engage with these stakeholders. In the first preparatory workshop, they received instructions and some supplementary explanations regarding the concept of external stakeholders. However, the required information had already been covered in the preceding lectures on enterprises for the whole group.

The measurement

To assess the effect of the interventions all students were presented with two surveys, one to measure their pro-diversity mindset prior to the intervention (October 2023) and one at the end of the course, after the intervention (December 2023). The pre-test was conducted five weeks before the first workshop, and right before the students received their specific assignments. The pre-test was part of a broader survey, unrelated to the course. The post-test was conducted during the second workshop, three weeks after the first workshop and intervention. This post-test was presented as part of a feedback evaluation survey on the course.

The intervention and surveys were approved by the Social and Societal Ethics Committee, and Privacy and Ethical Review of KU Leuven (G-2022-5665). The students who participated in the surveys also gave consent to use their information for research purposes.

3.2 Participants

The pre- and post-test were administrated across three campuses, including the one where the intervention took place. This means that the pre-test was conducted with 236 participants in total, which is the dataset used for the survey development.

The intervention itself took place on one campus, where all 88 first-year engineering students enrolled in the course 'Enterprises and Ethics' participated. Out of these 88 students, 65 completed both the pre- and post-test (74% response rate), of which 31 students were in the experimental group, and 34 students were in the control group. Among the 65 participants who completed the surveys, 2 (2%) were female, and 7 (11%) had a migration background. The result section is based on the data of these 65 participants.

3.3 Survey development

Test phase

The survey development started by identifying four main themes relevant to a pro-diversity mindset through a literature study: (1) support for initiatives on promoting diversity (Maestas, Vaquera, and Zehr 2007); (2) the importance of working in diverse teams (Bennett and Sekaquaptewa 2014; Kauff et al. 2019); (3) the students' comfortableness with diversity (Miville et al. 1999); and (4) the enjoyment of- or interest in diversity (Murrar, Campbell, and Brauer 2020; Nakui, Paulus, and Van der Zee 2011). Drawing from this literature and additional discussions within the research team, 25 items were included in the study. The items were measured on a Likert scale from 1 (strongly disagree), to 7 (strongly agree) and tested during a pilot study with second-year engineering technology students (N=45). After evaluation, six items were removed due to excessive skewness, or failure to load on any of the factors in exploratory factor analysis (EFA). Additionally, the students gave feedback after conducting the survey, saying that they had difficulty with answering items such as '*to become a successful engineer, it is important to be able to work with diverse people*'; as they felt they could not know if this was true. Difficult to respond items were removed or rephrased to measure opinions. There were 15 items that remained in the survey.

Validating the scales

After the test phase, the 15 remaining items were used for the pre- and post-test. To incorporate the items in a broader study, the Likert scale was modified to a Likert scale from 1 (strongly disagree), to 5 (strongly agree). Additionally, some of the items were reformulated into a negative form. When conducting the survey with the first-year students in the context of the intervention, the positive and negative questions were alternated, to avoid acquiescence bias and socially desirable answers. To minimize the latter, we also added a message stating that a variety of opinions on the topic of diversity exists, and there are no right or wrong answers.

Since the pre-test was part of a broader survey, it was administered across multiple campuses, giving us a larger sample size to validate the scales (N=236). The Kaiser-Meyer-Olkin (KMO) test revealed a good level of intercorrelation among the variables (MSA = 0,81) and the Bartlett's test of sphericity further supported the dataset's appropriateness for factor analysis (chi-square = 980,17; df = 105; p-value = 0). The

EFA with a varimax rotation resulted in three coherent factors after cutting the loadings under 0.4 (cumulative var. = 39,4%; chi-square = 113.54; df = 63; p-value = 0,00) (Field, Miles, and Field 2012). Three items did not significantly load on any of the extracted factors, excluding them from further analysis. After exclusion, the above-mentioned tests were repeated, reaffirmed the findings.

The Cronbach's alpha coefficients indicated an acceptable consistency, after which the three pro-diversity mindset scales were computed based on the average scores of the items per factor. This, to ensure that no individual item disproportionately influenced the results based on one sample. An overview of the scales, their explanations, and an example item can be found in Table 1 *(Detailed scale items are available on request).*

Table 1: Overview of the created pro-diversity mindset scales

SCALE	EXPLANATION	EXAMPLE ITEM
Diversity Initiatives (α = 0,78)	Assesses students' opinion on whether initiatives to improve diversity are required.	Positive: Hiring a diverse team of teachers, should be a top priority of the Faculty of Engineering Technology.
Personal Attitudes (α = 0,73)	Assesses students' individual beliefs and perspectives concerning diversity, inclusion, and collaboration within academic environments.	Positive: I would like to learn more about the benefits of diversity in the engineering field.
Comfort (α = 0,74)	Assesses students' level of comfort and ease in interacting with peers from diverse backgrounds.	Negative: I feel most at ease with people who are similar to myself.

These scales are used to assess the effects of the intervention through a between-group comparison of both the individual mean scores on the post-test, as well as the change score (the difference between pre- and post-score). The Wilcoxon rank-sum test with alternative hypothesis 'greater', is employed to identify significant differences in a small sample size (n=65).

Notably, while these scales were validated within a larger cohort (n=236), it is imperative to acknowledge that the factor analysis resulted in divergent outcomes for the smaller intervention sample (N=88), accompanied by lower Cronbach's alpha coefficients (0,73; 0,59; 0,57 for the subscales respectively). Consequently, caution is advised in the interpretation of the results of the intervention.

4 RESULTS: A BETWEEN-GROUP COMPARISON

To evaluate the effectiveness of the intervention, this section examines the difference between the experimental (n=31) and control group (n=34). First, the post-test scores are compared to assess the difference between the groups in the pro-diversity mindset after the intervention. Second, we compare the change scores (the difference between pre- and post-score) between the groups. Importantly, the pre-test did not demonstrate any significant differences between the experimental and control group, suggesting successful random assignment.

Difference in pro-diversity mindset on the post-test

As shown in Table 2, the scale for *diversity initiatives* did not show any significant differences between the experimental and control group. For the scale *personal attitudes*, the experimental group displayed a small but significantly higher mean score (,.08) than the control group (2,94), with a small effect size (0,21). For the *comfort* scale, the experimental group displayed a mean score of 3.21, which is significantly higher than the control group (2,91), again with a small effect size (0,23).

Overall, there are small, but notable differences in mean scores between groups across the scales, with the experimental group consistently demonstrating higher mean scores compared to the control group.

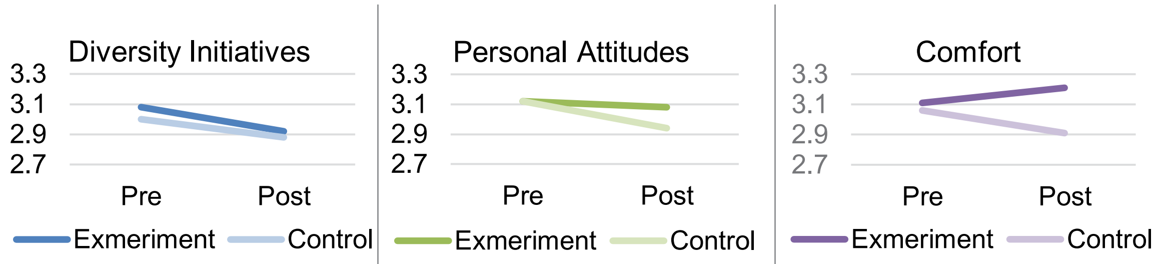
Table 2: Descriptive data pro-diversity mindset scales: post-test

	Group	*N*	*Mean*	*SD*	*Wilcoxon (W)*	*P-value*	*Effect size*
Diversity Initiatives	Experimental	31	2,92	0,96	REF	REF	REF
	Control	34	2,88	0,70	581,5	0,24	0,09 (/)
Personal Attitudes	Experimental	31	3,08	0,70	REF	REF	REF
	Control	34	2,94	0,52	656,5	**0,04**	**0,21 (small)**
Comfort	Experimental	31	3,21	0,66	REF	REF	REF
	Control	34	2,91	0,50	664,5	**0,03**	**0,23 (small)**

Difference over time

While some differences between the groups were observed during the post-test, it is important to also look at the change in relation to the pre-test to give a more powerful test of actual change.

Figure 1 illustrates the changes in the pro-diversity mindset scales over an 8-week period. These visualisations reveal distinct patterns between groups in participants' pro-diversity mindset. Both the intervention and control group attach less importance to *diversity initiatives* at the post-test, compared to the pre-test. However, while the *personal attitudes* towards diversity declines over time for the control group, the decline for the experimental group is significantly smaller (p=0,03). Additionally, the students in the intervention group show an increased *comfort level* with diversity compared to the decreased observed in the control group (p=0,05).



	EXPERIMENT	CONTROL	EXPERIMENT	CONTROL	EXPERIMENT	CONTROL
N	31	34	31	34	31	34
MEAN CHANGE SCORE	-0,15	-0,12	-0,04	-0,18	0.10	-0.15
SD	0,7	0,64	0,68	0,38	0.75	0.48
W	512		673,5		655	
P	0,58		**0,03**		**0,05**	
EFFECT-SIZE	0,02 (/)		**0,24 (small)**		**0,21 (small)**	

Figure 1: Visual representation of the change between the pre- and post-test

5 DISCUSSION AND CONCLUSION

This study investigated the effectiveness of an intervention aimed at fostering a pro-diversity mindset among first-year engineering students. Results indicate that incorporating a brief lecture and a reflective activity on diversity and inclusion within the regular curriculum, positively influenced students' pro-diversity mindset on two of the three outcome variables. While the impact of the intervention was small, it revealed that the students in the experimental group, compared to the control group, (1) attached more importance to diversity and inclusion in their personal attitudes; (2) and showed a higher level of comfortness with diversity settings. However, there was no significant difference in attitude towards initiatives to increase diversity and inclusion on campus or at the university between both groups. This result was confirmed by both a between-group comparison of the individual mean scores on the post-test, and the change scores (the difference between pre- and post-score).

We can conclude that the short explanation and reflective exercise possibly prompted students to evaluate their attitudes regarding personal diversity mindset in a positive light, resulting in greater comfort and more favourable attitudes. The lack of impact on the attitude with regard to the importance of diversity initiatives can possibly be attributed to the focus on first-year students. Since these students are still acclimating to university life and may have limited familiarity with existing initiatives, and the need for additional initiatives (Johnson 2012).

It is important to keep in mind that this was a small-scale explorative study, however, the observed results are in line with previous research, which showed that pro-diversity attitudes, behaviours, and beliefs, can be impacted by stating social norms. We indeed similarly affected these norms by telling students about the importance of diversity in the engineering field (Bennett and Sekaquaptewa 2014; Murrar, Campbell, and Brauer 2020; Moreu, Isenberg, and Brauer 2021).

The limitations of this study must be acknowledged. Firstly, the small sample size restricts the generalizability of the findings. Secondly, the observed effects were modest and should be interpreted cautiously. To enhance effectiveness, further optimization, validation and reliability confirmation of survey items and additional data collection are necessary.

This opens possibilities for further research. Replicating the intervention and collecting additional data would refine both the intervention and pro-diversity mindset scales and offer deeper insights into related concepts like minority students' sense of belonging. Additionally, more fine-grained analyses as to for whom the intervention was effective, e.g., students who elaborated on the material more or those who followed instructions better, would allow firmer conclusions as to the effectiveness of the intervention. Testing the intervention in diverse settings would also offer valuable insights. For example, programmes or universities that have a more diverse student body, or programmes beyond engineering, like in social sciences. Lastly, longitudinal studies could explore the longer-term impact of pro-diversity mindset changes and their impact on students' academic and professional paths.

While it is crucial to recognize that there is not a one-size-fits-all solution to address a lack of diversity in engineering, it is also important to appreciate the possible power of small actions. The current study suggests that a single intervention can influence students' pro-diversity mindset. It is worth considering the potential impact of systematically integrating this vital topic throughout the curriculum. Such an approach could educate responsible engineers who celebrate and welcome differences by learning from diverse perspectives and experiences.

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REFERENCES

Atadero, Rebecca A., Christina H. Paguyo, Karen E. Rambo-Hernandez, and Heather L. Henderson. 2018. “Building Inclusive Engineering Identities: Implications for Changing Engineering Culture.” *European Journal of Engineering Education* 43 (3): 378–98. https://doi.org/10.1080/03043797.2017.1396287.

Bennett, Jill E., and Denise Sekaquaptewa. 2014. “Setting an Egalitarian Social Norm in the Classroom: Improving Attitudes towards Diversity among Male Engineering Students.” *Social Psychology of Education* 17 (2): 343–55. https://doi.org/10.1007/s11218-014-9253-y.

Blosser, Emily. 2020. “An Examination of Black Women’s Experiences in Undergraduate Engineering on a Primarily White Campus: Considering Institutional Strategies for Change.” *Journal of Engineering Education* 109 (1): 52–71. https://doi.org/10.1002/jee.20304.

Campbell-Montalvo, R., H. Cooke, C.A.S. Smith, M. Hughes Miller, H. Wao, E. Puccia, M. Mayberry, and J. Skvoretz. 2022. “‘Now I’m Not Afraid’: The Influence of Identity-Focused STEM Professional Organizations on the Persistence of Sexual and Gender Minority Undergraduates in STEM.” *Frontiers in Education* 7. https://doi.org/10.3389/feduc.2022.780331.

Charles, Maria, and Karen Bradley. 2009. “Indulging Our Gendered Selves? Sex Segregation by Field of Study in 44 Countries.” *American Journal of Sociology* 114 (4): 924–76. https://doi.org/10.1086/595942.

Diekman, A.B., E.K. Clark, and A.L. Belanger. 2019. “Finding Common Ground: Synthesizing Divergent Theoretical Views to Promote Women’s STEM Pursuits.” *Social Issues and Policy Review* 13 (1): 182–210. https://doi.org/10.1111/sipr.12052.

Field, Andy, Jeremy Miles, and Zoë Field. 2012. *Discovering Statistics Using R*. *Choice Reviews Online*. Vol. 50. https://doi.org/10.5860/choice.50-2114.

González-Pérez, S., M. Martínez-Martínez, V. Rey-Paredes, and E. Cifre. 2022. “I Am Done with This! Women Dropping out of Engineering Majors.” *Frontiers in Psychology* 13. https://doi.org/10.3389/fpsyg.2022.918439.

Herring, Cedric. 2009. “Does Diversity Pay?: Race, Gender, Andthe Business Case for Diversity.” *AMERICAN SOCIOLOGICAL REVIEW* 74:208–24.

Isaac, Siara, Nihat Kotluk, and Roland Tormey. 2023. “Educating Engineering Students to Address Bias and Discrimination Within Their Project Teams.” *Science and Engineering Ethics* 29 (1). https://doi.org/10.1007/s11948-022-00426-w.

Johnson, Dawn R. 2012. “Campus Racial Climate Perceptions and Overall Sense of Belonging among Racially Diverse Women in STEM Majors.” *Journal of College Student Development* 53 (2): 336–46. https://doi.org/10.1353/csd.2012.0028.

Kauff, Mathias, Sebastian Stegmann, Rolf van Dick, Constanze Beierlein, and Oliver Christ. 2019. “Measuring Beliefs in the Instrumentality of Ethnic Diversity: Development and Validation of the Pro-Diversity Beliefs Scale (PDBS).” *Group Processes and Intergroup Relations* 22 (4): 494–510. https://doi.org/10.1177/1368430218767025.

Kottke, Janet L. 2011. “Additional Evidence for the Short Form of the Universality-Diversity Scale.” *Personality and Individual Differences* 50 (4): 464–69. https://doi.org/10.1016/j.paid.2010.11.008.

Maestas, Ricardo, Gloria S. Vaquera, and Linda Muñoz Zehr. 2007. “Factors Impacting Sense of Belonging at a Hispanic-Serving Institution.” *Journal of Hispanic Higher Education* 6 (3): 237–56. https://doi.org/10.1177/1538192707302801.

Miville, Marie L, Pauline Holloway, Charles J Gelso, Raji Pannu, Will Liu, and Pegah Touradji. 1999. “Appreciating Similarities and Valuing Differences: The Miville-Guzman Universality-Diversity Scale.” *Journal of Counseling Psychology*. Vol. 46.

Moreu, Gil, Naomi Isenberg, and Markus Brauer. 2021. “How to Promote Diversity and Inclusion in Educational Settings: Behavior Change, Climate Surveys, and Effective Pro-Diversity Initiatives.” *Frontiers in Education* 6 (July).

Murrar, Sohad, Mitchell R Campbell, and Markus Brauer. 2020. “Exposure to Peers’ Pro-Diversity Attitudes Increases Inclusion and Reduces the Achievement Gap.” *Nature Human Behaviour* 4:889–97.

Nakui, Toshihiko, Paul B. Paulus, and Karen I. Van der Zee. 2011. “The Role of Attitudes in Reactions toward Diversity in Workgroups.” *Journal of Applied Social Psychology* 41 (10): 2327–51. https://doi.org/10.1111/j.1559-1816.2011.00818.x.

Ong, Maria, Janet M. Smith, and Lily T. Ko. 2018. “Counterspaces for Women of Color in STEM Higher Education: Marginal and Central Spaces for Persistence and Success.” *Journal of Research in Science Teaching* 55 (2): 206–45. https://doi.org/10.1002/tea.21417.

Page, Scott E. 2017. *The Diversity Bonus. How Great Teams Pay Off in The Knowledge Economy.* Princeton University Press.

Palid, Olivia, Sarah Cashdollar, Sarah Deangelo, Chu Chu, and Meg Bates. 2023. “Inclusion in Practice: A Systematic Review of Diversity-Focused STEM Programming in the United States.” *International Journal of STEM Education*. Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s40594-022-00387-3.

Villa, E.Q., A. Esquinca, E. Hampton, and H.M. Guerra. 2020. “‘Is Engineering for Me?’: Examining Latinas’ Narratives of Resilience and Agency to Confront Enduring Struggles and Challenges in Undergraduate Engineering Studies.” *Peace and Conflict* 26 (4): 403–13. https://doi.org/10.1037/pac0000427.

IS IT A NEED OR A WANT? PERCEPTIONS OF THE NEED FOR A PEER MENTOR FROM UNDERGRADUATE ENGINEERING STUDENTS WITHOUT ONE

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ABSTRACT

Mentorship is a reciprocal relationship where two or more people are guiding and supporting one another in growth and development. This can be in professional and

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career development support, role modeling, and/or psychosocial support. Peer mentorship is when this relationship exists between two people that are at a similar level. Peer mentorship is shown to be generally beneficial to both mentors and mentees. To better understand undergraduate engineering students' needs and perceptions of peer mentorship, a mixed-methods research instrument was utilized to retrieve these thoughts from students at a western institution of the United States early in the COVID-19 pandemic.

There were 223 complete responses to the survey and 144 of those students indicated that they did not currently have a peer mentor after being presented with a definition and examples of peer mentorship. These 144 students were then provided a definition of a need and were asked if they felt they needed a peer mentor with four options provided for answer: 1) Yes, I have a need for a peer mentor; 2) No, but I would like and could benefit from a peer mentor; 3) No; and 4) Not sure. Of those 144 students, 78 chose to elaborate on their answer. Those 78 are the responses that are analyzed in this study through qualitative coding means. From this analysis, recommendations for areas of focus are provided on what may be important when crafting a culture of mentorship in undergraduate engineering programs.

1 INTRODUCTION

1.1 Defining Mentorship & its Benefits

Mentorship can be defined as a reciprocal relationship in which a more knowledgeable or experienced person guides and supports the professional development or growth of another, which can be outside the typical co-worker, manager, fellow student relationship, or student-faculty relationship (Lawrence Berkeley National Laboratory 2023; National Academies of Sciences Engineering and Medicine 2019; Kram and Isabella 1985). In other words, mentorship goes above and beyond required training and professional communication to emphasize helping the individual grow and accomplish their goals (National Academies of Sciences Engineering and Medicine 2019). These relationships can either occur organically, which is known as informal mentorship, or be formed through an organization's mentorship program, which is known as formal mentorship (National Academies of Sciences Engineering and Medicine 2019). A mentoring experience provides professional and career development support, role modelling, and psychosocial support (National Academies of Sciences Engineering and Medicine 2019).

Peer mentorship is when two or more people at roughly the same level in some aspect (e.g., age, educational stage, career stage, or hierarchical level) have a mentor-mentee relationship (National Academies of Sciences Engineering and Medicine 2019; Kram and Isabella 1985; Collier 2017). Within peer mentoring, near peer mentoring (i.e., mentor and mentee are at same stage) and step-ahead peer mentoring (i.e., mentor was recently in the same developmental stage as the mentee and is now in the next stage) are the two main types, both of which can be an approachable, comfortable, and valuable alternative to traditional faculty mentorship models found in academic settings (Ensher, Thomas, and Murphy 2001; National Academies of Sciences Engineering and Medicine 2019).

Regardless of type, peer mentorship has been shown to have numerous benefits, especially for promoting academic success in college student populations (Collier 2017). A more comprehensive summary of the benefits of peer mentorship are available in Christensen (2021). Some examples are that peer mentorship provides a way for students to gain emotional competence, build friendship, connect to campus, increase confidence, decrease isolation, and increase satisfaction, performance, and retention for both mentors and mentees (Elegbe 2015; Colvin and Ashman 2010; National Academies of Sciences Engineering and Medicine 2019; Kiyama and Luca 2014; Ghosh and Reio 2013).

1.2 Status of Undergraduate Engineering Mentorship

Christensen (2021) undertook a formal search to determine the prominence of undergraduate engineering peer mentoring programs and found overall there was a lack of formalized research publications on the programmatic characteristics and the associated decision making when designing and facilitating peer mentorship in engineering programs. While programs do exist and tout generally positive outcomes, the documentation in scholarly research is primarily focused on evaluation of existent peer mentorship programs versus focusing on the why of the design of said programs. That reasoning on mentorship initiatives or program design as well as consideration of students' perceptions of needs and experiences with regard to peer mentorship was sparse, calling for the need of Christensen's (2021) design and validation of a mixed-methods instrument to begin considering factors that should be considered in peer mentorship facilitation.

The study for this paper focused on analysing student perspectives from one of the unexplored questions from Christensen's (2021) larger study. The exploration focuses on the perspectives of the need for and benefits of peer mentoring, specifically by those who currently do not have a peer mentor but may have had one in the past. Previous studies by Christensen have focused either on the whole population or just solely on the perspectives of those who do have a peer mentor (Christensen and Villanueva Alarcón 2023; Christensen, Villanueva Alarcón, and Corrigan 2023; Christensen 2021). By studying the student perspectives of those who do not currently have a peer mentor, design of peer mentoring efforts can be more intentional in delivering high quality support to a breadth of students.

2 METHODOLOGY

2.1 Instrument & Rationale

An exploratory mixed-methods instrument was used to collect data for this study. This data was collected from a previous study by Christensen (2021) to explore students' perceptions of the need for peer mentorship. Students first provided consent for the study. Then, they were asked to provide information regarding their experience with peer mentorship after being provided with a definition of peer mentorship with examples (Christensen 2021, 258–59). Depending on the students' responses to whether they have a peer mentor or not, they were presented with a set of questions regarding their peer mentoring needs. The analysis of this paper was focused on one of the questions posed to those who indicated they did not have a peer mentor. The question stated the following:

A **need** is defined as a **gap between your current state and your desired future state. Since you indicated you do not currently have a peer mentor, do you have a need for a peer mentor?** Please explain.

Students were able to answer in one of the following four ways: 1) Yes, I have a need for a peer mentor; 2) No, but I would like and could benefit from a peer mentor; 3) No; and 4) Not sure. In this current study, the researchers focused on the students who elaborated on their answers with open-ended responses.

2.2 Research Question

To better understand how to support students who don't currently have a peer mentor, the following research question was formed: **"What is the perceived need for peer mentors from those who don't currently have a peer mentor?"** It is recognized that for this particular study, just one question's multiple-choice and open-ended elaborations were utilized, which may be a limitation but serves as a foundation for future studies in this space.

2.3 Recruitment

Christensen (2021) describes all recruitment, survey participation, and IRB approval procedures. When asked, "Do you currently have a peer mentor?" 144 (65%) of the participants answered no. Of the 144 participants who answered no, 78 (54%) elaborated on their answers. Demographic information of the participants is shown in Table 1. While the demographic information is not utilized for comparative purposes in responses of this study, it is presented to show that the "no" participants were representatively similar with "all" participants; thus demographic differences were not relevant in this study.

Table 1. Demographic information for the 223 participants (abbreviated "part.") and the 79-participant subset who indicated they currently have a peer mentor (Christensen 2021).

Year in Undergraduate Engineering			**Declared Major**		
Category	**All Part.**	**"No" Part.**	**Category**	**All Part.**	**"No" Part.**
Freshman	19.7%	21.5%	Mechanical	55.6%	54.1%
Sophomore	13.0%	12.5%	Civil / Environmental	18%	21.5%
Junior	40.4%	41.0%	Biological	6.7%	4.9%
Senior	24.2%	23.6%	Electrical / Computer	15.7%	16.0%
Other	2.7%	1.4%	Intend to Pursue	0.9%	1.4%
			Other	3.1%	2.1%
Self-Identified Gender Identity			**Of Hispanic, Latinx, or Spanish Origin**		
Category	**All Part.**	**"No" Part.**	**Category**	**All Part.**	**"No" Part.**
Male	74.0%	75.0%	Yes	3.0%	2.1%
Female	23.8%	22.9%	No	90.0%	91.0%
Prefer not to	2.2%	2.1%	Prefer not to answer	7.0%	6.9%
First Generational Status			**Race**		
Category	**All Part.**	**"No" Part.**	**Category**	**All Part.**	**"No" Part.**

Yes	7.6%	8.3%	White	91.0%	90.3%
No	91.5%	91.0%	Person of Color	3.2%	2.8%
Prefer not to	0.9%	0.7%	Prefer not to answer	5.8%	6.9%

Note: *More options may have been included in the multiple-choice answers, only responses that participants chose are shown in the table. All other options can be found in Christensen* (2021)*. This table was adapted from Christensen et al.* (2022a; 2023).

2.4 Research Team Positionality

The research team aimed to be bias-free in their interpretations through the same procedures that are described in other previous publications surrounding the same instrument (Christensen and Villanueva Alarcón 2023; 2022a; 2022b; Christensen, Villanueva Alarcón, and Corrigan 2023). The first author on this current research team has extensive knowledge of this research topic due to her dissertation work on peer mentorship. The first author collected data from students at a Western institution in the United States, where she was completing graduate studies at the time of data collection. She has since transitioned into an assistant professor role at a different undergraduate engineering institution and remains heavily involved with mentorship. The three student researchers, which include one graduate and two undergraduate students, provided new perspectives in the realm of mentorship and desired to learn more about the need for peer mentorship in engineering education. The final author provides expertise in the realm of mentorship, teaching, and research to support analysis related to peer mentorship.

2.5 Qualitative Analysis Procedures

The qualitative analysis of student's open-ended elaborations on whether there is a need for peer mentorship was coded using a phenomenological approach, which is similar to past studies conducted by Christensen (Christensen 2021; Christensen and Villanueva Alarcón 2023; 2022a; 2022b; Christensen, Villanueva Alarcón, and Corrigan 2023). For the first round of coding, open, in-vivo coding methods (Saldaña 2013) were utilized by the first author. The 78 participant responses from those who chose to elaborate on their answer to "Do you have a need for a peer mentor?" were coded participant by participant. These participants came from the subset of the 144 students that answered no to "Do you currently have a peer mentor?".

Once the first round of coding was completed, coding categories were axially identified from the in-vivo codes to answer the research question (Saldaña 2013). For example, responses like "talk to another peer about struggles" (Participant 8) and "I had a reliable student to bounce ideas and topics off of" (Participant 23) were grouped under a coding category titled "Listener & Sounding Board". After creating these coding categories, two overarching thematic areas that addressed the research question emerged: "A mentor could provide…" and "I don't see a need for a mentor because…". This gave space for student responses to show both the benefits and influence a mentor could have as well as hesitations that students have relating to peer mentorship. The two overarching thematic areas and all associated coding categories were organized in a codebook. The additional three authors proceeded with an intercoder agreement utilizing the codebook to verify the coding directions, draw connections, and gain a consensus on the student responses. Multiple codes, regardless of what thematic area they came from, could be assigned to a single participant response. Through three rounds of coding and discussion, the original coding categories generated from the primary coder were reduced and refined from 16 categories to 11 categories. A consensus was reached on the two thematic areas and 11 coding categories by agreeing 100% on how they applied to each participant response.

3 RESULTS

Table 2 shows the results of the participant's responses to the question, "Since you indicated you do not currently have a peer mentor, do you have a need for a peer mentor? Please explain." As a reminder, this was only asked of the students who answered no to "Do you currently have a peer mentor?" While 12.8% of students did not feel they needed a peer mentor, 62.8% of participants in some way indicated they had the need or could recognize the benefit of a peer mentor as indicated by summing the first two rows of Table 2.

Table 2. Frequency count for 78 participant answers to "Since you indicated you do not currently have a peer mentor, do you have a need for a peer mentor? Please explain."

Response Category	Frequency
Yes, I have a need for a peer mentor	10 (12.8%)
No, but I would like and could benefit from a peer mentor	39 (50.0%)
No	10 (12.8%)
Not sure	19 (24.4%)

The following sections will describe and share examples of student responses in the two thematic areas for each of the 11 coding categories. It should be noted that any participant quotes that are used in the descriptions are direct copies of student responses, and any spelling or grammatical errors that were present are preserved.

3.1 "A mentor could provide…"

The codes and frequencies displayed in Table 3 give an idea of the areas where students see a need that could be addressed with a peer mentor.

Table 3. Coding scheme and frequency counts for those instances when the 78 students stated something that aligned with "A mentor could provide…"

Code #	Code	Frequency
1	Guidance in Pathway, Load Management, & Decisions through Experience, Advice, & Resource Sharing	18 (23.1%)
2	Accountability & Motivation	5 (6.4%)
3	A Support System *(e.g., listening ear, sounding board, friend, relatability, belonging, etc.)*	9 (11.5%)
4	General Positive Influence (*no specifics given, but the response is positive for need of a mentor)*	8 (10.3%)

Representative quotes from each of these sub-codes are shown in Table 4.

Table 4. Representative quotes relating to each of the sub-codes represented in Table 3.

Code #	Representative Quote

1	• I would love a mentor to help a little in the last year of school and research opportunities / club involvement / lab opportunities. (Participant 7) • I would really appreciate having…someone who is farther ahead and can give me an idea what to look out for, show me the ropes, if you will. (Participant 9) • I wouldn't mind having someone that could warn me "hey, this class sucks." (Participant 13) • A lot of engineering homework help is easier understood when it's coming from a person rather than online. (Participant 41) • It would be nice to have someone else have ideas I have not thought of, and advice to help me reach my current goals. (Participant 44) • I think someone to help me figure out where to apply to for internships and jobs would be great. (Participant 63)
2	• It would help me stay on track and keep motivated for the upcoming semesters. (Participant 3) • As I start taking harder classes it would be nice to have someone to help keep me on pace and be able to study with. (Participant 19)
3	• It would be nice to have someone to talk to who has been in a similar situation to me so that I feel like I am not alone in my path. (Participant 5) • I would really appreciate having someone that I can bounce questions off of as we are figuring out how to understand the content within our engineering field. (Participant 9) • A peer mentor is a way to develop a support system and friendship with others who have similar goals as you have. (Participant 30) • It would help me feel like I belong. (Participant 40)
4	• I think everyone needs a mentor in some form. (Participant 2) • I feel like having a peer mentor can only be beneficial. (Participant 6) • Peer mentor would be nice. (Participant 15)

3.2 "I don't see a need for a mentor because…"

The codes and frequencies displayed in Table 5 give a scope of the reasoning why students may not feel that they need a peer mentor.

Table 5. Coding scheme and frequency counts for those instances when the 78 students stated something that aligned with "I don't see a need for a mentor because…"

Code #	Code	Frequency
5	I'm not interested or don't see a need/benefit right now	6 (7.7%)
6	I don't need one, but I can see the benefit/want one *(e.g., not currently struggling but could be at some point)*	22 (28.2)
7	I don't really know what I'm missing out on or don't understand the benefit or process	5 (6.4%)

8	Wrong Timing *(e.g. too late/graduating, don't have time, ready to shift to helping, past being peer mentee, etc.)*	17 (21.8%)
9	I already have a support system	5 (6.4%)
10	I work best on my own or can figure it out myself	4 (5.1%)
11	I don't have access to the peer mentor I need or prefer	3 (3.8%)

Representative quotes from each of these sub-codes are shown in Table 6.

Table 6. Representative quotes relating to each of the sub-codes represented in Table 5.

Code #	Representative Quote
5	• not really interesting in finding someone who is a "mentor". (Participant 50) • I feel like I am doing fine as is. (Participant 67) • I am not sure If a peer mentor would help me more than the other resources already established. (Participant 72)
6	• I don't "need" a perr mentor. If I do not have one I will still be successful but having one would help me enjoy college more. (Participant 34) • I don't feel like I have a need for one, but I do admit it would be helpful. (Participant 39) • No doubt a mentor would help and im sure im missing critical information because i dont have one. Nevertheless im still going to find a way to succeed. (Participant 47) • I believe that peer mentors are certainly beneficial, but are by no means essential for success. (Participant 49)
7	• I am not sure because I am not fully struggling yet and don't know if I really need a mentor. (Participant 62) • I don't know enough about the process to be sure if I need one. I would be interested in trying it out, though. (Participant 76)
8	• I think it would also be good for me to help others. (Participant 11) • Not that I think they wouldn't be helpful but at this point I'm in my senior year, getting ready to graduate and start a career. This probably would have been more applicable prior to now. (Participant 53) • It seems like a great and helpful idea, I just don't know what kind of commitment and time I have towards something like this. (Participant 60)
9	• I have someone I consider a mentor (just not necessarily a peer since he is in industry) who I can turn to when I have questions or need advice, so I don't have the need currently. (Participant 54) • I talked to some friends and learned some from them, though I wouldn't consider them to be peer mentors. (Participant 56) • Also I have a brother who graduated as an engineer so I can ask him for advice. (Participant 59)

	• I have been going through engineering relaying on help from my friends and people that are in my classes. (Participant 75)
10	• Most of the time I can find the answers on my own. (Participant 17) • Although I can see the benefit of a peer mentor, I prefer to work by myself. (Participant 38)
11	• I don't really like formal peer mentors. (Participant 21) • I prefer someone much further down the road that has a greater hindsight perspective (Participant 51)

4 DISCUSSION & RECOMMENDATIONS

Based on the results of this study, three overarching recommendations arose with regard to peer mentorship efforts from those who do not currently have a peer mentor, but it may also be able to apply generally to undergraduate engineering peer mentorship efforts.

First, when combined, codes 1 to 4 and 6 evidence that 79.5% of participants mentioned recognizing some benefit of peer mentorship even though only 10 of the participants originally stated "Yes, I have a need for a peer mentor". This may be directly correlated to a gap recognized by the student or a recognition of the potential for improvement of experience as mentors are involved. This emphasizes that the majority of students recognize the importance of having someone involved in their undergraduate engineering education. That being said, all of these students don't currently have peer mentors. While many students may find great value in a peer mentor, they often do not have the resources or the knowledge to reach out and find one, and many just do not know where to start, which is known to disproportionally affect minoritized students (National Academies of Sciences Engineering and Medicine 2019), though in this study, the "no" participants were a demographically similar subset of the total population. **This speaks to the necessary efforts to create cultures and programmatic efforts in undergraduate engineering programs to help students find the peer mentors they need.** While scholarly literature does generally share that mentoring outcomes are positive (as indicated in the introduction), simply talking about its importance without taking action to provide access and opportunity to all students is not enough.

This is also a note that a friend can be a suitable support system. As stated by some of the participants, many students may already have all the mentorship they need, even if they don't recognize those friends formally as mentors. This means that **undergraduate engineering programs can help create connections in various forms**. This could include student life activities, formal mentorship programs, alumni involvement, study group creation, etc.

Second, it is surprising that 24.4% of the participants were not sure whether they needed a peer mentor or not, which further affirms the importance of not just evaluating outcomes when a student has a mentor but also determining the needs of those who may not fully understand or have access to mentoring (Christensen 2021). While many students showed a drive to overcome challenges by themselves, they may not understand the benefits they are missing out on when collaborating with others. **This speaks to the necessary effort to inform all students of the**

importance of not navigating their educational pathway on their own. This can come with early and intentional effort in first-year programs, which has been shown to be helpful for multiple reasons (Budny, Paul, and Newborg 2010; Meyers et al. 2010), as well as through continual efforts in all years of engineering education. Being a mentor in those later years of undergraduate engineering years can positively affect student experience and growth (Good, Halpin, and Halpin 2000). Students need to be informed of both the importance and mechanisms of mentorship and then provided with the spaces to make that happen as both mentors and mentees.

Lastly, there are strong areas of guidance in how to train mentors given by what students said they do need in a mentor, which was shown in sub-codes 1 to 3. **These areas can help in knowing how to prepare potential mentors and leaders in the roles they may need to fill throughout their mentoring experience in undergraduate engineering programs to help mentees.** Students may be intimidated by what will be expected of them as a peer mentor. Training in these areas will help them to feel better prepared in knowing what to expect in their mentoring relationships and how to handle a variety of situations (Garringer et al. 2015; Eby et al. 2010).

Overall, the responses given by students who currently do not have a peer mentor for various reasons can help undergraduate engineering programs, faculty, advisors, supporting staff, etc., know what efforts can be made to help students be supported on their engineering journey.

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REFERENCES

Budny, Dan, Cheryl A Paul, and Beth Bateman Newborg. 2010. “Impact of Peer Mentoring on Freshmen Engineering Students.” *Journal of STEM Education* 11 (5/6): 9–24. http://cyber.usask.ca/login?url=http://search.proquest.com/docview/858459447?accountid=14739%5Cnhttp://sfx.usask.ca/usask?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ:education&atitle=Impact+of+Peer+Mentoring+on.

Christensen, Darcie. 2021. “A Mixed-Methods Approach to Explore Student Perceived Needs for Peer Mentorship in a College of Engineering.” *All Graduate Theses and Dissertations*. https://doi.org/10.26076/ee04-a10e.

Christensen, Darcie, and Idalis Villanueva Alarcón. 2022a. “Peer Mentorship: Exploring the Unmet Needs of Current Mentees During COVID-19.” In *50th Annual SEFI Conference Proceedings*, 189–98. https://doi.org/10.5821/conference-9788412322262.1250.

Christensen, Darcie, and Idalis Villanueva Alarcón. 2022b. “What Do Undergraduate Engineering Students at the Onset of Emergency Hybrid Learning During COVID-19 Say About Peer Mentorship?” In *ASEE Annual Conference & Exposition*.

Christensen, Darcie, and Idalis Villanueva Alarcón. 2023. “Descriptions of Peer Mentors as Told by Undergraduate Engineering Student Mentees (Research Paper).” In *SEFI 2023 Conference Proceedings*. Dublin, Ireland.

Christensen, Darcie, Idalis Villanueva Alarcón, and Quinn Alessandro Corrigan. 2023. “What Makes an Effective Peer Mentor? Perceptions of Undergraduate Engineering Students During COVID-19.” In *ASEE Annual Conference & Exposition*.

Collier, Peter J. 2017. “Why Peer Mentoring Is an Effective Approach for Promoting College Student Success.” *Metropolitan Universities* 28 (3). https://doi.org/10.18060/21539.

Colvin, Janet W., and Marinda Ashman. 2010. “Roles, Risks, and Benefits of Peer Mentoring Relationships in Higher Education.” *Mentoring and Tutoring: Partnership in Learning* 18 (2): 121–34. https://doi.org/10.1080/13611261003678879.

Eby, Lillian T, Marcus M Butts, Jaime Durley, and Belle Rose Ragins. 2010. “Are Bad Experiences Stronger than Good Ones in Mentoring Relationships? Evidence from the Protégé and Mentor Perspective.” *Journal of Vocational Behavior* 77 (1): 81–92. https://doi.org/10.1016/j.jvb.2010.02.010.

Elegbe, Joel Alemibola. 2015. “Emotional Intelligence : Missing Priority in Engineering Programs.” *Journal of Business Studies Quarterly* 7 (2): 1–12.

Ensher, Ellen A, Craig Thomas, and Susan E Murphy. 2001. “Comparison of Traditional, Step-Ahead, and Peer Mentoring on Protégés’ Support, Satisfaction, and Perceptions of Career Success: A Social Exchange Perspective.” *Journal of Business and Psychology* 15 (3): 419–38. https://doi.org/157.242.198.117.

Garringer, Michael, Janis Kupersmidt, Jean Rhodes, Rebecca Stelter, and Tammy Tai. 2015. *Elements of Effective Practice for Mentoring*. 4th ed. MENTOR: The National Mentoring Partnership. http://www.mentoring.org/downloads/mentoring_1222.pdf.

Ghosh, Rajashi, and Thomas G. Reio. 2013. “Career Benefits Associated with Mentoring for Mentors: A Meta-Analysis.” *Journal of Vocational Behavior* 83:106–16. https://doi.org/10.1016/j.jvb.2013.03.011.

Good, Jennifer M, Glennelle Halpin, and Gerald Halpin. 2000. “A Promising Prospect for Minority Retention: Students Becoming Peer Mentors.” *The Journal of Negro Education* 69 (4): 375. https://doi.org/10.2307/2696252.

Kiyama, Judy Marquez, and Sandra Guillen Luca. 2014. “Structured Opportunities: Exploring the Social and Academic Benefits for Peer Mentors in Retention Programs.” *Journal of College Student Retention: Research, Theory, & Practice* 15:489–514.

Kram, Kathy E., and Lynn A. Isabella. 1985. “Mentoring Alternatives: The Role of Peer Relationships in Career Development.” *The Academy of Management Journal* 28 (1): 110–32. https://doi.org/10.2307/256064.

Lawrence Berkeley National Laboratory. 2023. “What Is Mentorship?” Berkeley Lab Computing Sciences CSA Mentoring Program. September 27, 2023.

Meyers, Kerry L., Stephen E. Silliman, Natalie L. Gedde, and Matthew W. Ohland. 2010. “A Comparison of Engineering Students’ Reflections on Their First-Year Experiences.” *Journal of Engineering Education* 99 (2): 169–78. https://doi.org/10.1002/j.2168-9830.2010.tb01053.x.

National Academies of Sciences Engineering and Medicine. 2019. *The Science of Effective Mentorship in STEMM*. Edited by Angela Byars-Winston and Maria Lund Dahlberg. *The Science of Effective Mentorship in STEMM*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25568.

Saldaña, Johnny. 2013. *The Coding Manual for Qualitative Researchers*. Second. Thousand Oaks: SAGE Publications Inc. www.sagepublications.com.

ACADEMIC RESILIENCE: A STUDY OF PARENTAL BACKGROUND'S CONTRIBUTION TO ENGINEERING IDENTITY IN THREE EUROPEAN ENGINEERING FACULTIES

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***Conference Key Areas**: Engineering skills, professional skills, and transversal skills; Diversity, equity and inclusion in our universities and in our teaching*

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***Keywords**: academic resilience, skills, identity, parental background*

ABSTRACT

To create more equitable engineering education, it is essential to understand the adversity faced by students due to their socio-economic status; the impact it has on their academic journey, and how to adapt to overcome it. An aim of the EUniWell "Maximising Academic and Social Outcomes in Engineering Education" (MASOEE) project is to understand student disadvantage and its effect on engineering skill and identity development across 3 European universities. This multiphase, mixed-method research explored the association between adversity through parental education and adaptability through academic self-concept, utilising data from a structured questionnaire and 1-to-1 interviews. We found that students who are first generation in their family to attend university is a common indicator of adversity, and that, on average, their self-concept specific academic skills – communication, networking, and entrepreneurial resourcefulness – is lower compared to other students. The thematic analysis of the 1-to-1 interviews reveals 5 recurrent themes when discussing academic resilience and success with students: social factors, networking, extra-curricular skills development, skill confidence and improvement, and engineering identity fluidity. The findings add to previous research, and the need to develop targeted interventions around these uncovered themes.

1 INTRODUCTION

1.1 Academic resilience

Academic resilience refers to student's capacity to achieve success despite experiencing disadvantage. Within this project we are specifically examining the impact of a student's socio-economic status (SES) through parental education level, which is one of many possible factors affecting resilience. The Organisation for Economic Co-operation and Development reports SES as correlated with academic outcomes, arguing for more equitable higher education (OECD 2018). Students with challenging personal circumstances are less likely to succeed, motivating large-scale international studies to explore this variability and close the attainment gap. Academic resilience is conceptualised in the literature as adversity - representing the level of disadvantage faced by a student, and adaptation - their ability to overcome adversity (Ye, Strietholt, and Blömeke 2021).

1.2 Adversity: disadvantage and social-economic status

Adversity and disadvantage are terms which are used interchangeably in this study, the former relating it to the wider literature of academic resilience, where adversity can also include Diversity, Equality, and Inclusion (DEI) and attitudinal issues like personality traits. Disadvantage is frequently used to describe the narrower consideration of parental and home circumstance. There are many common approaches used by universities to identify such disadvantage. For example, in the UK, universities consider family income and home postcode as reliable predictors of educational outcomes (Jerrim 2020). Furthermore, during the COVID-19 pandemic, Italian families' access to free school meal programs and parental education levels were used to identified disadvantaged students (Gross, Francesconi, and Agostini 2021). Consideration is also given to the impact the status first generation – neither parent attended university - has on student achievement, with (Martin et al. 2020) noting that there are some differences in family support for first generation students who specified a more emotional support system from their families, in contrast to a more academic specific support experienced by those from families with higher education backgrounds. Moreover, a study from Sweden found that parental education not only influences academic achievement, but also the type of education, leading to student segregation (Hällsten and Thaning 2018). Spiegler and Bednarek (2013) also highlighted that within their USA first-generation students, a higher proportion were from lower-income backgrounds and were seemingly less prepared for university level education. Networks can help with being or becoming prepared, particularly in terms of career advice from those they meet in a professional capacity and that some first-generation students face difficulties in identifying and accessing resources available through these networks (Martin et al. 2020) . Finally, differences in academic achievement are attributed to whether a student learns in their native language with those who do not scoring lower (Schnepf 2007). These non-exhaustive examples suggest that despite differences in how disadvantage is identified in education across the European context, there is sufficient commonality to permit a small scale-study of engineering faculties using a shared measure of adversity based on disadvantage.

1.3 Adaptation: academic self-concept and identity

Academic self-concept (ASC) is a helpful measure for the second concept of academic resilience - adaptation. Unlike objective measures of cognition such as test scores and grades, ASC is considered a subjective, non-cognitive measure that reflects a student's self-evaluation of their academic encompassing a student's reflections on their learning and skills abilities (Ye, Strietholt, and Blömeke 2021). ASC has been shown as a reliable predictor of academic retention and progression (Marsh and O'Mara 2008). An important component of ASC is engineering identity - a concept which captures the self-perception and external perception of students in relation to the engineering profession. In a synthesis of work on engineering identity, (Patrick and Borrego 2016) draw parallels to work in science education, noting that the strength identity correlates with performance, recognition, and competence (Carlone and Johnson 2007). Furthermore, identity is linked to persistence, motivation, and the support structures that underpin informed career decisions (Lucas, Claxton, and Hanson 2014). Identity is heterogeneous; the engineer's skill set has diversified beyond technical expertise into other skills. Consequently, emerging identities are associated with the growing necessity for entrepreneurial, sustainability, and professional competencies in modern engineers (Berge, Silfver, and Danielsson 2019). In response, the educator's curriculum development has been facilitated by detailed skill inventories related to these identities, and accreditation bodies have integrated these skill sets to assure quality e.g. (Ward et al. 2021). Furthermore, students use these inventories to reflect on their skill acquisition. Out of the countless skill inventories published, three are used in this work to represent the emergence of corresponding engineering identities associated with entrepreneurial, professional, and sustainability competencies; the EU EntreComp framework (Bacigalupo et al., 2016), the WEF 21st century professional skills (Soffel 2016), and EU GreenComp (Bianchi, Pisiotis, and Cabrera Giraldez 2022) respectively.

1.4 Research aims, objectives, and questions

The "Maximising Academic and Social Outcomes in Engineering Education" (MASOEE) project is an ERASMUS+ University alliance funded project, conducted across three European universities (Cooke et al. 2023). The project's aims to share and develop best practice for skills teaching with ethical approval granted at all institutes. This part of the project explores the relationship between a students' parental education background - SES - and their self-perception as engineers - ASC. In considering academic resilience and its two key elements adversity and adaptation, three research questions are posited:

1. Which common metrics can be used to measure academic resilience (SES and ASC) across the 3 institutions?
2. What is the relationship between SES, ASC, and engineering identity using these metrics?
3. Which methods do students employ to advance their ASC, and how is this progression influenced by SES considerations?

Instead of the more objective common measure of test scores to measure outcome, this work focuses on students' perceptions of themselves as engineers i.e. their ASC. This includes how students rate themselves against the contemporary engineering skill set, as well as how they identify as engineers. This approach is motivated by two reasons: The well-established correlation between SES and academic performance offers limited novelty for further research, and there are inherent challenges in comparing scores across varying year groups, programmes, and institutions. Furthermore, the importance of self-perception of skills and professional identity formation are gaining traction as key themes in engineering education research and carry potential for gaining a holistic understanding of student learning and future success (Lindsay et al. 2023).

2 RESEARCH METHODOLOGY

2.1 Measures of adversity (RQ1)

Partners reported challenges in obtaining SES statistics for student cohorts; enrolment data was typically only available from centralised university functions rather than at faculty level, and its quality and type varied. Consequently, there were 5 types of disadvantage measure reported by partners (Table 1) which are used within faculty, with the number of parents who attended university common to all.

Table 1. SES measures in common use in engineering faculties

Measure of disadvantage	University partner		
	Birmingham(UK)	Linnaeus(Sweden)	Florence(Italy)
Free school meals (FSM)	✓	×	×
Home postcode	✓	×	✓
Parents attend university	✓	✓	✓
First language	×	✓	✓
Government scholarship	×	×	✓

2.2 Multi-lingual survey (RQ2 data collection)

A 25-question online survey was designed to capture students' SES and ASC. To support access and reduce the risk of misinterpretation, the survey was written in each partner's primary language. For SES, it asked if one or both parents attended university. Although there is some variation in the preferred definition of first-generation, for the purpose of this study the definition is based on neither parent attending parent attending higher level education (Spiegler and Bednarek 2013). Six questions captured demographic information including year of study, foundation/pre year, discipline, countries of birth and secondary school education. ASC had 17 Likert-scale quantitative questions measured self-perception of 4 engineering identities proposed in (Berge, Silfver, and Danielsson 2019) 'Traditional engineer'; 'Self-made engineer'; 'Professional engineer'; 'Ethical engineer', with 13 skill levels covering these identities as outlined in section 1.3. More qualitative aspects of ASC were explored using 3 free-text questions. A purposive sampling method (Berndt 2020; Taherdoost 2016) was used to allow the research to target specific engineering student populations as to ensure adequate representation. As advised by Mann (2003, 56), to improve response rates, guidance e-mails were sent out to students with the survey link on a regular basis, with follow up e-mails sent from the team to specific students who met the criteria.

2.3 Interviews (RQ2/RQ3 data collection)

Online interviews with students were semi-structured with prompts based on the DICE approach (descriptive, idiographic, clarifying, and explanatory) (Robinson

2023). The students all signed a letter of participation explaining informed consent (BERA, 2018). This information was repeated verbally at the beginning of each interview, with verbal clarification of agreement received from each participant. All interviews were automatically transcribed, checked, then anonymised in preparation for thematic analysis, which followed six specific steps advised in (Braun and Clarke 2006; Maguire and Delahunt 2017): 1) Data Familiarisation, 2) Initial code generation, 3) Theme search, 4) Theme review, 5) Define themes, 6) Write up. Eight initial codes were generated, and 14 themes identified. Self-selection sampling (Berndt, 2020) was initially used to recruit interviewees who had completed the survey and voluntarily left contact details to take part. However, the availability of respondents who volunteered was lower than expected, and consequently a second sampling method – convenience sampling (Taherdoost 2016) - was used, where the recruited students were identified by faculty programme leads. This introduced representation bias; the interviewees were mostly from later year groups and restricted access to a more representative sample of students. To offset these bias concerns, participants' responses were contextualised within the initial participant criteria such as the year group. As a result, the interviews aimed to explore survey results rather than provide generalisable findings (Florczak 2022).

3 RESULTS

3.1 Survey: The relationship between SES and ASC

The survey was completed by 186 students across the 3 partners: 53, 71, and 59 from Birmingham, Florence and Linnaeus respectively. Only the former two obtained parental background information due to unresolved ethical review issues at the time of data capture. Consequently, 50, 32, and 36 students reported none, one, or both parents attended university respectively (n=124). Whilst these sample counts are different, they are sufficiently large (n≥30) for the central limit theorem to hold and increase the confidence that each group is normally sampled. Fig. 1 compares the average student self-identified skill level for each of the 13 skills. The results indicate that first generation students rate themselves lower for 7 of the skills. In contrast, students with both parents having a university education rate higher for 10 of the skills. These findings suggest that there is a correlation between SES and ASC when measured in this way. For students who have only one parent with a university education, there appears to be, on average, less variation between skills. The largest statistically significant ($p<0.5$) differences between groups were for skills in communication and networking, entrepreneurial resourcefulness, and social-technical responsibility. Parents educational background shows a weak positive correlation with other skills, although the relationship was generally not statistically significant as illustrated in Fig. 1 by the overlapping error bars. Students were grouped according to which of the four engineering identities they primarily related to. There were no statistically significant ($p<0.5$) differences found as to whether parental background correlates with preferred engineering identity. However, further exploration comparing the strongest identity with individual skills (Fig. 2) reveals some trends; communication and networking skills were rated lowest in 3 of the 4 identities, while systems thinking was similarly rated highest.

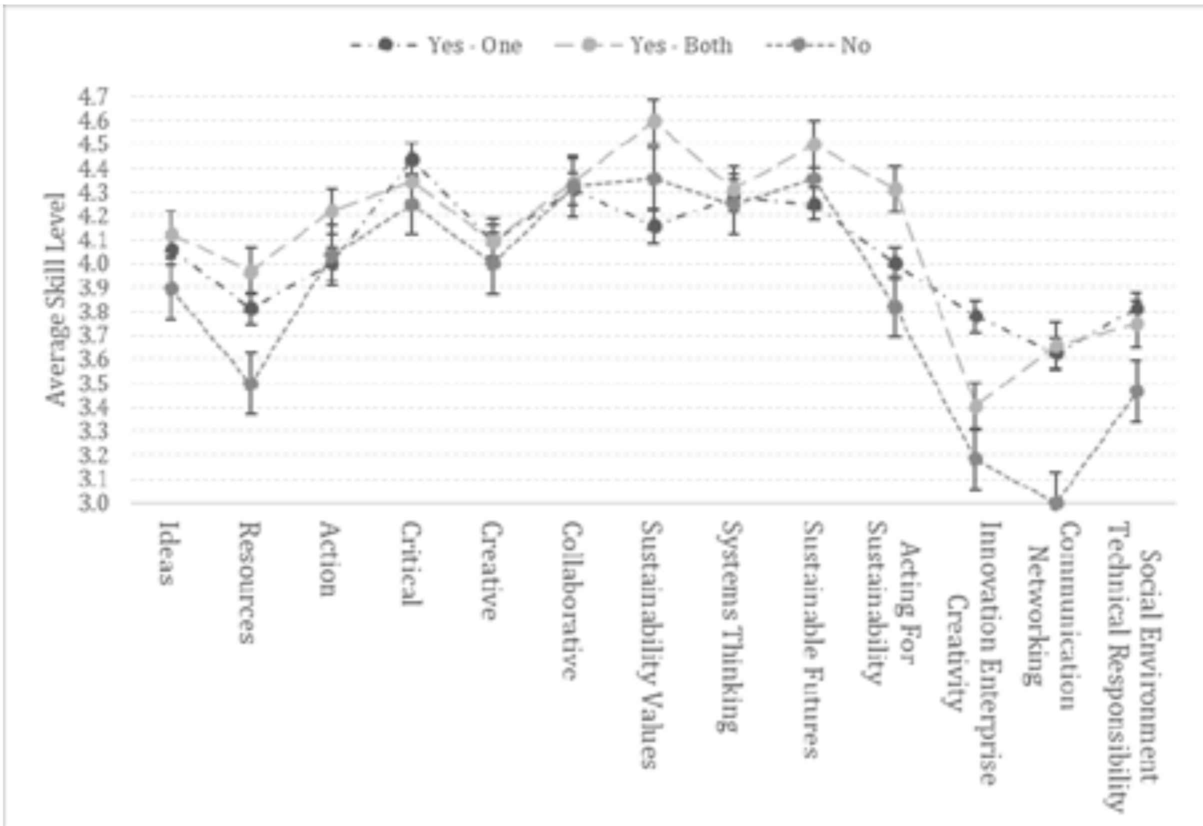

Figure 1 ASC (average self-rating of skill) compared to SES (parents attended university) (n=124)

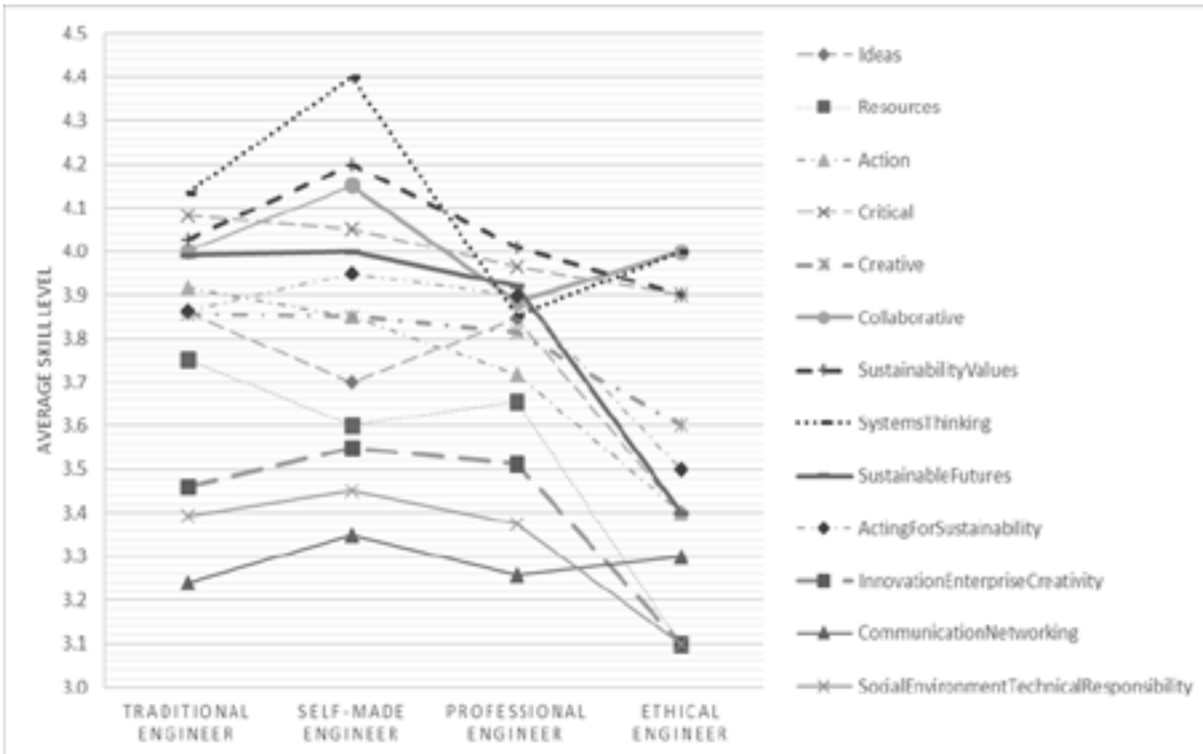

Figure 2 ASC (average self-rating of skill) compared to preferred identity (n=186)

3.2 Interviews: Thematic insights

Seven students were interviewed who are labelled P1-P7 respectively. Interviewees were a mixture of first-generation students (P1, P5, and P6) and those from a family with a higher education background. The thematic analysis generated 14 themes in 4 broad areas: Skills (balance, change, effectiveness of teaching & external skill development, Hard vs Soft, implicit or explicit, improvement, university support), Social factors (work, parents educational background), Networking, and Identity. Five key themes are explored below.

Theme 1: Social factors: parents educational background

40% of students in the survey disclosed that neither parent attended university. P1 and P5 discussed the impact of attending university as first-generation. P1 acknowledged friends who had higher educated parents had advantage: *"… some of my housemates … know what they're getting themselves into … I can't really ask my parents for help… I can't really ask… anyone…" (P1)*. The feeling of uncertainty experienced by P1 is not uncommon e.g. Spiegler and Bednarek (2013). This lack of preparedness is also seen by P5 who said that the lack of guidance impacted their organisation but there was also a higher expectation placed on them: *"my mom…she always told me you have to study more, more and more so you can change your life" (P5),* which might be considered an advantage.

Theme 2: Networking

The importance of networking, as highlighted by Martin et al. (2020) was something also seen during the interviews, with examples shared of the impact networking has had, with P6 sharing their experience of gaining work experience. Additionally, networking is acknowledged as key area of support for disadvantaged SES students (APPG 2017) and this was evident in P1's reflections. P6 – also a first-generation student - reflected on their ability to network through external opportunities, such as sports and student associations, as well as internships which underscores the importance of universities providing access to networking opportunities in the form of practical partner-based projects: *"I've actually worked at a company last summer that I'm going back to this summer and that connection was established during a project course that we had" (P6).*

Theme 3: Extra-curricular skills development

During the interviews, there were discussions around the development of skills independently of, and external to, the university. For some, prior opportunities helped them to develop leadership and team skills: *"I used to do the cadets when I was younger, so that's … helped my leadership … I'm not sure …I would be as effective at uni as I am now" (P1).* P1 believed that the university left *"it to the person to…grow"* the professional skills needed. P2 also felt that it was important to develop professional skills independently of the university, reflecting on joining a boat rowing club. When asked to expand on how this supported skills development, they said feelings of resilience, discipline, and teamwork grew as they trained.

Theme 4: Skill confidence and improvement

Confidence was a topic discussed throughout the interviews as a quality they needed to develop. This differed for each student: P2, P5, and P6 felt the need to develop their ability to communicate effectively, hoping to work on their language skills, supporting the findings of (Obilor 2019) that confidence is a by-product of good communication. Students also identified confidence in leadership and teamwork as desirable, congruent with employer's top desired skills for graduates (Stewart and Wall (2016). P4 expressed the need to develop teamwork skills through extra project work. P1 noted reservations to lead if someone else stepped forward: *"The confidence to lead I think is quite a big one … I'm not sure if I'm good enough." (P1)*

Theme 5: Engineering identity fluidity

Establishing a professional engineer identity is considered to persevere in studying and working in engineering(Lakin et al. 2020). This influence was evident, with all interviewees seeing themselves as a mixture of 2 or more of the 4 engineering identities presented in the study. Most interviewees conveyed that identity as a concept was fluid, anticipating it to evolve alongside career stages e.g. student, young professional, management. P1 shared feelings of uncertainty in terms of feeling like an engineer: *"I think up until the start of this year, I didn't really feel like an engineer. I felt like I was just a student learning engineering."*. P2 and P5 reflected on the importance of the individual personality on the development of an engineer's identity: *"I'm thinking about like it's determined by kind of your personality too, right? … I think nothing is static" (P5)*. P6 conveyed uncertainty over their engineering identity: *"My …kind of engineering is not so defined yet …I need to… maybe understand and do many other things … to finally understand who I am" (P6).*

4 SUMMARY AND DISCUSSION

Several studies show that parental education level affects achievement, type of study, and preparedness (Martin et al. 2020; Hällsten and Thaning 2018;Spiegler and Bednarek 2013). This study narrowed the focus of academic resilience to adversity caused by being a first-generation student, and to adaptability measured through academic self-concept and identity. As expected, and in-line with previous findings, first-generation students spoke of feeling underconfident, uncertain, and ill-prepared in comparison to those with university-educated parents. One interesting result is that lower self-concept of skills in communication, networking and resourcefulness differentiate this cohort, suggesting a targeted approach to closing gaps. An unanticipated finding is that notions of preferred engineering identity do not correlate with parental background or students' self-concept of their underlying skills, underlining the need to exercise caution in future research when characterising students as disadvantaged. A further interesting observation is that students were more likely to conceptualise identity aligned to career status and seniority rather than the entrepreneurial, professional and ecological orientations presented to them in the survey. A limitation of this study is compromises to sampling introduced biases affecting result generalisation. Nevertheless, this contribution highlights the value of applying wider discourse on academic resilience to the engineering education context.

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REFERENCES

APPG. 2017. “The Class Ceiling: Increasing Access to the Leading Professions: All Party Parliamentary Group on Social Mobility.” UK. http://www.socialmobilityappg.co.uk.

Berge, Maria, Eva Silfver, and Anna Danielsson. 2019. “In Search of the New Engineer: Gender, Age, and Social Class in Information about Engineering Education.” *European Journal of Engineering Education* 44 (5): 650–65. https://doi.org/10.1080/03043797.2018.1523133.

Bianchi, Guia, Ulrike Pisiotis, and Marcelino Cabrera Giraldez. 2022. “GreenComp The European Sustainability Competence Framework.” Joint Research Centre (Seville site).

Braun, Virginia, and Victoria Clarke. 2006. “Using Thematic Analysis in Psychology Using Thematic Analysis in Psychology.” *Qualitative Research in Psychology* 3 (2): 77–101. http://www.tandfonline.com/action/journalInformation?journalCode=uqrp20%5Cnhttp://www.tandfonline.com/action/journalInformation?journalCode=uqrp20.

Carlone, Heidi B., and Angela Johnson. 2007. “Understanding the Science Experiences of Successful Women of Color: Science Identity as an Analytic Lens.” *Journal of Research in Science Teaching* 44 (8): 1187–1218. https://doi.org/10.1002/tea.20237.

Cooke, Neil, Sarah Chung, Kamel Hawwash, Daniel Cottle, Enrica Caporali, Gianni Bartoli, Jörgen Forss, Jesper Andersson, and Pascal Chargé. 2023. “Euniwell: Maximising Academic And Social Outcomes In Engineering Education.” In *1st Annual Conference of the European Society for Engineering Education (SEFI)*, 1857–65. Dublin: European Society For Engineering Education (SEFI).

Florczak, Kristine L. 2022. “Best Available Evidence or Truth for the Moment: Bias in Research.” *Nursing Science Quarterly* 35 (1): 20–24. https://doi.org/10.1177/08943184211051350.

Gross, Barbara, Denis Francesconi, and Evi Agostini. 2021. “Ensuring Equitable Opportunities for Socioeconomically Disadvantaged Students in Italy and Austria during the First Wave of the COVID-19 Pandemic: A Qualitative Analysis of Educational Policy Documents.” *Giornale Italiano Della Ricerca Educativa* 27:13. https://doi.org/10.7346/sird-022021-p27.

Hällsten, Martin, and Max Thaning. 2018. “Multiple Dimensions of Social Background and Horizontal Educational Attainment in Sweden.” *Research in Social Stratification and Mobility* 56 (August):40–52. https://doi.org/10.1016/j.rssm.2018.06.005.

Jerrim, John. 2020. “Measuring Socio-Economic Background Using Administrative Data. What Is the Best Proxy Available?” https://EconPapers.repec.org/RePEc:qss:dqsswp:2009.

Lakin, Joni M., Ashley H. Wittig, Edward W. Davis, and Virginia A. Davis. 2020. “Am I an Engineer yet? Perceptions of Engineering and Identity among First Year Students.” *European Journal of Engineering Education* 45 (2): 214–31. https://doi.org/10.1080/03043797.2020.1714549.

Lindsay, Euan D., Roger G. Hadgraft, Fiona Boyle, and Ron Ulseth. 2023. “Disrupting Engineering Education.” In *International Handbook of Engineering Education*

Research, edited by Aditya Johri, 115–33. New York: Routledge. https://doi.org/10.4324/9781003287483.

Lucas, Bill, Guy Claxton, and Janet Hanson. 2014. “Thinking Like an Engineer: Implications for the Education System.”

Maguire, Moira, and Brid Delahunt. 2017. “Doing a Thematic Analysis: A Practical, Step-by-Step Guide for Learning and Teaching Scholars.” *AISHE-J - The All Ireland Journal of Teaching and Learning in Higher Education* 8 (3). http://ojs.aishe.org/index.php/aishe-j/article/view/335.

Mann, C. J. 2003. “Observational Research Methods. Research Design II: Cohort, Cross Sectional, and Case-Control Studies.” *Emergency Medical Journal* 20 (1): 54–60. https://doi.org/10.1136/emj.20.1.54.

Marsh, Herbert W., and Alison O’Mara. 2008. “Reciprocal Effects Between Academic Self-Concept, Self-Esteem, Achievement, and Attainment Over Seven Adolescent Years: Unidimensional and Multidimensional Perspectives of Self-Concept.” *Personality and Social Psychology Bulletin* 34 (4): 542–52. https://doi.org/10.1177/0146167207312313.

Martin, Julie P., Shannon K. Stefl, Lindsey W. Cain, and Aubrie L. Pfirman. 2020. “Understanding First-Generation Undergraduate Engineering Students’ Entry and Persistence through Social Capital Theory.” *International Journal of STEM Education* 7 (1). https://doi.org/10.1186/s40594-020-00237-0.

Obilor, Esezi Isaac. 2019. “Soft Skills and Students’ Academic Achievement.” *International Journal of Innovative Psychology & Social Development* 7 (2). https://www.researchgate.net/profile/Esezi-Isaac-Obilor/publication/343609946_Soft_Skills_and_Students’_Academic_Achievement/links/5f33ee4b299bf13404bb2425/Soft-Skills-and-Students-Academic-Achievement.pdf.

OECD. 2018. *Equity in Education*. OECD. https://doi.org/10.1787/9789264073234-en.

Patrick, Anita D, and Maura Borrego. 2016. “A Review of the Literature Relevant to Engineering Identity.” In . https://api.semanticscholar.org/CorpusID:183493933.

Robinson, Oliver C. 2023. “Probing in Qualitative Research Interviews: Theory and Practice.” *Qualitative Research in Psychology* 20 (3): 382–97. https://doi.org/10.1080/14780887.2023.2238625.

Schnepf, Sylke Viola. 2007. “Immigrants’ Educational Disadvantage: An Examination across Ten Countries and Three Surveys.” *Journal of Population Economics* 20 (3): 527–45. https://doi.org/10.1007/s00148-006-0102-y.

Soffel, Jenny. 2016. “What Are the 21st-Century Skills Every Student Needs.” In *World Economic Forum*. Vol. 10.

Spiegler, Thomas, and Antje Bednarek. 2013. “First-Generation Students: What We Ask, What We Know and What It Means: An International Review of the State of Research.” *International Studies in Sociology of Education*. https://doi.org/10.1080/09620214.2013.815441.

Stewart, Carol, and Alison Wall. 2016. “Mixed Signals: Do College Graduates Have the Soft Skills That Employers Want?” https://www.researchgate.net/publication/316066488.

Taherdoost, Hamed. 2016. “Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research.” *International Journal of Academic Research in Management (IJARM)*. Vol. 5. https://ssrn.com/abstract=3205035.

Ward, Rupert, Oliver Phillips, David Bowers, Tom Crick, James H. Davenport, Paul Hanna, Alan Hayes, Alastair Irons, and Tom Prickett. 2021. “Towards a 21st Century Personalised Learning Skills Taxonomy.” In *2021 IEEE Global Engineering Education Conference (EDUCON)*, 344–54. IEEE. https://doi.org/10.1109/EDUCON46332.2021.9453883.

Ye, Wangqiong, Rolf Strietholt, and Sigrid Blömeke. 2021. “Academic Resilience: Underlying Norms and Validity of Definitions.” *Educational Assessment, Evaluation and Accountability* 33 (1): 169–202. https://doi.org/10.1007/s11092-020-09351-7.

THE ROAD NOT TAKEN: HOW FIRST-GENERATION STUDENTS DIFFER IN THEIR POSTGRADUATE EDUCATIONAL PATHS

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ABSTRACT

First-generation students (FGS) are traditionally underrepresented in higher education, including engineering education. To ensure equity in access and success in engineering, and thereby ensure that we educate responsible engineers who come from a diversity of backgrounds, we need to understand the unique challenges faced by these students. Using data collected from a survey that was sent to the alumni of our institution we explored differences between FSG and continuing-generation students (CGS) with respect to their choice of postgraduate degrees and time taken for completion of postgraduate education. Our data showed that FGS prefer classical engineering postgraduate degrees, and the difference between their choices is starkest for the domestic alumni. We also found that FGS take longer to

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complete their postgraduate education. We conclude by situating our findings in existing literature and discussing possible explanations for the trends we observed.

1 INTRODUCTION

Addressing the diversity of hurdles that lie in the path to building socially and environmentally sustainable societies (United Nations [UN] 2015), requires a diversity of perspectives and expertises (The United Nations Educational, Scientific and Cultural Organization [UNESCO] 2021; Lucena and Schneider 2008). Therefore, to ensure that the engineering field is populated with responsible engineers who are representative of the rich diversity of experiences and perspectives, we need to consider potential barriers to access and success. One of the populations that has traditionally faced issues with both access and success is first-generation students (Seymour and Hunter 2019; National Academies of Sciences, Engineering, and Medicine [NASEM] 2016).

The term "first-generation students" (FGS) refers to individuals entering higher education whose parents did not complete a higher education degree (Council for Opportunity in Education [COE], n.d.). This concept originated in the United States as a response to the changing demographics of students entering higher education, including an increase in women, racial and ethnic diversity, and students from low-income backgrounds (Levine and Associates 1989). When considering demographics (socioeconomic status, ethnicity, migration background, gender etc) these students are not homogeneous (Cho et al. 2008), however, they are underrepresented in postsecondary educational institutions (Cataldi et al. 2018) and face some common challenges.

1.1 University preparation and transition is challenging for first-generation students

FGS face disadvantages compared to continuing-generation students (CGS), including lower levels of knowledge about higher education and family support (York-Anderson and Bowman 1991), lower expectations of academic achievement (Stage and Hossler 1989), and coming from typically lower socio-economic backgrounds (Bui 2002; Kutty 2014). Additionally, their academic preparation is also less rigorous (Warburton et al. 2001). During their transition from secondary education to post-secondary education, in addition to the challenges faced by CGS, these FGS also face social and cultural challenges (London 1989; Terenzini et al. 1994).

1.2 University experiences are different for first-generation students

The variables that influence first generation students' choice of higher educational institution also vary from that of continuing students. With FGS there is much less active “choosing” of institutions (Reay et al. 2009). These choices often revolve around prioritising practical concerns such as financial (Cho et al. 2008; Bui 2002) and geographical (Reay et al. 2001), as well as psychosocial characteristics of the campus including safety, social climate, and social support (Cho et al. 2008; Kutty 2014).

Multiple studies have also shown that first-generation students have higher attrition rates in higher education (Ishitani 2006; Chen 2005; Soria and Stebleton 2012; Billson and Terry 1982; Cataldi et al. 2018). A French longitudinal study on the academic success of over 7.2 million students, of which 3.05 million were FGS, revealed that they are up to twice less likely to succeed in their first year and in university scientific fields as compared to their CGS counterparts (Kasatkina et al. 2020).

Enrolment in programmes differs in these two populations with first-generation students less likely to be enrolled in STEM majors in Europe (Isserstedt et al. 2010; Kasatkina et al. 2020). In their literature review which explored more than 70 research articles and international reports on FGS, Spiegler and Bednarek (2013) found that FSG are less likely to study prestigious subjects and are less likely to be enrolled in academically-selective institutions.

1.3 Research questions

A recent report on the enrolment of first-generation students in institutions across Switzerland showed that, even after controlling for students enrolled only in STEM disciplines, our institution had the lowest percentage of FGS and this percentage has steadily decreased over the last 15 years (Gerster et al. 2023). Therefore, based on an increased institutional focus to increase recruitment and retention of first-generation students, we wanted to get a better understanding of the educational paths taken by our FGS. Specifically, we ask: What are the differences between FSG and CGS with respect to their choice of postgraduate degrees and time taken for completion of postgraduate education.

2 METHODOLOGY

2.1 Settings, Participants, and Data Collection

This data was collected at a large, research-intensive Swiss engineering university, which offers Bachelor's, Master's, and Doctoral degrees in several fields. Data collection was done by sending a survey to the alumni of the institution. Such surveys, which are periodically used by the institution, are aimed at both serving as a quality-control tool as well as a means of identifying scope for improvement in the educational programming. While the questions posed differ slightly based on the year of graduation, the questions that generated the data for this paper remained constant across the graduating classes.

Using an inhouse server, a survey was sent to alumni that graduated from 1980 to 2019. The link to the survey was unique and no identity information was requested from respondents. Of the 29630 alumni that received the survey, 4385 responded. The demographics of this population was compared to the demographics of the graduating classes for the respective years as was considered to be representative with respect to degree obtained, year of graduation, department, and gender (Colzani et al. 2022). However, we do not know if it is also representative of first-generation status.

2.2 Data Analysis

This data was initially filtered to keep only responses from alumni who provided information relating to at least one graduating date (e.g. year in which they obtained their Bachelor's degree). Since gendered diversification of academic paths has been well documented in literature, so as to be able to make generalisable claims, we decided to further filter the data and retain only data for alumni who graduated between 2004 and 2019, as the gender demographics in this population are very close to the demographics of the graduating classes in those years. The final dataset that was used for the further analysis consisted of responses from 1328 alumni, 170 of which were first-generation students.

This data was analysed using Pearson's Chi-squared statistical test and Student t-test comparing FGS and CGS distributions. All analyses were performed using R Statistical Software (v4.3.2, R Core Team 2023). We used the *tidyr* (Wickham, Vaughan, et al. 2024) and *dplyr* (Wickham et al. 2023) packages for data processing, and the *ggplot2* package (Wickham, Chang, et al. 2024) for data visualisation.

3 RESULTS

3.1 First-generation students are more likely to choose classical engineering Masters programmes

We sorted the 26 different Master's programmes offered at our university into 6 categories, based on similarity.

1. Classical engineering: These programmes have existed globally for a long time and are easier for a non-specialist to recognise. 6 programmes (e.g. Mechanical engineering, Civil engineering)
2. Emergent engineering degrees: These programmes have been developed in response to the digital and technological advances in the last few decades, and as such these might not be as easy for a non-specialist to recognise. 8 programmes (e.g. Computational science and engineering, Energy science and technology)
3. Formal & Physical Sciences: 5 programmes (e.g. Physics, Mathematics)
4. Finance & Management: 2 programmes (e.g. Financial engineering, Management, technology and entrepreneurship)
5. Life Sciences & Environment: 4 programmes (e.g. Life sciences engineering, Environmental sciences and engineering)
6. Architecture: 1 programme

Of the 1328 alumni, 1124 provided information about their Master's programme, of these 13.25% were FGS. When we compared the choice of study programme (Fig. 1), we found that FGS were more likely to graduate with a Master's degree in one of the "Classical Engineering" programmes as compared to their CGS counterparts (Chi square - *p* <0.1). 29.53% of FGS graduated with classical engineering degrees while only 19.38 % of CGS did the same. Consequently, FGS were less likely to graduate with Master's in Architecture (5.36% compared to 9.23%), in one of the "Life Sciences and Environment" (14.09% compared to 17.74%) programmes or in one of the "Emergent Engineering" (22.15% compared to 24.41%) programmes. We did not find major differences in their choices for the "Finance & Management" and the Formal and Physical Sciences programmes.

Figure 1. Percentage of all the FGS and CGS who graduated with Master's degrees in the six categories of programmes offered by the institution.

3.2 Domestic students overwhelmingly prefer Classical Engineering degrees

The proportion of FGS was much higher among the domestic alumni (alumni that indicated Switzerland as their first nationality). Among the 564 domestic alumni, 21.28% were FGS. Therefore, to control for Alumni origin as a possible confounding variable, we compared the choice of study programme for domestic alumni (Fig. 2).

Figure 2. Percentage of all the Swiss FGS and CGS who graduated with Master's degrees in the six categories of programmes offered by the institution.

Swiss FGS were much more likely to graduate with a Master's degree in one of the "Classical Engineering" programmes as compared to their Swiss CGS counterparts (Chi square - p <0.05). 31.67% of Swiss FGS graduated with classical engineering degrees as compared to the 17.12% of Swiss CGS who did the same. Consequently, Swiss FGS were much less likely to graduate with Master's in all the other categories of programmes. The biggest differences were observed in the "Formal & Physical Sciences" programmes (15.86 compared to 19.59), "Life Sciences and Environment" programmes (13.33% compared to 16.89%), and in Architecture (4.17% compared to 7.66%).

3.3 Total duration of studies is longer for first-generation students

As an estimation for duration of studies we explored differences in time between successive graduations. On a smaller scale, when examined individually, we did not detect significant differences in time between Bachelor's and Master's graduations, or between Master's and Ph.D. graduations. However, when we look at a larger scale, we find that there is a significant difference (T-test, $p < 0.05$; Fig. 3) in time between Bachelor's and Ph.D. graduations for FGS (n = 50, mean study duration = 8.26 years) and CGS (n = 315, mean study duration = 7.44 years). FGS take approximately 10 months longer than their CGS counterparts.

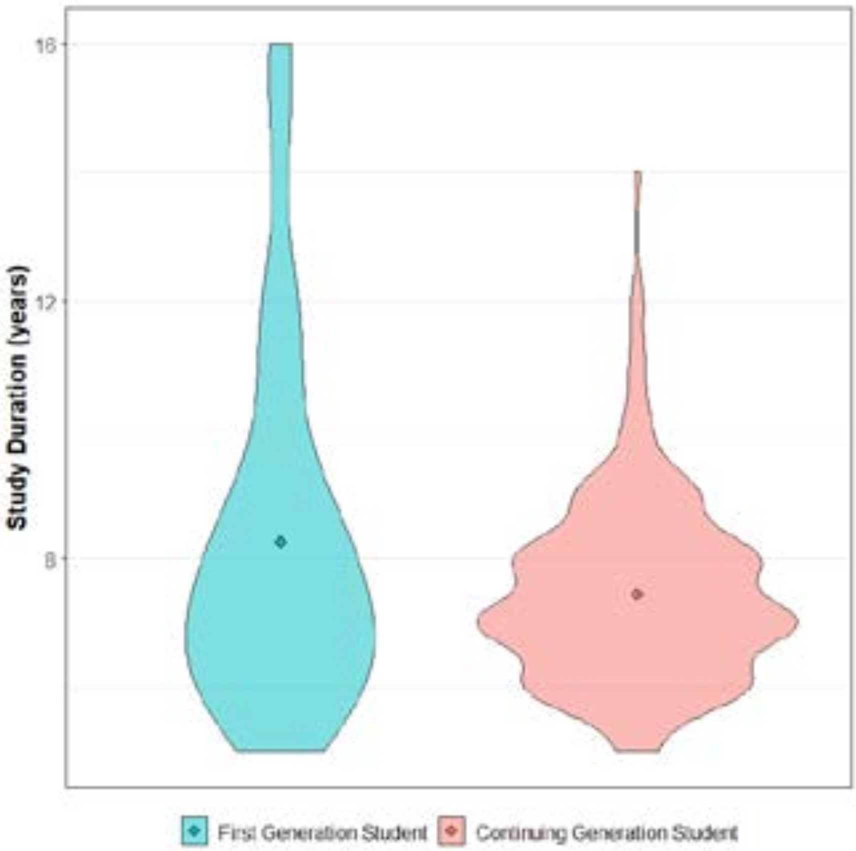

Figure 3. First generation students take longer between Bachelor's and Ph.D. graduations. Mean value indicated by the coloured dot. The width of the plot corresponds to the frequency of data points.

We did not find any difference between the proportions of FGS or CGS who completed a Ph.D.

3.4 Difference in total duration of studies is larger in domestic students

The proportion of FGS who completed a Ph.D. was much higher among the domestic alumni (alumni that indicated Switzerland as their first nationality). Among the 160 domestic alumni for whom we have data related to duration of studies, 23.13% were FGS (as compared to 13.69% of FGS in the total population). Therefore, to control for Alumni origin as a possible confounding variable, we compared the study duration for domestic alumni.

Our results indicated that there is a near-significant difference (T-test, $p = 0.056$; Fig. 4) in time between Bachelor's and Ph.D. graduations for domestic FGS (n =37, mean study duration = 8.19 years) and domestic CGS (n = 123, mean study duration = 7.23 years). Domestic FGS take almost one year (11.5 months) longer than their CGS counterparts.

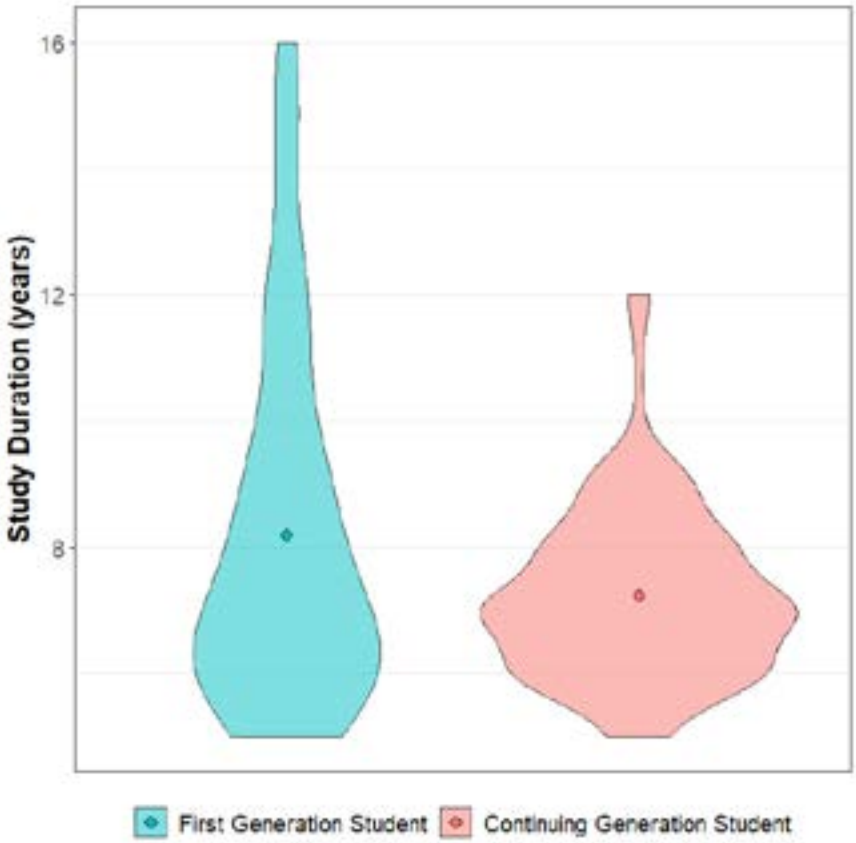

Figure 4. Domestic first-generation students take longer between Bachelor's and Ph.D. graduations. Mean value indicated by the coloured dot. The width of the plot corresponds to the frequency of data points.

4 DISCUSSION & CONCLUSIONS

Based on our data, it appears that there are distinct differences in the choices and duration of post-graduate education between first-generation students and their continuing generation counterparts. At our institution, there is a clear difference in the Master's degree choices with FGS being over-represented in the "Classical Engineering" programmes. These findings are in-line with other studies done in Europe that showed that FGS are under-represented in the more selective higher educational fields (Kasatkina et al. 2020; Isserstedt et al. 2010). One possible explanation for this discrepancy could be that FGS tend to make more 'safe' choices based on the limited information they have access to. The classical engineering fields, and associated job-opportunities better known in the society compared to the new programmes that have emerged with the progression of newer technologies. However, while the classical engineering programmes have been around longer, recent trends show that graduates from the fields that correspond to our emergent engineering programmes earn higher salaries (Michigan Technological University 2024). The lower likelihood of FGS alumni to pursue a diversity of options in their postgraduate education could be influenced by a variety of factors, including access to resources and mentorship. This highlights the importance of providing support and guidance to FGS who may be less familiar with their academic and post-academic options.

The preference for classical engineering degrees is even more stark in the domestic alumni. The domestic FGS are overrepresented in the classical engineering degree programmes and are especially underrepresented in the Formal & Physical Sciences programmes. Other researchers have similarly shown that minoritized students (e.g. low socioeconomic status, FGS) choose engineering degrees over science degrees (Potvin et al. 2009; Godwin et al. 2013; Verdin and Godwin 2015). This could be because of FGSs' interest in engineering as a job rather than the content of an engineering degree (Troiano and Elias 2014) or the perceived job security of engineering degrees over science degrees and a lack of family support to pursue science degrees (Verdin and Godwin 2015). Alternatively, it could be because of the prospects of immediate employment (and earning) after a Master's degree in engineering, as opposed to science degrees requiring additional time investment in education e.g. getting a PhD.

It is not surprising though that FGS are less likely to pursue a Master's in Architecture, a study from Spain showed similar findings (Troiano and Elias 2014). At our institution, the tuition costs for an Architecture degree are the same as any other Master's degree. However, Architecture students have additional out-of-pocket expenses as they are required to purchase the supplies they need to complete their projects and build their models, and since FGS are more likely to come from low socio-economic backgrounds (Bui 2002), and cost of education could be a significant barrier (Troiano and Elias 2014). It should be noted though that Architecture is the programme that is selected the least by both FGS and CGS, and this could be because of the choice of the institution rather than choice of the programme. For example, while there are only two institutions in the country which offer Master's degrees in Mechanical engineering, there are eight institutions that offer Master's degrees in Architecture.

Among the alumni who continued to pursue a Ph.D. after their Master's degree, it is interesting to note that the study duration for FGS was almost a year longer than their CGS counterparts. Similar findings have been reported in a study that showed FGS were likely to take more time to graduate (Ishitani 2006). This could also be attributed to a range of factors, such as the need to balance work and family responsibilities, financial constraints, or lack of access to academic support services (Gardner and Holley 2011). Additionally, FSG experience imposter syndrome (Holden et al. 2024) and a low sense of belonging in academia (McCarthy et al. 2023), which might lead to increases in the time they take to start their Ph.D.

In conclusion, the findings presented in this study underscore the importance of understanding and addressing the unique challenges faced by first generation students in higher education. By examining the study paths and choices of first-generation alumni, we can gain valuable insights into the factors that influence their academic success and develop targeted interventions to support their academic and career goals.

REFERENCES

Billson, J. M., and M. B. Terry. 1982. 'In Search of the Silken Purse: Factors in Attrition among First-Generation Students. Revised'. https://eric.ed.gov/?id=ED214431.

Bui, K. V. T. 2002. ‘First-Generation College Students at a Four-Year University: Background Characteristics, Reasons for Pursuing Higher Education, and First-Year Experiences.’ *College Student Journal* 36 (1): 3–12.

Cataldi, E. F., C. T. Bennett, and X. Chen. 2018. ‘First-Generation Students: College Access, Persistence, and Postbachelor’s Outcomes. Stats in Brief. NCES 2018-421’. *National Center for Education Statistics*. National Center for Education Statistics. https://eric.ed.gov/?id=ED580935.

Chen, X. 2005. ‘First-Generation Students in Postsecondary Education: A Look at Their College Transcripts’. U.S. Department of Education, National Center for Education Statistics. http://hdl.handle.net/10919/84052.

Cho, S., C. Hudley, S. Lee, L. Barry, and M. Kelly. 2008. ‘Roles of Gender, Race, and SES in the College Choice Process among First-Generation and Nonfirst-Generation Students’. *Journal of Diversity in Higher Education* 1 (2): 95–107. https://doi.org/10.1037/1938-8926.1.2.95.

Colzani, P., L. Ojjeh, and I. Lermigeaux-Sarrade. 2022. ‘EPFL Alumni Career Survey January 2022 Executive Summary’. Lausanne: The Swiss Federal Institute of Technology (EPFL). https://epflalumni.ch/medias/editor/oneshot-images/109075687264e347604321a.pdf.

Council for Opportunity in Education [COE]. n.d. ‘TRIO Defines First-Generation College Student’. TRIO Defines First-Generation College Student. Accessed 24 March 2024. https://coenet.org/first-generation-college-student/.

Gardner, S. K., and K. A. Holley. 2011. ‘“Those Invisible Barriers Are Real”: The Progression of First-Generation Students Through Doctoral Education’. *Equity & Excellence in Education* 44 (1): 77–92. https://doi.org/10.1080/10665684.2011.529791.

Gerster, S., T. Maillard, and O. Ballester. 2023. ‘Social Diversity among Students at EPFL’. Lausanne, Switzerland: École Polytechnique Fédérale de Lausanne (EPFL). https://www.epfl.ch/about/facts/social-mix-at-epfl/.

Godwin, A., G. Potvin, and Z. Hazari. 2013. ‘The Development of Critical Engineering Agency, Identity, and the Impact on Engineering Career Choices’. In, In *Proceedings of the 2013 ASEE Annual Conference & Exposition*, 23.1184.1-23.1184.14. https://doi.org/10.18260/1-2--22569.

Holden, C. L., L. E. Wright, A. M. Herring, and P. L. Sims. 2024. ‘Imposter Syndrome Among First- and Continuing-Generation College Students: The Roles of Perfectionism and Stress’. *Journal of College Student Retention: Research, Theory & Practice* 25 (4): 726–40. https://doi.org/10.1177/15210251211019379.

Ishitani, T. T. 2006. ‘Studying Attrition and Degree Completion Behavior among First-Generation College Students in the United States’. *Journal of Higher Education* 77 (5): 861–85. https://doi.org/10.1353/jhe.2006.0042.

Isserstedt, W., E. Middendorff, M. Kandulla, L. Borchert, and M. Leszczensky. 2010. ‘Die Wirtschaftliche Und Soziale Lage Der Studierenden in Der Bundesrepublik Deutschland 2009’.

Kasatkina, O., L. Lima, and N. Nakhili. 2020. 'La réussite académique à l'université dépend-elle des études supérieures de ses parents?' *Vie sociale* 29–30 (1–2): 55–71. https://doi.org/10.3917/vsoc.201.0055.

Kutty, F. M. 2014. 'Mapping Their Road to University: First-Generation Students' Choice and Decision of University'. *International Education Studies* 7 (13): 49–60. https://eric.ed.gov/?id=EJ1071170.

Levine, A., and Associates. 1989. *Shaping Higher Education's Future. Demographic Realities and Opportunities 1990-2000*. Jossey-Bass, Inc.

London, H. B. 1989. 'Breaking Away: A Study of First-Generation College Students and Their Families'. *American Journal of Education* 97 (2): 144–70. https://doi.org/10.1086/443919.

Lucena, J., and J. Schneider. 2008. 'Engineers, Development, and Engineering Education: From National to Sustainable Community Development'. *European Journal of Engineering Education* 33 (3): 247–57. https://doi.org/10.1080/03043790802088368.

McCarthy, K., K. Chavez, K. Gastelum, J. Gomez, J. Salas, Y. Severson, and J. Zabat. 2023. 'Imposter Phenomenon: The Occupational Experiences of First-Generation College Students'. *The Open Journal of Occupational Therapy* 11 (2): 1–18. https://doi.org/10.15453/2168-6408.2011.

Michigan Technological University. 2024. '2024 Engineering Salary Statistics'. Michigan Technological University. 2024. https://www.mtu.edu/engineering/outreach/welcome/salary/.

National Academies of Sciences, Engineering, and Medicine [NASEM]. 2016. *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways*. Washington, D.C.: National Academies Press. https://doi.org/10.17226/21739.

Potvin, G., R. Tai, and P. Sadler. 2009. 'The Difference between Engineering and Science Students: Comparing Backgrounds and High School Experiences'. In *2009 Annual Conference & Exposition*, 14–1202.

R Core Team. 2023. 'R: A Language and Environment for Statistical Computing'. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Reay, D., G. Crozier, and J. Clayton. 2009. '"Strangers in Paradise"?: Working-Class Students in Elite Universities'. *Sociology* 43 (6): 1103–21. https://doi.org/10.1177/0038038509345700.

Reay, D., J. Davies, M. David, and S. J. Ball. 2001. 'Choices of Degree or Degrees of Choice? Class, "Race" and the Higher Education Choice Process'. *Sociology* 35 (4): 855–74. https://doi.org/10.1017/S0038038501008550.

Seymour, E., and A. Hunter, eds. 2019. *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-25304-2.

Soria, K. M., and M. J. Stebleton. 2012. 'First-Generation Students' Academic Engagement and Retention'. *Teaching in Higher Education* 17 (6): 673–85. https://doi.org/10.1080/13562517.2012.666735.

Spiegler, T., and A. Bednarek. 2013. ‘First-Generation Students: What We Ask, What We Know and What It Means: An International Review of the State of Research’. *International Studies in Sociology of Education* 23 (4): 318–37. https://doi.org/10.1080/09620214.2013.815441.

Stage, F. K., and D. Hossler. 1989. ‘Differences in Family Influences on College Attendance Plans for Male and Female Ninth Graders’. *Research in Higher Education* 30 (3): 301–15. https://doi.org/10.1007/BF00992606.

Terenzini, P. T., L. I. Rendon, M. L. Upcraft, S. B. Millar, K. W. Allison, P. L. Gregg, and R. Jalomo. 1994. ‘The Transition to College: Diverse Students, Diverse Stories’. *Research in Higher Education* 35 (1): 57–73. https://doi.org/10.1007/BF02496662.

The United Nations Educational, Scientific and Cultural Organization [UNESCO]. 2021. *Engineering for Sustainable Development*. https://unesdoc.unesco.org/ark:/48223/pf0000375644.locale=en.

Troiano, H., and M. Elias. 2014. ‘University Access and after: Explaining the Social Composition of Degree Programmes and the Contrasting Expectations of Students’. *Higher Education* 67 (5): 637–54. https://doi.org/10.1007/s10734-013-9670-4.

United Nations [UN]. 2015. ‘Transforming Our World: The 2030 Agenda for Sustainable Development’. https://sdgs.un.org/2030agenda.

Verdin, D., and A. Godwin. 2015. ‘First in the Family: A Comparison of First-Generation and Non-First-Generation Engineering College Students’. In, 1–8. IEEE Computer Society. https://doi.org/10.1109/FIE.2015.7344359.

Warburton, E. C., R. Bugarin, and A. Nunez. 2001. ‘Bridging the Gap: Academic Preparation and Postsecondary Success of First-Generation Students. Statistical Analysis Report. Postsecondary Education Descriptive Analysis Reports’. ED Pubs, P. https://eric.ed.gov/?id=ED456168.

Wickham, H., W. Chang, L. Henry, T. L. Pedersen, K. Takahashi, C. Wilke, K. Woo, et al. 2024. ‘Ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics’. https://cran.r-project.org/web/packages/ggplot2/index.html.

Wickham, H., R. François, L. Henry, K. Müller, D. Vaughan, P. Software, and PBC. 2023. ‘Dplyr: A Grammar of Data Manipulation’. https://cran.r-project.org/web/packages/dplyr/index.html.

Wickham, H., D. Vaughan, M. Girlich, K. Ushey, Posit Software, and PBC. 2024. ‘Tidyr: Tidy Messy Data’. https://cran.r-project.org/web/packages/tidyr/index.html.

York-Anderson, D. C., and S. L. Bowman. 1991. ‘Assessing the College Knowledge of First-Generation and Second-Generation College Students’. *Journal of College Student Development* 32 (2): 116–22.

TRANSVERSAL SKILLS PRIORITIES AND CURRICULAR SUPPORT AS EXPERIENCED BY ENGINEERING STUDENTS ON THEIR PATH TO BECOMING RESPONSIBLE ENGINEERS

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Keywords: *transversal skills, engineering education, perceived curriculum*

ABSTRACT

Transversal skills (TS) are fundamental to both work effectively autonomously and with others in society. They are key to educating responsible engineers able to assess and proactively respond to issues and opportunities. As evidenced by recent course syllabi and accreditation requirements, TS are increasingly integrated in engineering curricula. However, little is known about students' perceptions of key pedagogical aspects related to skill development and the TS they prioritise. In light of previous work showing that demographics can influence students' perception of curricular experiences, this study reports on perceptions of 244 students on how TS are integrated into their programmes based on demographic information (discipline, year of study, gender) and participation in curricular activities (internships, mentoring programmes). Our data showed that students perceived low levels of receiving information and assessment, and even lower levels of receiving feedback related to

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TS. Open questions about the skills they most wanted to develop and which they received least support did not reveal major trends in relation to either curricular experiences or demographic characteristics. This lack of major trends is however a positive result, as it points to reasonably equitable experiences for students in the institution. So, while this study supports the importance of increased attention to developing TS, it also raises questions about how to interest and support students to develop robust TS and therefore prepare them to be responsible engineers.

1 INTRODUCTION

Building a society that is socially and environmentally sustainable requires graduating engineers to be proficient in a wide range of skills (National Academy of Engineering [NAE] 2017; United Nations [UN] 2015). The challenges that engineering graduates face are multifaceted, requiring them to work with other engineers and experts from different fields within complex systems. As they work with others and in communities to co-create future ways of being, transversal skills (TS), especially organisational skills (e.g. project planning, risk assessment) and interpersonal TS (e.g. communication, teamwork) are essential (Kolmos and Holgaard 2019; Passow and Passow 2017; Winberg et al. 2020). Current students understand the importance of well-developed TS (de Lima et al. 2024; Direito et al. 2014; Donald et al. 2019), yet studies with alumni find engineering graduates report insufficient development of TS (Kovacs et al. 2023). Employers have also been explicit about the importance of TS in order to be job-ready (Craps et al. 2022; Robles 2012; Succi and Canovi 2020). Recognising this need, multiple accreditation bodies explicitly include the development of TS in their criteria (Accreditation Board for Engineering and Technology [ABET] 2023; Commission des titres d'ingénieur [CTI] 2023; European Network for Accreditation of Engineering Education [ENAEE] 2023). Engineering programmes are responding by increasing the visibility of TS in their curricula to ensure students become the responsible engineers society needs to tackle a diversity of challenges. Do engineering students' perceptions of priorities and curricular opportunities correspond to institutional objectives and priorities?

1.1 Visibility of transversal skills in engineering curricula

Engineering curricula have become more explicit about the importance and opportunities to develop TS (Crawley et al. 2011; Kovacs et al. 2020) and multiple institutions have launched initiatives to further integrate them into the curriculum. However, enhancing engineering students' development of TS may require adjustments in the pedagogical approaches traditionally used to teach disciplinary knowledge and skills. Researchers have shown that students' perceptions of the content and aims of the curriculum can influence their learning (Kuhn and Rundle-Thiele 2009; Wijngaards-de Meij and Merx 2018). With respect to transversal skill development, teachers often assume that merely allowing students to practise the skill will lead to learning gains (Isaac et al. 2023) although it has been demonstrated that learning gains occur only when skills are explicitly addressed, such as through instruction and assessment (Kovacs, Milosevic et al. 2023; Picard et al. 2022). A recent innovation to assist teachers to integrate TS into the curriculum is the 3T PLAY trident from EPFL (de Lima et al. 2024; Isaac et al. 2024) which highlights three pedagogical aspects for learning skills: *Knowing*, *Experiencing*, and *Learning from Experience*. These aspects are informed by learning sciences research on skill development, as well as making the skill development more visible and explicit for both students and teachers.

1.2 Multiple factors influence students' curricular experiences

Students' perceptions of the relative importance of various learning outcomes (including skill development) can be different from educators' perceptions of the same (Myers 2008; Feldman 1988; Lemos 1996). This can lead to a mismatch between the skills that are integrated into the curriculum, and the skills that students actually prioritise. Multiple studies have also documented that factors independent of the learning experience can influence learning outcomes. These include students participation in extracurricular activities (Chan 2016; Guilmette et al. 2019; Shulruf 2010), as well as demographic factors such as gender (Aeby et al. 2019; Eddy and Brownell 2016) and coming from an immigration background (Joyce and Hopkins 2014; Stewart 2007).

1.3 Research questions

Building from the literature that highlights the importance of explicit incorporation of transversal skills in the curriculum, and the potential for differences in students' curricular perceptions and experiences, we ask the following questions:

- Do students perceive the integration of support for transversal skills development in their engineering studies? What pedagogical aspects (information, feedback, and assessment) are most visible to them?
- Do the skills students personally prioritise/need support to develop change across their studies or due to their curricular experiences? Do their demographic characteristics influence the skills they prioritise/need?

2 METHODOLOGY

2.1 Settings & participants

This study was conducted at a mid-sized European engineering institution. Teachers at this institution are required to specify learning objectives targeting transversal skills in their course syllabi (in addition to disciplinary knowledge and skills), and in general most course descriptions list several such learning objectives.

Student assistants (N = 244) enrolled in Bachelor and Masters programmes responded to a paper-based survey about their perceptions of the degree of integration of various transversal skills (TS) in their curricula. The student assistants (henceforth referred to as students) were participating in a pedagogical training workshop when the survey was administered. The affordances of choosing this population were an opportunistic sampling of students across programmes and years of study, and the ability to leverage their knowledge in distinguishing between the three pedagogical aspects targeted.

2.2 Data collection & analysis

Our first research question is addressed by the quantitative part of the survey asked students about their perceptions of receiving information/training, getting feedback, and being assessed on seven different categories of TS (e.g. Communication skills, Organisational skills). Students were instructed to think about their courses in the current semester (rather than the workshop they were attending) when responding to these Likert-style questions with a 6-point response scale spanning “I do not know (0)” to “in (almost) every course (5)”. We placed “I don’t know” at position zero on our scale, as students not even being able to answer this question corresponds to a serious lack of knowledge of TS. The numerical responses to each of the seven skills were aggregated and averaged to get one mean value per student for each of the three main pedagogical aspects.

Our second research question was addressed when students responded to open ended questions which asked them to list two TS that they were personally most interested in developing (218 responses containing 440 skills), and two for which they perceived receiving the least institutional support to develop (n of responses = 217 responses containing 440 skills). These brief responses were coded using qualitative content analysis (Schreier 2014) to identify 27 skills.

Finally, students were asked about their curricular experiences (year of study, internship, etc.) and their demographics (gender, immigration background etc.). Approval for this study was sought and obtained from the institutional ethics review board (HREC 072-2023).

3 RESULTS

3.1 Students perceive low integration of transversal skills in their curricula

Students perceived little training on transversal skills (TS) in their courses (n = 244, mean 1.89) and reported an equally low frequency of having their TS assessed in their courses (n = 244, mean 1.83; Fig. 1). Their perception of the frequency of receiving feedback was the lowest (n = 244, mean 1.57). Phrased another way, only 10% of students reported receiving information about TS in half of their course or more and 5% reported receiving feedback on their skills in half of their courses or more. Students may not have thought to separate these 3 pedagogical aspects previously, however the high response rates imply that students felt able to distinguish between them.

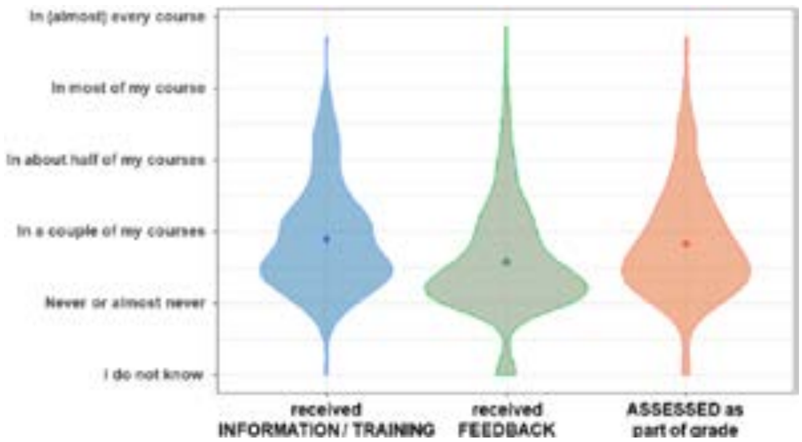

Figure 1. Students’ perception of curricular support for developing their transversal skills is lowest for receiving feedback as compared to receiving information and being assessed (t test 7.650 and -5.908 respectively, both significant <.001 with moderate effect size per Cohen’s d .65-.68)

3.2 Curricular experiences and demographics have little influence on students’ perceptions of transversal skills integration

Using ANOVA, we explored if students’ curricular experiences influenced their experiences of TS in their courses. While neither of the two major curricular elements (year of study & study programme) produced significant relations, several other aspects did show effects. Increased perception of both receiving information and feedback on TS were observed for students who had completed an internship ($F_{1,242}$ = 6.155, p = .014 & $F_{1,242}$ = 4.008, p = .046 respectively) and for students who studied in the UK/EU before EPFL ($F_{2,228}$ = 4.877, p = .008 & $F_{2,228}$ = 3.245, p = .041 respectively). The perception of TS being evaluated was higher for students who had completed individual course projects ($F_{1,241}$ = 7.174, p = .008) and semesters abroad ($F_{1,241}$ = 5.583, p = .019).

We next sought to identify if students' demographic characteristics influenced their experiences of TS in their courses. In our institution, the required courses for each degree leave little space for optional courses. Students' demographic characteristics therefore would not influence what they encounter in class per se but could influence their perception of the integration of transversal skill development in their courses. In our data set few demographic characteristics were relevant, however students with parents/head of household born outside EU/UK/CH perceived less information about TS ($F_{1,227}$ = 4.04, p = .046) and non-gender binary students perceived less evaluation of their TS ($F_{2,224}$ = 3.278, p =.04) than either male or female students.

Although most curricular experiences are outside student control (i.e. course projects), interactions between demographic characteristics and curricular choices could potentially confound our analysis. We identified only three such interactions: (i) Students with recognised neurological conditions were more likely to participate in mentoring programmes (χ^2 = 4.293, p=.038), (ii) Students with long term illness were more frequent in lower years (χ^2 =19.939, p<.001), (iii) Students with a EU/UK parent were more likely to participate in study abroad programmes than those with domestic or non-EU/UK parents (χ^2 = 4.797, p=.029).

3.3 Curricular experiences and demographics have some influence on categories of transversal skills prioritised by students.

Table 1. Count by categories of transversal skills that students deem important and under-addressed in their curricular experiences.

	Communication Skills	Interpersonal skills	Thinking & reasoning skills	Entrepreneurship skills	Intrapersonal skills	Ethics & Sustainability	Organisational skills	Other
Personally develop (PD skills)	122	82	69	62	37	37	23	8
Least supported (LS skills)	123	84	68	60	37	37	23	8

To identify the categories of TS that students deem important and under-addressed in their curricular experiences, we thematically associated their open -ended responses with the 7 categories of TS (Table 1) inspired by those used by our institution (EPFL 2021). Communication skills, such as 'oral communication' and 'written communication', and Interpersonal skills, such as 'networking' and 'teamwork', were cited most often as both the skill sets students wanted to develop and those for which they received the least support. Indeed, there was a tight association between the skills that a student most wanted to develop and those they felt were least supported for all categories. Thinking and reasoning skills, such as ‘critical thinking’ and ‘systems thinking’, and Entrepreneurship skills, such as ‘creativity’ and ‘entrepreneurship’, represent the other most common skills. To explore how students' curricular experiences and demographics influenced their responses, we considered each of the 27 skills individually.

3.4 Curricular experiences and demographics influence specific transversal skills prioritised by students.

We employed likelihood ratio (LR) statistical tests to explore how students' curricular experiences influenced their perception of specific TS. The LR is the likelihood of an unknown experience producing a given outcome compared to a specific experience producing the same outcome. Students’ responses in terms of the skills that they were personally most interested in developing (PD) and those they perceived to have the least support in the curriculum (LS) were highly aligned (Table 2). The strongest effect size is seen between interest in developing ‘systems thinking’ and year of study with the interest shown by second- and third-year Bachelor students dropping in Masters. Doing team course projects and internship experiences both increase the perception that ‘communication skills’ are personally valuable but unsupported. Internships also increase students’ desire to develop ‘intrapersonal skills’. Desire to develop and need for ‘interpersonal skills’ peaks in students enrolled in the third year of Bachelor degree before dropping in Masters students. A desire to develop ethics reported by 18 students in some engineering, physical sciences, and computing programmes; students from these programmes were also more likely to see ‘intrapersonal’ as unsupported. Mentorship programme students report slightly less personal need to develop ‘intrapersonal’ and ‘sustainability’ skills and indeed no students participating in these programmes stated these skills are unsupported.

Table 2. Heat map showing effect size (Cramer’s v) for significant likelihood ratios between curricular experiences with “personally most interested to develop” (PD) and “least support to develop” (LS) skills. Values where n < 10 and/or likelihood ratio was not significant at p <.05 are omitted.

	n	Year of study		Discipline		Team project (course)		Internship		Mentorship	
		PD	LS	PD	LS	PD	LS	PD	LS	PD	LS
Communication	**98**					0.19	0.13	0.17	0.01		
Syst. Thinking	**50**	0.23	0.23								
Interpersonal	**48**	0.19	0.21								
Intrapersonal	**27**				0.22			0.16	0.15	0.12	0.12
Sustainability	**19**									0.10	0.10
Ethics	**18**			0.24							
Project Mgt.	**10**									0.19	

Considering both the frequency of occurrence in students’ responses and effect sizes (measured by Cramer’s V when likelihood ratio *p* value ≤ 0.05), the impact of curricular experiences on students’ interest in specific skills appears fairly random. Further, the relatively low number (combined 17 associations are statistically significant with moderate effect size out of 168 possible) suggests that curricular experiences do not have a major impact on what TS students want to develop nor those they find under supported.

Students' demographic characteristics had some influence on the skills they identified as personally important to develop and those missing in their programs (Table 3). Students who studied in EU/UK before coming to our institution were more likely than domestic or non-EU/UK students to flag 'sustainability' skills and express personal interest in developing such skills. Male students were more likely than other genders to both express an interest in developing and to report lack of support for 'communication skills'. As above, the relatively low number (combined 10 associations of 216 possible) suggests that students' demographic experiences did not have a major impact on the skills students want to develop nor on those they think need more support.

Table 3. Heat map showing effect size (Cramer's v) for significant likelihood ratios between demographic characteristics with "personally most interested to develop" (PD) and "least support to develop" (LS) skills. Values where n < 10 and/or likelihood ratio was not significant at p <.05 are omitted.

	n	non- EU/UK parent		EU/UK parent		Domestic parent		Prior education in EU/UK		Gender	
		PD	LS	PD	LS	PD	LS	PD	LS	PD	LS
Communication	98									0.19	0.19
Syst. thinking	50					0.13					
Oral Comm.	20			0.14	0.14						
Sustainability	19			0.14	0.14			0.17	0.17		
Project mgt.	10	0.13									

4 Discussions and Conclusions

The importance of transversal skill (TS) development for engineering students is well recognised and TS are increasingly integrated in engineering curricula (Crawley et al. 2011; Kovacs, Milosevic et al. 2023; ABET 2023; CTI 2023; ENAEE 2023). In this study, we examined the extent to which students perceive three key pedagogical aspects for skill development (receiving information about the TS, receiving feedback on their TS proficiency, and assessment of TS contributing to their grades). Further, we investigated the skills students most wanted to personally develop and those they perceived as being the least supported at the institution.

Our analysis of the Likert survey data indicates that students perceive little pedagogical integration of TS in their curriculum. Over ⅔ of students report that, with respect to TS, at most "a couple" of their courses provide them with information (65%), feedback (78%) or evaluate them (69%). This is coherent with previous findings that instructors expect students to spontaneously develop TS exclusively through experience (Isaac et al. 2023). That students perceive feedback as the least developed pedagogical aspect related to developing their transversal skills is coherent with previous work that has identified that students are dissatisfied with the feedback they receive at university (Beaumont et al. 2011; Higgins et al. 2001;

Poulos and Mahony 2008). It would therefore be relevant to explore if students' perception reflects a specific pedagogical lack or a general trend. Curricular experiences of internships, individual course projects and semesters abroad all had small but constructive effects on students' perception of TS in their courses. However, specific curricular elements had little effect on students' perception of TS in their courses. This indicates that efforts to increase teaching of TS are insufficient or are insufficiently visible to students. Future work could consider how the pedagogical conditions that led to increased perception of more feedback (i.e. internships) or assessment (i.e. individual course projects) could be leveraged in other contexts to provide support for students to develop their transversal skills.

As co-curricular and extra-curricular experiences enhance students' academic experiences (Buckley and Lee 2021) and future career prospects (Stuart et al. 2011) but are less available to non-traditional students (King et al. 2021; Stuart et al. 2011), it is relevant to investigate potential inequitable experiences of transversal skill development. It is therefore a positive finding that students' demographic characteristics did not exert a significant impact on their perception of TS in the curriculum. In our institutional context, it is particularly relevant to note that first generation students did not report different experiences.

The TS that students deem important and under-addressed in their curricular experiences align well with the 7 categories inspired by the TS working document. Considering that a recent study mapping TS in syllabi across the institution found that 'Communication skills' had the highest representation in the course documents (Kovacs et al. 2020), it is interesting to note that this was the skill set students were most interested in developing. The current study does not provide information as to whether these skills stand out because students need them now, see them as most relevant to their future careers, or associate them with professional engineering work. It is also possible that students have not (yet) encountered support for communication skills as these skills were addressed more often in non-mandatory and Master's level courses.

Statistical tests between the TS students identified as personally wanting to develop, TS they identified as insufficiently supported, and their curricular and demographic influences identified few interesting associations. The absence of clear patterns between the skills listed by students and their curriculum and demographic characteristics suggests that students' individual, specific experiences inform their perceptions and priorities. While clear trends (e.g. first years are interested in communication skills, architecture students need more support for teamwork), would have provided useful guidance for teachers, our data raises questions about how to effectively support students to develop TS across the curriculum. Students in our study value TS and have self-directed learning goals. Both our qualitative and quantitative data suggests that coherent "across the curriculum" development may be less effective than individualised approaches that offer more flexibility and choice to students for developing their TS.

It is relevant to note that the observations of this small study are limited in several ways. First, the convenience sample of student assistants is likely unrepresentative of the student body (e.g. higher than average grades). It is also difficult to make predictions about the relationships between the variables. For example, we found students with recognised neurological conditions were more likely to participate in mentoring/excellence programmes. This could be because students with such conditions are more likely to participate in such programmes, or because students in such programmes were encouraged to seek formal diagnosis. We also saw students with long term illness were more frequent in lower years. This could either be because such illnesses make it difficult for students to continue to be student teaching assistants, or that they leave the institution entirely. Another limitation is that students' responses to the open questions may have been primed by the Likert questions. Further, by specifying “in their courses” we excluded excellent extra-curricular opportunities that develop TS such as student associations and campus employment.

Overall, our data suggests that students' experience of transversal skills in their curriculum does not meet institutional objectives regarding educating responsible engineers. This could mean that such skills are not being taught, however students’ perspective captured by the methodological approach of this study is likely not an entirely accurate reflection. We can, however, conclude that students are not currently perceiving adequate and relevant opportunities to develop their transversal skills. Thus, we need to consider students’ evolving needs and priorities when integrating transversal skills into the curricula. Additionally, it is important to improve the coherence and visibility of efforts to teach transversal skills by attending to both implicit and explicit aspects of the curriculum. For instance, supporting teachers to incorporate opportunities for skill development in their courses (Kovacs et al. 2023; Picard et al. 2022; Isaac et al. 2023), particularly those that provide explicit information and relevant feedback on the skills themselves (Isaac and de Lima 2024a; 2024b) in (3T PLAY 2024).

REFERENCES

3T PLAY. 2024. *TEACHING TRANSVERSAL SKILLS FOR ENGINEERING STUDENTS - a Handbook of Practical Activities with Tangibles*. Lausanne: EPFL. https://doi.org/10.5281/zenodo.10392281.

Accreditation Board for Engineering and Technology [ABET]. 2023. ‘Criteria for Accrediting Engineering Programs, 2023 – 2024 | ABET’. 2023. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/.

Aeby, P., R. Fong, M. Vukmirovic, S. Isaac, and R. Tormey. 2019. ‘The Impact of Gender on Engineering Students’ Group Work Experiences’. *International Journal of Engineering Education* 35 (3): 756–65. https://www.ijee.ie/1atestissues/Vol35-3/06_ijee3754.pdf .

Beaumont, C., M. O’Doherty, and L. Shannon. 2011. ‘Reconceptualising Assessment Feedback: A Key to Improving Student Learning?’ *Studies in Higher Education* 36 (6): 671–87. https://doi.org/10.1080/03075071003731135.

Buckley, P., and P. Lee. 2021. ‘The Impact of Extra-Curricular Activity on the Student Experience’. *Active Learning in Higher Education* 22 (1): 37–48. https://doi.org/10.1177/1469787418808988.

Chan, Y. 2016. ‘Investigating the Relationship among Extracurricular Activities, Learning Approach and Academic Outcomes: A Case Study’. *Active Learning in Higher Education* 17 (3): 223–33. https://doi.org/10.1177/1469787416654795.

Commission des titres d'ingénieur [CTI]. 2023. 'The CTI's Major Criteria and Procedures – CTI – Commission Des Titres d'Ingénieur'. 2023. https://www.cti-commission.fr/en/fonds-documentaire.

Craps, S., M. Pinxten, H. Knipprath, and G. Langie. 2022. 'Different Roles, Different Demands. A Competency-Based Professional Roles Model for Early Career Engineers, Validated in Industry and Higher Education'. *European Journal of Engineering Education* 47 (1): 144–63. https://doi.org/10.1080/03043797.2021.1889468.

Crawley, E. F., J. Malmqvist, W. A. Lucas, and D. R. Brodeur. 2011. 'The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education'. In *Proceedings of the 7th International CDIO Conference*. Lyngby, Denmark.

de Lima, J., S. Isaac, and J. Dehler Zufferey. 2024. 'Distinctly Human - Students' Perception of Transversal Skills in Engineering Curriculum'. In *Proceedings of the 20th International CDIO Conference*.

Direito, I., A. Pereira, and A. M. De Oliveira Duarte. 2014. 'The Development of Skills in the ICT Sector: Analysis of Engineering Students' Perceptions about Transversal Skills'. *International Journal of Engineering Education* 30 (July): 1556–61.

Donald, W. E., Y. Baruch, and M. Ashleigh. 2019. 'The Undergraduate Self-Perception of Employability: Human Capital, Careers Advice, and Career Ownership'. *Studies in Higher Education* 44 (4): 599–614. https://doi.org/10.1080/03075079.2017.1387107.

Eddy, S. L., and S. E. Brownell. 2016. 'Beneath the Numbers: A Review of Gender Disparities in Undergraduate Education across Science, Technology, Engineering, and Math Disciplines'. *Physical Review Physics Education Research* 12 (2): 020106. https://doi.org/10.1103/PhysRevPhysEducRes.12.020106.

EPFL. 2021. 'Internal Report from Working Group on Transversal Skills'. Internal Report. Lausanne, Switzerland: EPFL.

European Network for Accreditation of Engineering Education [ENAEE]. 2023. 'EUR-ACE® Framework Standards and Guidelines'. *ENAEE* (blog). 2023. https://www.enaee.eu/eur-ace-system/standards-and-guidelines/.

Feldman, K. A. 1988. 'Effective College Teaching from the Students' and Faculty's View: Matched or Mismatched Priorities?' *Research in Higher Education* 28 (4): 291–329. https://doi.org/10.1007/BF01006402.

Guilmette, M., K. Mulvihill, R. Villemaire-Krajden, and E. T. Barker. 2019. 'Past and Present Participation in Extracurricular Activities Is Associated with Adaptive Self-Regulation of Goals, Academic Success, and Emotional Wellbeing among University Students'. *Learning and Individual Differences* 73 (July): 8–15. https://doi.org/10.1016/j.lindif.2019.04.006.

Higgins, R., P. Hartley, and A. Skelton. 2001. 'Getting the Message Across: The Problem of Communicating Assessment Feedback'. *Teaching in Higher Education* 6 (2): 269–74. https://doi.org/10.1080/13562510120045230.

Isaac, S., and J. de Lima. 2024a. 'How to Support Students Giving Each Other Constructive Feedback, Especially When It Is Difficult to Hear'. In *Teaching*

Transversal Skills for Engineering Students - A Handbook of Practical Activities with Tangibles. EPFL. https://doi.org/10.5281/zenodo.10392344.

Isaac, S., and J. de Lima. 2024b. 'How to Support Students to Develop Skills That Promote Sustainability'. In *Teaching Transversal Skills for Engineering Students - A Handbook of Practical Activities with Tangibles*. EPFL. https://doi.org/10.5281/zenodo.10731771.

Isaac, S., J. de Lima, Y. Jalali, V. Rossi, R. Tormey, and J. Dehler Zufferey. 2024. 'Exploring Engineering Students' Perception of Sustainability and Ethics in Their Curriculum across Disciplines'. In *Proceedings of 2024 IEEE Global Engineering Education Conference (EDUCON)*.

Isaac, S., N. Petringa, Y. Jalali, R. Tormey, and J. Dehler Zufferey. 2023. 'Are Engineering Teachers Ready to Leverage the Power of Play to Teach Transversal Skills?' In *Proceedings of the SEFI 2023 Conference*. https://doi.org/10.21427/QP3D-B914.

Joyce, T., and C. Hopkins. 2014. '"Part of the Community?" First Year International Students and Their Engineering Teams'. *Engineering Education* 9 (1): 18–32. https://doi.org/10.11120/ened.2014.00019.

King, A. E., F. A. E. McQuarrie, and S. M. Brigham. 2021. 'Exploring the Relationship Between Student Success and Participation in Extracurricular Activities'. *SCHOLE: A Journal of Leisure Studies and Recreation Education* 36 (1–2): 42–58. https://doi.org/10.1080/1937156X.2020.1760751.

Kolmos, A., and J. E. Holgaard. 2019. 'Employability in Engineering Education: Are Engineering Students Ready for Work?' In *The Engineering-Business Nexus: Symbiosis, Tension and Co-Evolution*, edited by S. H. Christensen, B. Delahousse, C. Didier, M. Meganck, and M. Murphy, 499–520. Philosophy of Engineering and Technology. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-99636-3_22.

Kovacs, H., I. Capdevila, I. J. L. Lermigeaux-Sarrade, and P. Jermann. 2023. 'From University to Work: Alumni Viewpoints'. In *Proceedings of the CDIO 2023 Conference*.

Kovacs, H., J. Delisle, M. Mekhaiel, J. Dehler Zufferey, R. Tormey, and P. Vuilliomenet. 2020. 'Teaching Transversal Skills in the Engineering Curriculum: The Need to Raise the Temperature'. *SEFI 48th Annual Conference: Engaging Engineering Education. Proceedings*, SEFI Annual Conference 48.

Kovacs, H., T. Milosevic, and A. Niculescu. 2023. 'Planned, Taught, Learnt: Analysis of Transversal Skills Through Curriculum Using Portfolio'. In *SEFI 2023 Proceedings*. https://doi.org/10.21427/R0JP-8277.

Kuhn, K., and S. Rundle-Thiele. 2009. 'Curriculum Alignment: Student Perception of Learning Achievement Measures'. *International Journal of Teaching and Learning in Higher Education* 21 (3): 351–61.

Lemos, M. S. 1996. 'Students' and Teachers' Goals in the Classroom'. *Learning and Instruction* 6 (2): 151–71. https://doi.org/10.1016/0959-4752(95)00031-3.

Myers, C. B. 2008. 'Divergence in Learning Goal Priorities Between College Students and Their Faculty: Implications for Teaching and Learning'. *College Teaching* 56 (1): 53–58. https://doi.org/10.3200/CTCH.56.1.53-58.

National Academy of Engineering [NAE]. 2017. 'Grand Challenges for Engineering'. Washington, DC. https://nae.edu/187212/NAE-Grand-Challenges-for-Engineering.

Passow, H. J., and C. H. Passow. 2017. 'What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review'. *Journal of Engineering Education* 106 (3): 475–526. https://doi.org/10.1002/jee.20171.

Picard, C., C. Hardebolle, R. Tormey, and J. Schiffmann. 2022. 'Which Professional Skills Do Students Learn in Engineering Team-Based Projects?' *European Journal of Engineering Education* 47 (2): 314–32. https://doi.org/10.1080/03043797.2021.1920890.

Poulos, A., and M. J. Mahony. 2008. 'Effectiveness of Feedback: The Students' Perspective'. *Assessment & Evaluation in Higher Education* 33 (2): 143–54. https://doi.org/10.1080/02602930601127869.

Robles, M. M. 2012. 'Executive Perceptions of the Top 10 Soft Skills Needed in Today's Workplace'. *Business Communication Quarterly* 75 (4): 453–65. https://doi.org/10.1177/1080569912460400.

Schreier, M. 2014. 'Qualitative Content Analysis'. In *The SAGE Handbook of Qualitative Data Analysis*, edited by Uwe Flick, 170–83. SAGE Publications, Inc. http://dx.doi.org/10.4135/9781446282243.n12.

Shulruf, B. 2010. 'Do Extra-Curricular Activities in Schools Improve Educational Outcomes? A Critical Review and Meta-Analysis of the Literature'. *International Review of Education* 56 (5): 591–612. https://doi.org/10.1007/s11159-010-9180-x.

Stewart, R. A. 2007. 'Investigating the Link between Self Directed Learning Readiness and Project-Based Learning Outcomes: The Case of International Masters Students in an Engineering Management Course'. *European Journal of Engineering Education* 32 (4): 453–65. https://doi.org/10.1080/03043790701337197.

Stuart, M., C. Lido, J. Morgan, L. Solomon, and S. May. 2011. 'The Impact of Engagement with Extracurricular Activities on the Student Experience and Graduate Outcomes for Widening Participation Populations'. *Active Learning in Higher Education* 12 (3): 203–15. https://doi.org/10.1177/1469787411415081.

Succi, C., and M. Canovi. 2020. 'Soft Skills to Enhance Graduate Employability: Comparing Students and Employers' Perceptions'. *Studies in Higher Education* 45 (9): 1834–47. https://doi.org/10.1080/03075079.2019.1585420.

United Nations [UN]. 2015. 'Transforming Our World: The 2030 Agenda for Sustainable Development'. https://sdgs.un.org/2030agenda.

Wijngaards-de Meij, L., and S. Merx. 2018. 'Improving Curriculum Alignment and Achieving Learning Goals by Making the Curriculum Visible'. *International Journal for Academic Development* 23 (3): 219–31. https://doi.org/10.1080/1360144X.2018.1462187.

Winberg, C., M. Bramhall, D. Greenfield, P. Johnson, P. Rowlett, O. Lewis, J. Waldock, and K. Wolff. 2020. 'Developing Employability in Engineering Education: A

Systematic Review of the Literature'. *European Journal of Engineering Education* 45 (2): 165–80. https://doi.org/10.1080/03043797.2018.1534086.

Learning Analytics with Matlab Grader in Undergraduate Engineering Courses

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Conference Key Areas: *Digital tools and AI in engineering education,* Open and online education for engineers
Keywords: *Learning Analytics, Matlab Grader, Individual support for first-year students, IT tools in teaching*

ABSTRACT

The presented paper deals with the development and evaluation of a teaching-learning innovation for better student support in the introductory phase of engineering studies. Previous results of a longitudinal study on the study entry phase have shown that there is a strong heterogeneity in terms of prior knowledge of maths and electrical engineering and that there are general deficits in computer skills.

To counteract this, a digitally supported introductory study phase was designed with the help of learning analytics through data acquisition via matlab grader, which enables an effective transition from school to university and improves study skills at the start of the degree programme. In the long term, the implementation of learning analytics should also serve to recognise students at risk at an early stage and enable interventions. This paper aims to contribute to the current discussion on technology in engineering studies, offering both theoretical and practical perspectives. Topics such as the design of an improved introduction phase, agile adaptations to future developments and support for students in the use of technology is addressed, and approaches to evaluation methods for quality assurance and validation will be presented. The evaluation results of the teaching-learning innovation with Matlab Grader show that there is a correlation between the exam grade and the use of

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Matlab Grader. It was also found that the number of tasks completed has a significant correlation on the grade achieved. The feedback from students on the introduction of the new concept indicates that the use of Matlab Grader helps many students to solve exercises and also increases motivation.

1 Introduction

With the emergence of new technologies and the constant development of digital tools and platforms, the way we communicate, work, learn and live has changed fundamentally. Under these changing conditions, graduates should have the ability to identify and describe problems and develop suitable solutions in order to actively participate in future-oriented change processes in a digitalised society (Auer and Kim 2018, Harteis 2018, Uskov and Howlett and Jain 2018). Increasing digitalisation has led to the establishment of e-learning platforms, online courses and digital learning resources that enable learners to learn in a more flexible and individualised way. The use of such tools can help to solve key problems faced by universities. One major challenge for universities, for example, is the early identification of potential dropouts in technical degree programmes, as dropout rates of over 30 % are sometimes reported (Heublein et al. 2017). At the same time, it is increasingly important to facilitate the transition from school to university and to provide students with personalised feedback (Heublein and Hutzsch and Schmelzer 2022). The use of digital tools and learning analytics provides teachers with valuable data on user behaviour. On the one hand, this enables the introduction of an early warning system to identify potential dropouts (Brozina et al. 2019) and, on the other hand, can increase student satisfaction through personalised feedback and have a positive impact on test results (Pardo et al. 2019). The use of evidence-based teaching is particularly important with regard to upcoming transformation processes (Borrego and Hendernson 2014). Prior to this publication, a concept for the evidence-based design of an introductory study phase was already presented, which supports the learning success of students in a technology-based and individualised way (Block and Dethmann 2024). The aim of this article is to implement learning analytics to support student learning success in the first semesters and to present the benefits achieved. To this end, the implementation was analysed and evaluated using the data collected by the Matlab Grader platform and a regular course questionnaire that was supplemented by feedback questions regarding Matlab Grader. The findings are used to derive targeted measures that will positively influence the quality of future teaching. The paper is structured as follows: In Part 2, the research method and the research objectives are defined. Part 3 deals with the implementation of learning analytics using Matlab Grader. In Part 4, the results are presented and analysed. Finally, the paper is summarised and measures for the continuation of the study in teaching practice and EER are presented.

2 Methodology

The aim of this study is the design and implementation of learning analytics using Matlab Grader as well as evidence-based data collection. On the one hand, insights

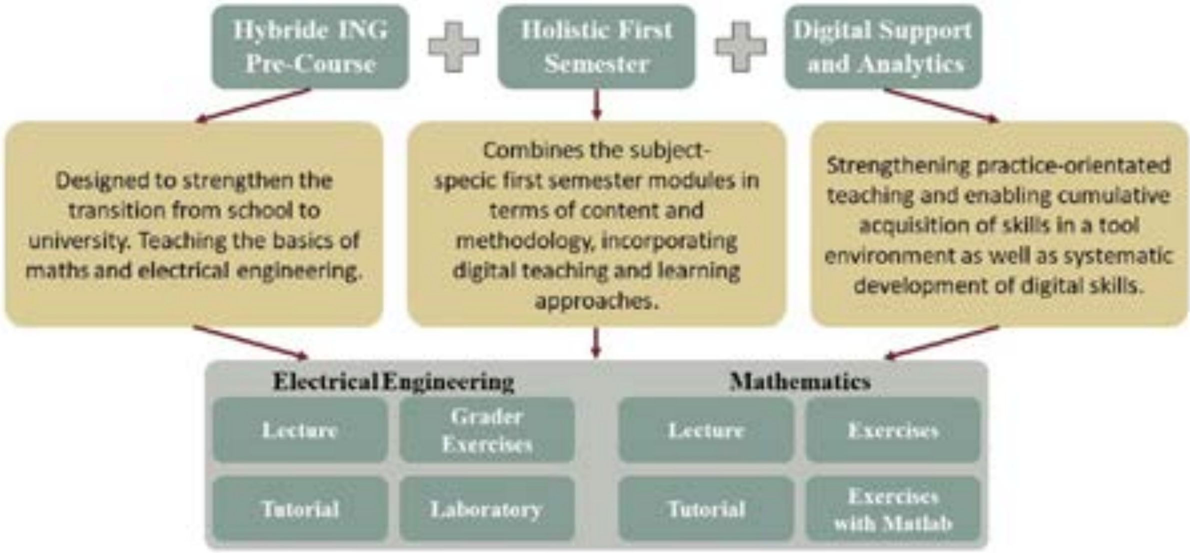

Fig. 1. Structure of the introductory phase

are to be gained for lesson design and, on the other hand, empirical information about the students' learning approaches and success predictors is to be collected in order to enable more targeted and effective support. Design-Based Research (DBR) was therefore selected as the method for the design and investigation within the same research process (McKenney and Reeves 2024). During the *analysis* part, a longitudinal study of the introductory phase of the programme revealed that the students exhibited strong heterogeneity in terms of prior knowledge in the subjects of mathematics and electrical engineering (Block et al. 2023, Block and Dethmann 2024). There were significant deficits in terms of practical knowledge and computer skills. During the *design* phase, an integrative introductory period was created, with its structure illustrated in Fig. 1. The concept for the start of the programme provides for a hybrid preliminary course that facilitates the transition from school to university by teaching the basics of mathematics and electrical engineering and providing introductions to current topics such as energy, electromobility and sustainability. In the holistic subject-related first semester, the subject-specific maths and electrical engineering modules are combined in terms of content and methodology and digital teaching and learning approaches are integrated. By linking electrical engineering and mathematics, synergies can be created that make mathematical training more practice-orientated. The modules consist of lectures, exercises, tutorials and practical laboratory exercises in small groups in which students carry out experiments. The use of Matlab Grader[2] is embedded in the "Digital Support and Analytics" concept. Matlab Grader provides an online-based, interactive environment for creating tasks with automatic evaluation, allowing all students to learn at their own pace and at their individual level. A detailed explanation with an example is given in the following chapter. The *evaluation* and reflection of the implementation of learning analytics through Matlab Grader took place at the end of the winter semester 23/24 and provided new insights that will be incorporated into the redesign of the concept.

[2] Further information on Matlab Grader can be found at https://de.mathworks.com/products/matlab-grader.html.

3 DESIGN AND IMPLEMENTATION OF LEARNING ANALYTICS WITH MATLAB GRADER

The participants in the study were engineering students at Leuphana University Lüneburg in Germany. The Electrical Engineering 1 course is mandatory for all students of the major. 55 people registered for the course at the beginning of the semester, 42 of whom took part in the exam in February 2024. The course took place during the winter semester from October 2023 to January 2024. The course includes lectures, laboratory experiments and tutorials. It is structured in such a way that theoretical content is first covered in the lectures and later deepened through practical experiments in the laboratory. In addition to the lectures, voluntary tutorials are offered, which are led by students from higher semesters. So far, students have been provided with the slides and exercises online in PDF format after each lecture, which they should work on independently at home. Students could contact the tutors during the tutorial if they had any questions or needed help with solving the exercises. For this study, the provision of exercises was supplemented by the implementation of MATLAB Grader. The on-site tutorials continued to take place in parallel. MATLAB Grader is a web-based online platform that is characterised by performance assessments with automatic feedback. As a result, students receive feedback on the accuracy of their results immediately after solving a task. In the event of incorrect answers, students can also be given a hint to help them determine the correct solution. To ensure that all students can use the platform, an introductory course for MATLAB Grader was offered in the first week. Students have access to Matlab Grader throughout the whole semester and can track the status of the tasks (processed, unprocessed, correct, incorrect). Fig. 2 shows an example of a task used in the course. The procedure for creating each task is identical. First, the task must be defined and it must be clear which variables the solutions should contain in order to enable automated checking. Depending on the type of task, images can also be added to make it easier to understand. In the script box, students can assign their solution to the target value. It is also possible to define auxiliary variables, for example to record intermediate results. Students can then test compile the code

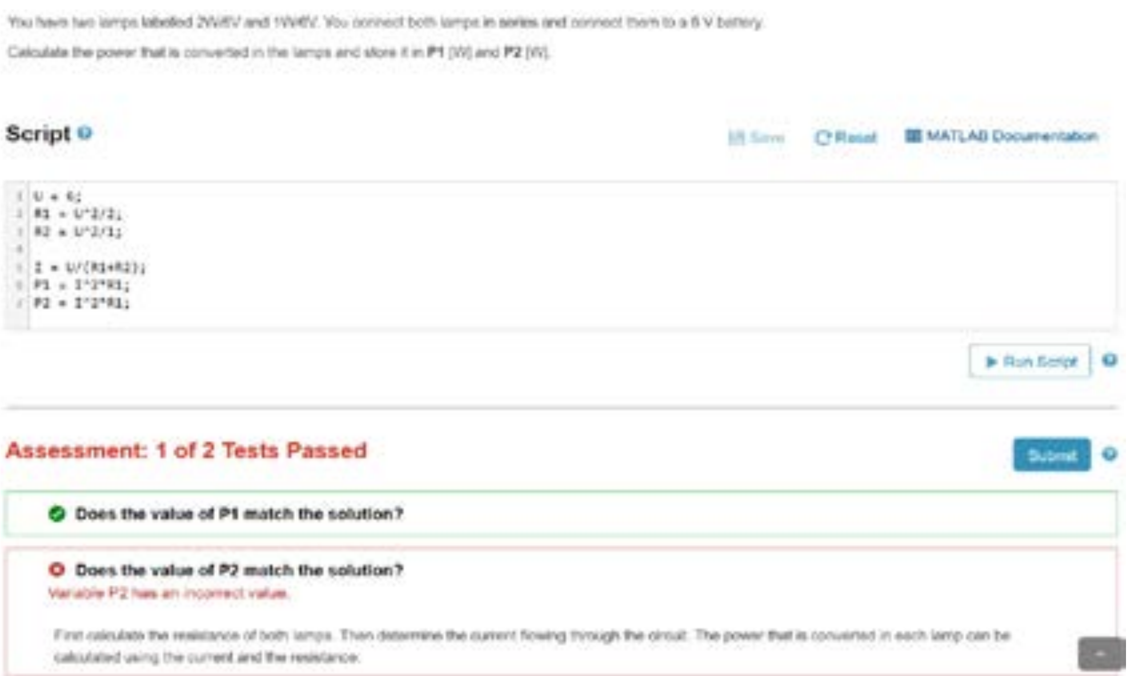

Fig. 2. Example of a Matlab Grader Task

before submitting it in order to recognise errors. After submission, students receive immediate feedback. In the example task, only one of the two variables queried has the correct target value. A message box appears for the incorrect variable, giving tips on how to solve it. The number of possible attempts per task can be set flexibly by the teacher. For this study, the students had two attempts to solve the tasks correctly. The thematically relevant tasks were provided after the lectures in order to avoid an overload of information. It was possible to answer the questions throughout the semester.

4 EVALUATION OF LEARNING ANALYTICS: EVIDENCE-BASED FINDINGS ON STUDENT LEARNING STRATEGIES AND PREDICTORS OF SUCCESS

In order to obtain evidence-based findings on students' learning strategies and the success of learning support for students, two approaches were pursued. On the one hand, data was available from MATLAB Grader (including usage statistics) and the exam results. In addition, data was available from the evaluation of a questionnaire that collected student feedback on the implementation of Matlab Grader at the end of the semester. For the statistical analysis, a value of $\alpha = 0.05$ was assumed for all tests in which a significance level is required. This was adjusted according to the number of groups using the Bonferroni correction. Effect sizes and correlations were categorised according to Cohen (Cohen 1969). The current status of this research work shows limitations with regard to the general validity of the effectiveness of the concept. In subsequent rounds, the population size will increase and possibly lead to an expansion of the validity.

4.1 Correlation between exam grade and utilisation of Matlab Grader

A correlation test according to Spearman was used to investigate whether there was a correlation between the exam grade achieved and the use of Matlab Grader. In addition to the correlation coefficients between the exam grades and the submitted and correctly submitted Matlab Grader tasks, Table 1 also contains the variable of how actively a student participated in the tutorials. The correlation between the exam grade and the submitted tasks (-0.689) and the exam grade and the correctly submitted tasks (-0.710) can be interpreted as a strong correlation according to Cohen. The correlation between the exam grade and participation in the tutorial (-0.417) can be assessed as a medium correlation. The results of the correlation test indicates that a high participation rate in Matlab Grader leads to a better exam grade. The difference between pure participation and answering the questions correctly is very small. Active participation in the tutorials has a smaller influence compared to the use of Matlab Grader.

Table 1. Correlation matrix of exam grade, submitted grader tasks, correct grader tasks and tutorial participation

Variables	Exam Grade 23/24	Submitted Grader Tasks	Correct Grader Tasks	Attendance at tutorial
Exam Grade 23/24	**1.000**	**-0.689**	**-0.710**	**-0.417**
Submitted Grader Tasks	**-0.689**	**1.000**	**0.973**	**0.545**
Correct Grader Tasks	**-0.710**	**0.973**	**1.000**	**0.608**

Attendance at tutorial	-0.417	0.545	0.608	1.000

4.2 Influence of the number of completed Matlab Grader tasks on the exam grade

A total of 168 tasks were available in Matlab Grader over the entire period. The students were divided into five groups to assess whether the number of tasks completed had an influence on the exam grade achieved. The first group did not use Matlab Grader. Groups two to five were each separated in an ascending interval of 25 %. The result of a Kruskal-Wallis test shows that the samples do not come from the same population (p-value=0.004). The output of a Dunn-Bonferroni test is shown in Table 2. In this context, it can be seen that the group of students who did not complete any tasks and those who completed 25 % of the tasks differed significantly from the group who completed more than 75 % of the tasks. The Cohen effect size is 3.19 and 1.80 respectively and can therefore be interpreted as a strong effect. From this it can be deduced that there is a measurable difference in the exam results between students who completed more than 75 % of the tasks and those who completed ≤ 25 %.

Table 2. Dunn-Bonferroni test between five different groups in relation to the number of Matlab grader tasks completed

Groups	$0\,\%$	$0\,\% < x \leq 25\,\%$	$25\,\% < x \leq 50\,\%$	$50\,\% < x \leq 75\,\%$	$75\,\% < x \leq 100\,\%$
$0\,\%$	1	0.414	0.103	0.180	**0.001**
$0\,\% < x \leq 25\,\%$	0.414	1	0.266	0.456	**0.001**
$25\,\% < x \leq 50\,\%$	0.103	0.266	1	0.743	0.048
$50\,\% < x \leq 75\,\%$	0.180	0.456	0.743	1	0.021
$75\,\% < x \leq 100\,\%$	**0.001**	**0.001**	0.048	0.021	1

Bonferroni-corrected significance level: 0.005

4.3 Student´s perception of Matlab Grader

At the end of the semester, the students were asked for feedback on the implementation of Matlab Grader by means of a regular course questionnaire that was supplemented by feedback questions regarding Matlab Grader. To ensure

transparency, students were informed at the beginning of the semester that participation in Matlab Grader is voluntary and that the data will be used for research purposes. The results of the survey are shown in Fig. 3. The evaluation of the statement "I had no difficulties using MATLAB Grader platform" shows that 36 % of students at least disagree. This suggests that the introductory course was not comprehensive enough. "The immediate feedback as to whether I answered a question correctly motivated me to continue" was answered positively by more than half of the students. Only 20 % felt no increase in motivation. Half of the students also agreed with the statement "The additional information in case of an incorrect answer helped me". 16.60 % did not perceive any help. In response to the question "How many submission options for the tasks do you find the most useful", the majority voted in favour of three. Only 12 % are satisfied with the current status of two submissions, while the remaining students would like four or unlimited submissions.

5 SUMMARY AND OUTLOOK

The studies show that the use of Matlab Grader for learning analytics can be useful. It is shown that the use of Matlab Grader correlates with the exam grade and that the group with a very high number of submissions differs statistically significantly from the groups with a very low number of submissions. This implies that students at risk use matlab grader only a little or not at all. Some of the students had problems using the platform and some of them were not helped by the additional hints when they gave an incorrect answer. The evaluation findings are being incorporated into the redesign of the concept for learning analytics with Matlab Grader. The following changes will be made for the continuation of the concept in the coming semester:

1. introduction of bonus system and time limit for submission

In order to increase students' motivation to actively work on the exercises, bonus points will be awarded for the exam. These will be added depending on the number of Matlab Grader exercises completed correctly. In addition, the exercises will only be available online until the next lecture and no longer for the entire semester.

2. individual feedback

There will be weekly evaluations that show how actively each student is working on the tasks. Statistics will be compiled so that each participant receives feedback on how their activity level compares to all other participants. Students with particularly low activity levels are encouraged to participate more actively through personalised messages so that students at risk in particular are addressed.

3. increasing the number of submissions and revising the instructions

Due to feedback that the number of submissions of two is too low and students are sometimes demotivated as a result, this will be increased to three. In addition, the instructions for incorrect answers will also be revised.

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REFERENCES

Auer, M.E. and K.S. Kim, 2018. *Engineering Education for a Smart Society: World Engineering Education Forum & Global Engineering Deans Council 2016.* Advances in Intelligent Systems and Computing, vol. 627. Cham: Springer International Publishing, 2018.

Block, B-M., Haus, B., von Geyso, T., Steenken, A. “Remote Labs in Electrical Engineering to address heterogeneous student competencies in undergraduate Engineering Education”. In *2023 IEEE Global Engineering Education Conference (EDUCON), Salmiya, 2023.* https://doi.org/10.1109/EDUCON54358.2023.10125109

Block, B-M., Dethmann, J., Haus, B. "Work-in-Progress: Technology-driven introductory phase in engineering sciences for sustainable individual support of students' academic success". Accepted in *21. International Conference on Smart Technologies and Education (STE). Helsinki, 2024.*

Borrego, M. and C. R. Henderson. "Increasing the Use of Evidence-Based Teaching in STEM Higher Education: A Comparison of Eight Change Strategies." Journal of Engineering Education 103(2) (2014): 220–252. *https://doi.org/*10.1002/jee.20040

*Brozina, C., D.B. Knight, T. Kinoshita and A. Johri. "Engaged to Succeed: Understanding First-Year Engineering Students' Course Engagement and Performance Through Analytics." IEEE Access 7 (2019): 163686-163699. https://doi.org/*10.1109/ACCESS.2019.2945873

Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*. Hillsdale: Erlbaum, 1969

Harteis, C. *The impact of digitalization in the workplace: An educational view.* Professional and practice-based learning, vol. 21. Wiesbaden: Springer, 2018.

Heublein, U., J. Ebert, C. Hutzsch, S. Isleib, R. König, J. Richter and A. Woisch. *Zwischen Studienerwartungen und Studienwirklichkeit: Ursachen des Studienabbruchs, beruflicher Verbleib der Studienabbrecherinnen und Studienabbrecher und Entwicklung der Studienabbruchquote an deutschen Hochschulen*. Hannover: Forum Hochschule, 2017.

Heublein, U., C. Hutzsch and R. Schmelzer. *Die Entwicklung der Studienabbruchquoten in Deutschland. Hannover: DZHW, 2022.*

Klöpping, S., M. Scherfer, S. Gokus, S. Dachsberger, A. Krieg, A. Wolter, R. Bruder and W. Ressel. *Studienabbruch in den Ingenieurwissenschaften: Empirische Analyse und Best Practices zum Studienerfolg (acatech STUDIE), München: Herbert Utz Verlag, 2017*

McKenney, S. and T.C. Reeves. "Educational design research." In: Spector, J.M., Merrill, M.D., Elen, J., Bishop, M.J. *Handbook of Research on Educational Communications and Technology,* (2014) pp. 131–140. New York, NY: Springer New York.

Pardo, A., J. Jovanović, S. Dawson, D. Gašević and N. Mirriahi. "Using learning analytics to scale the provision of personalised feedback." British Journal of Educational Technology 50 (2019): 128-138. https://doi.org/10.1111/bjet.12592

Uskov, V.L., R.J. Howlett and L.C. Jain. 2018. *Smart Education and e-Learning 2017.* Smart Innovation, Systems and Technologies 1st edition 2018 edn. Springer International Publishing: Cham, 2018.

ACADEMICS' PERCEPTIONS OF TRANSVERSAL SKILLS: A CASE STUDY IN A NEW ENGINEERING PROGRAMME AT THE NORWEGIAN DEFENCE UNIVERSITY COLLEGE

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Conference Key Areas: *Professional skills and transversal skills.*
Keywords: *Transversal Skills, Staff Perceptions*

ABSTRACT

This case study explores academic staff's perceptions of 'Transversal Skills' (TS) and the impact of educational philosophies on their development within the Civil Engineering Programme at the Norwegian Military Academy, part of the Norwegian Defence University College (NDUC). The study employs Colaizzi's descriptive phenomenology (Beck 2023) to capture academics' views through five interviews, a focus group for reflective discussion on the initial findings, and an analysis of key documents.

The findings highlight an implicit recognition among the staff of the significance of TS for practising engineers. Influencing their perceptions were personal experiences, formal and informal training, institutional frameworks, and governmental regulations. Nonetheless, ambiguity and discrepancies in terminology persist. Challenges in developing TS include achieving a balance between ensuring staff autonomy and providing more structured guidance, better aligning programme elements, and leveraging relatively small class sizes.

Furthermore, this paper delves into the concept of skills, questioning the sufficiency of 'skill' to encapsulate complex practical knowledge, especially against the backdrop of an evolving work landscape driven by technological advancements (Mitchell and Guile 2022). The literature review reveals a lack of research focusing on educators. The findings suggest a need for more explicit definition and integration of TS, guidance in curriculum design, the development of more robust evaluation and assessment techniques and a need for more specific staff support. This aligns with

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the overarching aim of this preliminary study, which is to enhance the teaching, development, and assessment of TS.

1 INTRODUCTION

The critical role of engineers in addressing societal challenges is universally acknowledged. Various initiatives and reports underscore the necessity of equipping them with 'transversal skills' (TS) for active participation in the global workforce (UNESCO 2021; Jalali et al. 2022). Evidence reveals a positive correlation between the integration of TS in university curricula and graduates' performance in the workplace, yet also often reveals a misalignment between educational outcomes and employer expectations (Souppez 2023; Belchior-Rocha, Casquilho-Martins, and Simões 2022). In response, Norwegian Higher Education (HE), guided by government regulations, emphasises the development of TS without explicitly mentioning the term (Meld. St. 14 (2022-2023)).

This study presents preliminary findings from my doctoral research at the Institute of Education (IOE), UCL's Faculty of Education and Society. My initial focus was on incorporating 'global responsibility' within engineering education (Truslove et al. 2022). However, the accelerating workplace evolution, particularly with the mainstreaming of Artificial Intelligence (AI), redirected my research towards clarifying and cultivating the wider range of skills modern engineers require in the workplace (Mitchell and Guile 2022; Munir 2022). This paper, stemming from an Institution Focused Study (IFS), advocates for an educational paradigm that transcends technical knowledge to enhance skills like communication, cooperation and empathy, fostering a supportive learning environment where students benefit from both their successes and failures.

1.1 Context

Since 1750, the Norwegian Military Academy has educated engineering officers, adapting to evolving professional demands. The conceptual framework of TS emerged from the traditional 'soft skills' concept, originally rooted in US Army initiatives from the late 1960s (CONARC Staff 1973). Despite ongoing debates about the definition of soft skills, their importance has continued to gain acceptance (Joie-La Marle et al. 2022). This has led to the current exploration of TS within the Academy's Engineering Programme. The study leverages insights from the *European Transferability of Skills Across Economic Sectors* report and the ESCO/EQF expert group taxonomy to examine how TS are integrated and perceived in engineering education.

Fig. 1. The transversal skills and competences model (ESCO/EQF TSC expert group, 2021) Hart et al. 2021.

Summarised in Figure 1, TS are defined as essential abilities for effective action in any work, learning, or life activity, encompassing personal effectiveness, relationship, impact and influence, achievement, and cognitive skills (Hart et al. 2021).

This study examines staff perceptions of TS and aligns with the European Commission's Skills Agenda (2020). It distinguishes students' lifelong learning from employability and work readiness, aiming to align educational outcomes with the demands of both military service and the broader engineering profession.

1.2 Aims and Objectives

My study aimed to critically examine the staff's perceptions of TS within the Academy's Engineering Programme, aligning with my belief in the necessity of engineering curricula to extend beyond technical proficiency. The primary research question was: *How do academic staff perceive transversal skills and their development in the new engineering programme at the Norwegian Military Academy?* This was supported by sub-questions addressing the influence of institutional and broader engineering sector factors on TS definition, the emphasis on TS in the programme's learning outcomes, and the integration and support for TS within the educational approach.

The objectives were to understand how past experiences, societal influences, and individual educational beliefs interact with institutional expectations to shape TS development. The study aimed to enhance understanding of how TS are perceived, developed, assessed, and evaluated by the Academy's staff, hopefully contributing to meaningful future improvements. Although the site is a military academy, the engineering component adheres to curriculum regulations, with most staff being civilian educators and engineers. The study hopes to offer broader insights into engineering education and address a gap in current research on TS, particularly regarding educators' perspectives.

2 CONCEPTUAL FRAMEWORK

In writing the IFS, I chose to present a conceptual framework, based on existing theories and research (Maxwell 2022). Given the interpretive paradigm of my study, developing a theoretical framework to address the complex phenomenon proved impractical (Jabareen 2009). Instead, I focused on defining 'skills,' a concept often vaguely treated in soft skills research. Skills are often conflated with related concepts such as attitudes, beliefs, and values (Matteson, Anderson, and Boyden 2016, 80). Further complicating discourse, skills, generally referring to the application of methods in specific tasks, are again conflated with 'competencies,' which encompass broader capabilities in complex situations (Hart et al. 2021). The Norwegian Qualifications Framework (2011) and OECD (2015) highlight this distinction by categorising skills into cognitive, practical, creative, and communicative types. Winch (2010) emphasises that skill development involves more than technique (or technical knowledge); it requires judgment, perceptual abilities, and consistent habits. Schraw & Moshman (1995) add that procedural and conditional knowledge are essential for mastering techniques and understanding their application. This conceptual complexity guided my framework, informing my literature review and subsequent analysis. By grounding my study in a nuanced understanding of skills, I aim to contribute to my own conceptual understanding and provide a foundation for further exploration in my upcoming doctoral thesis.

3 LITERATURE REVIEW

The IFS drew on 40 articles from the ERIC database, exploring the dialogue on the intersection of soft skills terminologies with the domains of 'education' and 'engineering' with only a selection of those articles presented in this paper. There was a notable gender balance in authorship despite predominantly featuring Western perspectives. The review also incorporates pivotal documents such as the *Norwegian National Curriculum Regulations for Engineering Education* (2018). A thematic content analysis (Daley and Baruah 2021) of this document reveals a strong emphasis on problem-solving, analytical thinking and interpersonal skills. This reflects findings from other studies (Saunders and Bajjaly 2022) and suggests that regulations might benefit from a more balanced approach to TS.

The reviewed literature predominantly addresses student development and pedagogical methods, and studies on perceptions offer mainly industry and student views on TS (Groeneveld, Vennekens, and Aerts 2022; Markes 2006; Munir 2022; Rayner and Papakonstantinou 2015; Boelt, Kolmos, and Holgaard 2022; Chan, Zhao, and Luk 2017). The review illustrates a gap in research focusing on teachers' perceptions of TS despite their significant role in shaping educational outcomes. Some studies touch on teacher perspectives but focus on subgroups like pre-service science teachers or investigate specific educational strategies without thoroughly exploring teachers' conceptual understanding of TS (Erdogan and Ciftci 2017; Rahman et al. 2022; Lima et al. 2007; Alves et al. 2016). Saunders and Bajjaly's (2022) survey of over 1000 academic staff across six disciplines was one notable study in which they highlight this oversight and suggest a broader concern in higher education about integrating and teaching soft skills. The review suggests a need for more research into how educators perceive and teach these skills, especially in engineering education, where practice and learning are central (Johri and Olds 2014).

Furthermore, the review highlights the methodological challenges inherent in assessing and evaluating TS, an issue echoed across the literature. While various pedagogical approaches for developing TS were examined, there is an expressed need for robust assessment tools capable of capturing the nuances of these skills (Cruz, Saunders-Smits, and Groen 2020). The selected literature underscores the complexity of defining, teaching, and evaluating TS within engineering education.

4 METHODOLOGY

My experience as an engineer and educator in Norway, shaped by a diverse professional journey through engineering, military, humanitarian, and academic realms, informed the research design (Maxwell 2013). My positionality as both an outsider in Norway and an insider within engineering and military education enriched my perspective, offering a nuanced understanding of the challenges in these fields (Bukamal 2022). Guided by an interpretive paradigm, the study valued personal meaning to understand complex human experiences through qualitative methodologies (Maxwell 2013). Focusing on individual academic lecturers in the Academy's Engineering Programme, this study utilised phenomenology to uncover their perceptions of TS (Larsen and Adu 2022).

4.1 Method

This study adopted Paul Colaizzi's descriptive phenomenology, aiming to reveal phenomena (Beck 2023) and practise 'qualified naïveté' to remain open to new phenomena without preconceived notions (Brinkmann and Kvale 2018). Acknowledging the limitations of completely setting aside biases, as suggested by Merleau-Ponty (1956), the method involved five semi-structured interviews to prompt in-depth reflections on TS, complemented by an ex-post focus group to discuss initial findings collectively (Morse 2006). Colaizzi's procedure guided the extraction and interpretation of significant statements (see Figure 2).

A case study approach enabled an empirical investigation of TS conceptualisation within the real-life context of the Academy's Engineering Programme, incorporating multiple sources of evidence (Robson and McCartan 2016). The flexible nature of qualitative research allowed responsiveness to developments throughout the study (Maxwell 2013). Triangulation ensured a comprehensive exploration, supported by peer debriefing with the doctoral programme cohort (Robson and McCartan 2016, 172). This approach reflected my positionality as an educator-researcher, aiming to scrutinise TS from an educational perspective rather than a practitioner's viewpoint in developing these skills in the classroom.

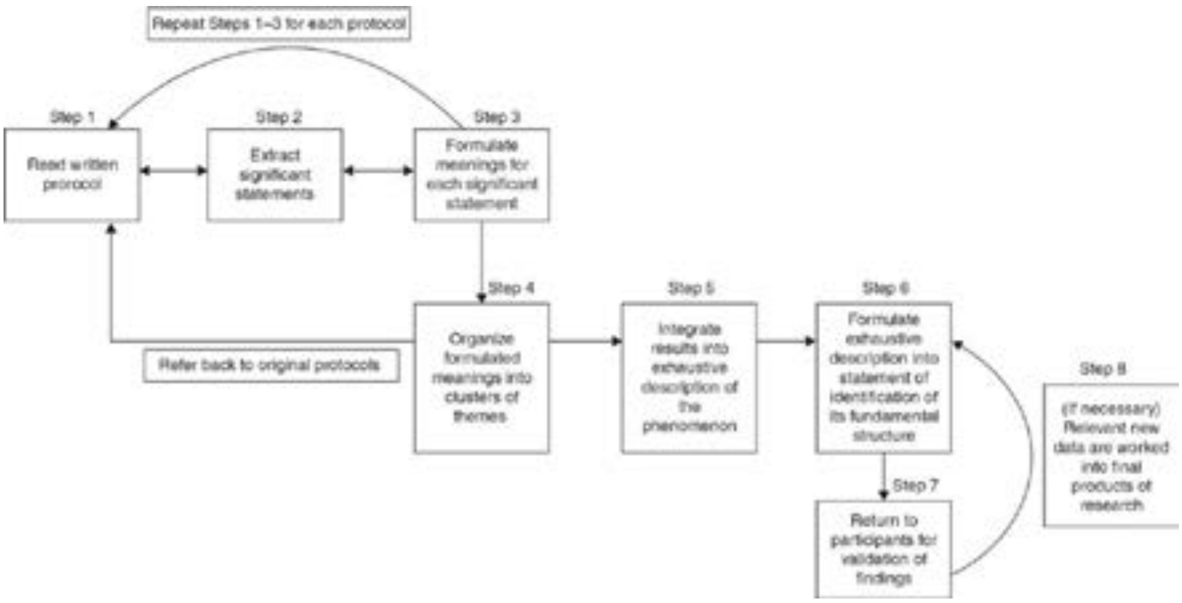

Fig. 2. Colaizzi's procedure and steps for analysing data phenomenologically (Beck and Watson 2008, 231) Used with permission from Wolters Kluwer Health Copyright © 2008.

Gender perspectives were considered to address the traditional male dominance in engineering and military environments (Korsvik and Rustad 2018). Ethical considerations were integrated throughout the research process, from planning to conclusion, with particular attention to potential impacts on participants and the broader educational community (Kara 2018). Ethical standards were maintained by obtaining informed consent, navigating potential conflicts of interest, and securing approval from relevant bodies (BERA 2018; Sikt 2023).

The validity of the research was grounded in a rigorous methodological approach, though further validation was sought through a focus group in step 7 of Colaizzi's procedure. Triangulation, employing multiple data sources (Maxwell 2013, 128), and peer debriefing reinforced the study's aim. These steps aimed to enhance understanding of how academic staff perceive and integrate TS, contributing to meaningful improvements in TS development.

5 FINDINGS

The Academy's Engineering Programme prepares students as professional engineers and military leaders. The objective of the study was to contribute to existing knowledge and provide a basis for programme development and future research. The study uncovered varied perspectives among academic staff on TS, revealing nuanced differences in conceptualisation yet a common acknowledgement of their importance for students' success. Six key themes emerged around the implicit understanding of TS, the impact of institutional structures on their development and integration into pedagogy, and the challenges of aligning these with the Programme's learning outcomes, summarised in Table 1.

Table 1. A summary of key themes and corresponding statements of identification were revealed during the phenomenological study of staff perceptions of TS.

Perceptions and Conceptual Understanding of Transversal Skills	Staff perceive TS as fundamental yet implicitly understood aspects of the Academy's programme and an engineer's future practice. They were defined as competencies developed through practical experience, reflective practice, and teaching-learning interactions. This view frames TS as embedded within educational activities, encompassing, but not limited to, problem-solving, critical thinking, communication, and social skills. Most staff emphasise the acquisition of TS through maturation rather than direct instruction.
Institutional Barriers and Opportunities	Methods for developing TS revealed a tension between the value staff place on autonomy and a need for more structured guidance from the institution. Although all staff appreciate their freedom in choosing teaching methods, there is a visible yet often unarticulated need for more guidance in integrating TS into the curriculum. This situation highlights the challenges of ensuring the programme's outcomes while maintaining diverse pedagogical approaches, further challenged by the limitations of a small professional community, disparate programme components, limited timeframes, and lack of leadership of programme implementation.
Pedagogical Approaches to Developing Transversal Skills	Staff lean towards active learning methods, such as Problem-Based Learning (PBL), for the development of TS with an emphasis on creating a secure and supportive learning environment. Reflection from staff reveal a challenge in balancing teaching theoretical knowledge with practical application, crucial for embedding technical and soft skills engineering education. Achieving this balance involves navigating the complexities, but also opportunities, of incorporating TS into a curriculum that also satisfies the Curriculum Regulations.
Staff's Professional Development and Learning	Professional development and learning among staff are depicted as a personal journey, merging formal education with practical experience and learning. Some staff align their teaching approaches through formal education, while others depend more on practical experience, shaped by personal and professional values. This blend exposes a tension between available formal education opportunities and more informal, experience-based development. A lack of perceived awareness to structured professional development opportunities also was evident.
The Evaluation of Transversal Skills Development	The limited discourse on the evaluation of TS indicates a nascent interest in developing assessment methods that reflect the integrated nature of TS within the Programme. Although efforts to establish TS evaluation strategies are in their infancy, there is a recognised need for clearer, more systematic approaches, aligning with the

	Programme's learning outcomes with the aim of enhancing cadet development.
Education in a Military Context	The educational attitude within the military context seeks to balance individual advancement with collective responsibility, merging technical knowledge with leadership training grounded in the Armed Forces' core values. Insights from staff suggest an educational philosophy that goes beyond traditional engineering instruction, aiming to cultivate responsibility, leadership, and a collective identity further enhancing the development of TS critical for cadets' success in their roles as officers.

The investigation reveals a complex interplay of perceptions and institutional influences on the development of TS. Staff members shared that their professional, cultural, and social backgrounds heavily influenced their implicit and sometimes explicit understanding of TS, aligning with findings from McDonald (2011) on perception as a subjective process shaped by individual experiences. A fragmented perception and a lack of consistent terminology were noted, suggesting a gap between individual concepts and broader soft skills terminologies, as discussed by Markes (2006) and Matteson et al. (2016). This supports the literature on the often-ambiguous nature of soft skills terminology, indicating a need for more precise definitions, at least within the context of the NDUC.

Teaching approaches were often influenced by staff experiences and the belief in the value of experiential learning, with a focus on methods like PBL and reflective activities, pointing to the effectiveness of these strategies in TS development. However, concerns were raised about balancing the technical content with soft skills development, suggesting that TS emerge through maturing, experience, and reflection rather than traditional teaching methods (Mitchell et al. 2019). Institutional structures, including NDUC and Armed Forces guidelines, and the broader Norwegian engineering education sector, play a subtle yet significant role in defining TS and again influencing pedagogical practices. Interviews revealed a disconnect between regulations and soft skills terminology, suggesting room for better alignment.

In conclusion, academic staff at the Academy implicitly understand and perceive the development of TS, while stating their importance for student's success. This is reflected in their approaches to integrating skills like communication and critical thinking into their teaching. Their engagement with pedagogical approaches balanced both technical and soft skill development, while emphasising experimental learning. Staff critically reflected on the resources and development opportunities provided by the NDUC, while highlighting challenges such as balancing teaching autonomy with more structured guidance and leveraging small class sizes. These reflections underscore the need for more precise guidance, focused leadership, and better integration of TS, aligning with the broader goal of this study to investigate the integration of soft skills into teaching, as recommended in the HE literature (Saunders and Bajjaly 2022). Understanding staff perceptions of TS aligns with my belief that engineering curricula must extend beyond technical proficiency and balance theoretical knowledge with a more diverse skill sets needed by engineers in the 21st century. These insights are crucial for exploring improvements to staff professional development, programme content, and evaluation and assessment methods.

6 SUMMARY

This preliminary study delved into the nuanced and complex perceptions of academic staff regarding transferable skills (TS), highlighting both the philosophical discussions surrounding the concept of skills and the practical implications in educational settings. The findings underscore the varied perspectives on TS, reflecting broader discussions on the nature of skill and competence in the literature. Despite the acknowledged importance of TS for students' development, a noticeable gap exists in teacher-focused research, with existing studies primarily concentrating on industry and student perspectives. This study also revealed that while staff recognise the significance of TS, challenges persist in integrating these skills into the curriculum, impaired by the lack of clear guidance and the need for improved assessment methods.

Winch (2010) argues that the term 'skill' is insufficient to describe the complexities of practical knowledge, while Dennett (2018) suggests that competence can exist without full comprehension, indicating that our understanding might be limited by our first-person perspective. This notion extends to the evolving nature of skills in the age of machine learning and AI, where we benefit from advanced algorithms without fully understanding them (Daugherty and Wilson 2018). Despite the importance of comprehending skills, few studies focus on teachers' perceptions, unlike numerous studies on industry professionals, employers, and students. Saunders and Bajjaly (2022) also highlighted this gap, noting that professional development often addresses soft skills without verifying if they are already being taught. This lack of focus on teachers might be due to engineering education research traditionally emphasising practice and learning (Johri and Olds 2014).

To address these challenges, several action points are considered, including defining TS within the specific context of the programme at NDUC, while acknowledging that a universal definition is unlikely; more detailed mapping of the development of TS and competencies within the programme; investigating, developing, and validating robust TS assessment and evaluation methods, potentially leveraging AI and learning analytics; and improving opportunities for professional development and understanding of the Scholarship of Teaching and Learning (SoTL) within the programme.

Reflecting on my findings, it is evident that while academic staff have a sense that their current practices are effective, the mechanisms and reasons for their effectiveness remain unclear, opening multiple avenues for further research. Finally, despite this study being conducted at a military academy, it is believed that the findings are applicable across engineering education in Norway and potentially Europe. These insights contribute to a deeper understanding of TS within engineering education and signal a need for further research, particularly in evaluating and assessing TS development to better align with the objectives of outcomes-based education.

REFERENCES

Alves, Anabela C., Rui M. Sousa, Sandra Fernandes, Elisabete Cardoso, Maria Alice Carvalho, Jorge Figueiredo, and Rui M. S. Pereira. 2016. 'Teacher's Experiences in PBL: Implications for Practice'. *European Journal of Engineering Education* 41 (2): 123–41. https://doi.org/10.1080/03043797.2015.1023782.

Beck, Cheryl Tatano. 2023. 'Introduction to Phenomenology: Focus on Methodology'. In , by pages 1-8. Thousand Oaks: SAGE Publications, Inc. https://doi.org/10.4135/9781071909669.

Beck, Cheryl Tatano, and Sue Watson. 2008. 'Impact of Birth Trauma on Breast-Feeding: A Tale of Two Pathways'. *Nursing Research* 57 (4): 228–36. https://doi.org/10.1097/01.NNR.0000313494.87282.90.

Belchior-Rocha, Helena, Inês Casquilho-Martins, and Eduardo Simões. 2022. 'Transversal Competencies for Employability: From Higher Education to the Labour Market'. *Education Sciences* 12 (4): 255. https://doi.org/10.3390/educsci12040255.

BERA. 2018. 'Ethical Guidelines for Educational Research, Fourth Edition'. London: British Educational Research Association [BERA]. https://www.bera.ac.uk/publication/ethical-guidelines-for-educational-research-2018-online.

Boelt, A. M., A. Kolmos, and J. E. Holgaard. 2022. 'Literature Review of Students' Perceptions of Generic Competence Development in Problem-Based Learning in Engineering Education'. *European Journal of Engineering Education* 47 (6): 1399–1420. https://doi.org/10.1080/03043797.2022.2074819.

Brinkmann, Svend, and Steinar Kvale. 2018. *Doing Interviews*. SAGE Publications Ltd. https://doi.org/10.4135/9781529716665.

Bukamal, Hanin. 2022. 'Deconstructing Insider–Outsider Researcher Positionality'. *British Journal of Special Education* 49 (3): 327–49. https://doi.org/10.1111/1467-8578.12426.

Chan, Cecilia K. Y., Yue Zhao, and Lillian Y. Y. Luk. 2017. 'A Validated and Reliable Instrument Investigating Engineering Students' Perceptions of Competency in Generic Skills'. *Journal of Engineering Education* 106 (2): 299–325. https://doi.org/10.1002/jee.20165.

CONARC Staff. 1973. 'CONARC Soft Skills Training Conference.' I. Fort Bliss, Texas: US Continental Army Command. https://apps.dtic.mil/sti/citations/ADA099612.

Cruz, Mariana Leandro, Gillian N. Saunders-Smits, and Pim Groen. 2020. 'Evaluation of Competency Methods in Engineering Education: A Systematic Review'. *European Journal of Engineering Education* 45 (5): 729–57. https://doi.org/10.1080/03043797.2019.1671810.

Daley, Joshua, and Bidyut Baruah. 2021. 'Leadership Skills Development among Engineering Students in Higher Education -- An Analysis of the Russell Group Universities in the UK'. *European Journal of Engineering Education* 46 (4): 528–56. https://doi.org/10.1080/03043797.2020.1832049.

Daugherty, Paul R., and H. James Wilson. 2018. *Human + Machine: Reimagining Work in the Age of AI*. La Vergne, UNITED STATES: Harvard Business Review Press. http://ebookcentral.proquest.com/lib/ucl/detail.action?docID=5180063.

Dennett, Daniel. 2018. 'Précis of From Bacteria to Bach and Back'. *Teorema: Revista Internacional de Filosofía* 37 (3): 107–10.

Erdogan, Ibrahim, and Ayse Ciftci. 2017. 'Investigating the Views of Pre-Service Science Teachers on STEM Education Practices'. *International Journal of Environmental and Science Education* 12 (5): 1055–65.

European Commission. 2020. 'European Skills Agenda for Sustainable Competitiveness, Social Fairness and Resilience'. European Commission. https://doi.org/10.1787/9789264312012-en.

Groeneveld, Wouter, Joost Vennekens, and Kris Aerts. 2022. 'Identifying Non-Technical Skill Gaps in Software Engineering Education: What Experts Expect but Students Don't Learn'. *ACM Transactions on Computing Education* 22 (1). https://doi.org/10.1145/3464431.

Hart, John, Martin Noack, Claudia Plaimauer, and Jens Bjørnåvold. 2021. 'Towards a Structured and Consistent Terminology on Transversal Skills and Competence'. Cedefop. https://esco.ec.europa.eu/en/about-esco/publications/publication/towards-structured-and-consistent-terminology-transversal.

Jabareen, Yosef. 2009. 'Building a Conceptual Framework: Philosophy, Definitions, and Procedure'. *International Journal of Qualitative Methods* 8 (4): 49–62. https://doi.org/10.1177/160940690900800406.

Jalali, Yousef, Helena Kovacs, Siara Isaac, and Jessica Dehler Zufferey. 2022. 'Bringing Visibility to Transversal Skills in Engineering Education: Towards an Organizing Framework'. In *Towards a New Future in Engineering Education, New Scenarios That European Alliances of Tech Universities Open Up*, 1252–59. Universitat Politècnica de Catalunya. https://doi.org/10.5821/conference-9788412322262.1251.

Johri, Aditya, and Barbara M. Olds, eds. 2014. *Cambridge Handbook of Engineering Education Research*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139013451.

Joie-La Marle, Chantal, François Parmentier, Morgane Coltel, Todd Lubart, and Xavier Borteyrou. 2022. 'A Systematic Review of Soft Skills Taxonomies: Descriptive and Conceptual Work'. https://doi.org/10.31234/osf.io/mszgj.

Kara, Helen. 2018. *Research Ethics in the Real World*. Euro-Western and Indigenous Perspectives. Policy Press. https://doi.org/10.56687/9781447344780.

Korsvik, Trine Rogg, and Linda M. Rustad. 2018. 'Hva Er Kjønnsperspektiver i Forskning? Eksempler Fra Tverrfaglige Forskningsområder.' Lysaker, Norway: Kilden kjønnsforskning.no. https://kjonnsforskning.no/sites/default/files/hva_er_kjonnsperspektiver_i_forskning_rogg_korsvik.pdf.

Larsen, Henrik Gert, and Philip Adu. 2022. *The Theoretical Framework in Phenomenological Research: Development and Application*. 1st ed. New York, NY: Routledge. https://doi.org/10.4324/9781003084259.

Lima, Rui M., Dinis Carvalho, Maria Assuncao Flores, and Natascha Van Hattum-Janssen. 2007. 'A Case Study on Project Led Education in Engineering: Students' and Teachers' Perceptions'. *European Journal of Engineering Education* 32 (3): 337–47. https://doi.org/10.1080/03043790701278599.

Markes, Imren. 2006. 'A Review of Literature on Employability Skill Needs in Engineering'. *European Journal of Engineering Education* 31 (6): 637–50. https://doi.org/10.1080/03043790600911704.

Matteson, Miriam L., Lorien Anderson, and Cynthia Boyden. 2016. '"Soft Skills": A Phrase in Search of Meaning'. *Portal: Libraries and the Academy* 16 (1): 71–88.

Maxwell, Joseph Alex. 2013. *Qualitative Research Design: An Interactive Approach*. 3rd ed. Applied Social Research Methods Series. Los Angeles: SAGE Publications.

Maxwell, Joseph Alex. 2022. 'Interactive Approaches to Qualitative Research Design'. In The SAGE Handbook of Qualitative Research Design, edited by Uwe Flick, 1:41–54. United Kingdom: SAGE Publications Ltd. https://doi.org/10.4135/9781529770278.

McDonald, Susan M. 2011. 'Perception: A Concept Analysis'. *International Journal of Nursing Terminologies and Classifications*, November, j.1744-618X.2011.01198.x. https://doi.org/10.1111/j.1744-618X.2011.01198.x.

Meld. St. 14. 2022. *Utsyn over Kompetansebehovet i Norge*. Kunnskapsdepartementet. https://www.regjeringen.no/contentassets/d4a1053c98614420a71de98352902464/no/pdfs/stm202220230014000dddpdfs.pdf.

Merleau-Ponty, Maurice. 1956. 'What Is Phenomenology?' Translated by John F. Bannan. *CrossCurrents* 6 (1): 59–70.

Mitchell, John, and David Guile. 2022. 'Fusion Skills and Industry 5.0: Conceptions and Challenges'. In *Insights Into Global Engineering Education After the Birth of Industry 5.0*, edited by Montaha Bouezzeddine. IntechOpen. https://doi.org/10.5772/intechopen.100096.

Mitchell, John, Abel Nyamapfene, Kate Roach, and Emanuela Tilley. 2019. 'Philosophies and Pedagogies That Shape an Integrated Engineering Programme'. *Higher Education Pedagogies* 4 (1): 180–96. https://doi.org/10.1080/23752696.2018.1507624.

Morse, Janice M. 2006. 'Insight, Inference, Evidence, and Verification: Creating a Legitimate Discipline: Keynote Address for the II Congreso Iberoamericano de Investigación Cualitativa En Salud Madrid 22–25 de Junio de 2005'. *International Journal of Qualitative Methods* 5 (1): 93–100. https://doi.org/10.1177/160940690600500108.

Munir, Fouzia. 2022. 'More than Technical Experts: Engineering Professionals' Perspectives on the Role of Soft Skills in Their Practice'. *Industry and Higher Education* 36 (3): 294–305. https://doi.org/10.1177/09504222211034725.

NOKUT. 2011. 'The Norwegian Qualifications Framework for Lifelong Learning (NQF)'. Ministry of Education and Research. https://www.nokut.no/en/norwegian-education/the-norwegian-qualifications-framework-for-lifelong-learning/.

OECD. 2015. 'Skills for Social Progress: The Power of Social and Emotional Skills'. OECD Skills Studies. Paris: OECD Publishing. https://doi.org/10.1787/9789264226159-en.

Rahman, Noor Anita, Roslinda Rosli, Azmin Sham Rambely, Nur Choiro Siregar, Mary Margaret Capraro, and Robert M. Capraro. 2022. 'Secondary School Teachers' Perceptions of STEM Pedagogical Content Knowledge'. *Journal on Mathematics Education* 13 (1): 119–34.

Rayner, Gerry M., and Theo Papakonstantinou. 2015. 'Employer Perspectives of the Current and Future Value of STEM Graduate Skills and Attributes: An Australian Study'. *Journal of Teaching and Learning for Graduate Employability* 6 (1): 100–115.

Regulations for Engineering Education. 2018. 'National Curriculum Regulations for Engineering Education'. Oslo, Norge: Ministry of Education and Research. https://www.regjeringen.no/contentassets/389bf8229a3244f0bc1c7835f842ab60/kd_forskrift-om-rammeplan-for-ingeniorutdanning_oppdat-engelsk-versjon.pdf.

Robson, Colin, and Kieran McCartan. 2016. *Real World Research: A Resource for Users of Social Research Methods in Applied Settings*. Fourth Edition. Hoboken: Wiley. https://bibliu.com/app/#/view/books/9781119083412/pdf2htmlex/index.html#page_C1.

Saunders, Laura, and Stephen Bajjaly. 2022. 'Direct Instruction and Assessment of Personal and Professional Skills across Disciplines: Faculty Perspectives'. *International Journal of Teaching and Learning in Higher Education* 33 (3): 374–84.

Schraw, Gregory, and David Moshman. 1995. 'Metacognitive Theories'. *Educational Psychology Review* 7 (December): 351–71. https://doi.org/10.1007/BF02212307.

Sikt. 2023. 'Sikt - Norwegian Agency for Shared Services in Education and Research'. Sikt. 2023. https://sikt.no/en/home.

Souppez, Jean-Baptiste RG. 2023. 'Engineering Employability Skills: Students, Academics, and Industry Professionals Perception'. *International Journal of Mechanical Engineering Education*, November, 03064190231214178. https://doi.org/10.1177/03064190231214178.

Truslove, Jonathan, Emma Crichton, Shannon Chance, Inês Direito, Katie Cresswell-Maynard, and John Mitchell. 2022. 'Global Responsibility of Engineering'. London, UK: Engineers Without Borders UK.

UNESCO. 2021. *Engineering for Sustainable Development: Delivering on the Sustainable Development Goals*. Beijing, China: United Nations Educational, Scientific and Cultural Organization.

Winch, Christopher. 2010. 'Beyond Skill - the Complexities of Competence'. In *Dimensions of Expertise: A Conceptual Exploration of Vocational Knowledge*. London, UK: Continuum. https://doi.org/10.5040/9781472541093.

FROM THEORY TO PRACTICE: THE PERSONAL DEVELOPMENT PROCESS IN AN E-PORTFOLIO TO PREPARE FOR LIFELONG LEARNING

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ABSTRACT

E-portfolios offer numerous advantages in engineering education, including the possibility for students to construct their own learning journey. By engaging in this individual learning journey, students acquire the competencies which are essential for lifelong learning (LLL). This study outlines the implementation of an e-portfolio based on the personal development process to support engineering students in the development of these LLL competencies. Using a pre-post design, the effectiveness of this e-portfolio is measured using a LLL attitude questionnaire in the first and second bachelor. Findings reveal a nuanced progression in LLL attitude, warranting further research. Next steps for research and practice are discussed.

1 INTRODUCTION

1.1 E-portfolios in higher education

E-portfolios have been a popular educational tool in higher education for quite some time and have been deployed in a diverse range of disciplines and contexts (Chaudhuri and Cabau 2017; Harun, Hanif, and Choo 2021).

The use of an e-portfolio in higher education has many advantages. First, it allows students to construct their own learning trajectory. Students can have different educational backgrounds, learning experiences, interests, and competency levels. An e-portfolio allows for students to work on competencies which are relevant to them individually and, as such, plays into today's diversity in student groups (Chaudhuri and Cabau 2017; Roger and Kolmos 2020). Second, an e-portfolio can be the common thread in study programmes with integrated learning experiences. It supports educators in seeing the bigger picture of an individual student and students in saving their feedback and reflection for future use (Chaudhuri and Cabau 2017; Alam et al. 2015). Final, the e-portfolio allows students to communicate their acquired competencies to possible future employers or use its content to construct their cv (Alam et al. 2015; Gutiérrez-Santiuste et al. 2022).

This study focuses on the first advantage of students being able to construct their own learning journey by engaging with the e-portfolio. Students not only acquire and record competencies in the context of the e-portfolio, they also gain other competencies by going through this learning journey. For example, students rely on themselves to take charge of their learning process. They have to take initiative and responsibility to learn in a self-directed manner (Alam et al. 2015; Huang et al. 2012). This is strengthened by reflection that takes a central role in effective e-portfolios (Alam et al. 2015; Harun, Hanif, and Choo 2021). E-portfolios oblige students to reflect about themselves, their competencies, the curriculum, their learning approach, their results and other topics depending on the context. Reflection about necessary and acquired competencies relates to the learning competencies of self-assessment and self-evaluation. These learning competencies, and many more such as goal setting, self-regulation, and motivation, can be acquired by engaging with an e-portfolio (Alam et al. 2015; Harun, Hanif, and Choo 2021; Huang et al. 2012).

1.2 Lifelong learning (competencies)

Due to continuous changes in technology, techniques and tools, as well as changes in required professional competencies, engineers need to constantly go through a learning process making lifelong learning (LLL) essential (Galanis et al. 2017; Authors Sankaran and Rath 2021). For engineers, (Cruz, Saunders-Smits, and Groen 2020) identified five competencies that are essential to act as a lifelong learner: (1) locating and scrutinizing information, (2) willingness, motivation and curiosity to learn, (3) self-monitoring, (4) self-reflection, and (5) creating a learning plan. When looking at the learning competencies triggered by e-portfolios, considerable overlap between these competencies and the LLL competencies can be noted. It becomes clear that the use of an e-portfolio and the opportunity to construct a learning journey can contribute to the LLL competency development.

Higher education carries the responsibility to adequately prepare engineering students for their professional career, and thus for lifelong learning (Yap and Tan 2022; Authors 2023). This means that the competencies necessary for LLL need to be part of the engineering programme and the e-portfolio seems a valuable tool to fulfil this role.

1.3 The personal development process

This raises the question of what an e-portfolio can and should look like. Patel et al. (2013) argue that competency development is not achieved through merely filling in a form a couple of times per year. Students have to engage in a learning process, which is dynamic and continuous. This also relates to the discussion on product versus process-based approach in e-portfolios (Alam et al. 2015). A showcase e-portfolio is meant to show accomplishments and competencies to potential future employers and is focused on the *product*. A developmental e-portfolio focuses on the *process* by providing a space where students can reflect on their competencies and competency development. While both are valuable, the latter is the most relevant for preparing students for LLL.

In their work, Patel et al. (2013) define a five-step personal development process (PDP) which can serve as the base of an e-portfolio:

1. **Identifying** gaps in competencies (skills, knowledge, and attitudes).
2. **Prepare** for learning by setting a (SMART) goal and identifying resources and opportunities.
3. **Act** on this plan.
4. **Monitor** the learning process.
5. **Reflect** on how the learning process can be improved and what the future learning needs are.

1.4 The current study

Although the engineering education literature agrees on the importance of lifelong learning and its role in higher education, research on the implementation of interventions for this purpose is limited. This paper aims to answer the following research question: To what extent can an e-portfolio based on the personal development process contribute to an increase in the LLL attitudes of engineering students?

This paper describes the implementation of an e-portfolio, specifically based on the personal development process. The long-term goal of this e-portfolio is to prepare engineering students for LLL by including LLL competencies in the curriculum. First and second year bachelor students are asked about their attitude towards LLL and the LLL competencies before and after a semester of using the e-portfolio. The effectiveness of the e-portfolio as a tool to promote LLL is investigated by comparing the change in students' perceptions before and after the use of the e-portfolio.

2 METHODOLOGY

2.1 Sample and procedure

Students from an engineering technology faculty in Belgium (Flanders) in the engineering technology bachelor programme participated in this study. Data was collected via a survey at the start of the second semester of academic year 2022 – 2023 (pre-test) and at the beginning of the first semester of academic year 2023 – 2024 (post-test). The pre-test was filled in by the first (N = 21, see Table 1) and second year (N = 30) bachelor students. Later for the post-test, the same student groups were asked to fill in the survey and a subset of the first (N = 20) and second year (N = 23) replied. Some students filled in both surveys (N_1 = 14; N_2 = 16). Students were asked by a PhD researcher to participate during a class according to privacy and ethical guidelines (G-2022-5292-R2(MAR)). For example, it was stressed that participation was voluntary and not rewarded.

Table 1. Participating students (N)

	Pre-test	Post-test	Overlap pre and post-test
Bachelor 1	21	20	14
Bachelor 2	30	23	16
Total	51	43	30

2.2 Materials and measurements

The **PDP e-portfolio** was integrated into a project-based learning course and presented as a tool to develop students' professional competencies during the project. An overview of the topics included in the e-portfolio to trigger each of the PDP steps is included in Appendix A.

A **survey** including three questions to measure students' attitude towards LLL was distributed via pre-post testing. In the pre-test students' perceptions were asked about (1) the importance of each of the LLL competencies in engineering practice, (2) the extent to which the competencies are taught in their curriculum, and (3) the extent to which the competencies are assessed. In the post-test the students were asked about (1) the importance of each of the LLL competencies in engineering practice, (2) the extent to which the LLL competencies are present in their curriculum, and (3) how competent they think they are in the LLL competencies. All questions allowed responses on a four-point scale with the following structure: Not important – Somewhat important – Important – Very important. The students answered each question for each of the LLL competencies, namely (1) locating and scrutinizing information, (2) willingness, motivation and curiosity to learn, (3) self-monitoring, (4) self-reflection, and (5) creating a learning plan. In addition, (6) lifelong learning by itself was also added as one of the competencies.

2.3 Research design and analysis

The pre and post-test were first analysed separately using descriptive statistics and correlational analysis. Differences between the bachelor years were tested using a Wilcoxon test after a Shapiro-Wilk normality test indicates a non-normally distributed data. For this analysis the full dataset was used, meaning that, for example for the pre-test, all students who filled in the pre-test were included regardless of whether they filled in the post-test.

These cross-sectional analyses were followed by a longitudinal analysis using the data from the students who filled in both the pre and post-test (see Table 1). The differences between the pre and post-test were tested using a random intercepts model. This is a linear model which allows for a different intercept for each individual and exists of:

- A fixed main effect of the timing of the survey: pre or post (categorical)
- A fixed main effect of the student group: bachelor 1 or 2 (categorical)

- A fixed interaction effect between the timing of the survey and the student group

The random intercepts model is visualised to aid interpretation.

Data analysis was conducted in R Studio using the nlme package for the linear mixed model and ggplot2 for visualisations.

3 RESULTS

3.1 Cross-sectional analysis of the pre-test

Table 2 includes the descriptive statistics of the pre-test. The Wilcoxon test indicates no significant differences between the first and second bachelor.

Table 2. Descriptive statistics of the pre-test

	Importance				Taught				Assessed			
	Ba 1		Ba 2		Ba 1		Ba 2		Ba 1		Ba 2	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Locating and scrutinizing information	**3.2**	0.6	**3.2**	0.9	**2.9**	0.3	**2.9**	0.6	**2.5**	0.8	**2.5**	1.1
Willingness, motivation, and curiosity to learn	**3.2**	0.5	**3.2**	0.9	**2.1**	0.9	**2.1**	0.8	**1.8**	0.7	**1.8**	1.1
Self-monitoring	**3.1**	0.6	**2.9**	0.8	**2.1**	0.7	**2.5**	0.9	**1.9**	0.8	**2.0**	0.8
Self-reflection	**3.1**	0.7	**2.7**	1.0	**2.7**	0.7	**3.3**	0.7	**2.3**	0.9	**2.9**	1.1
Creating a learning plan	**3.0**	0.9	**2.1**	0.9	**2.3**	0.9	**1.9**	0.8	**1.7**	0.5	**1.8**	1.0
Lifelong learning	**3.5**	0.7	**3.1**	0.8	**2.4**	0.8	**1.9**	0.8	**1.9**	0.9	**2.1**	1.2

3.2 Cross-sectional analysis of the post-test

The descriptive statistics of the post-test can be found in Table 3. The Wilcoxon test indicates no significant differences between the first and second bachelor.

Table 3. Descriptive statistics of the post-test

	Importance				Presence				Competence			
	Ba 1		Ba 2		Ba 1		Ba 2		Ba 1		Ba 2	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Locating and scrutinizing information	**3.2**	0.7	**3.3**	0.8	**2.8**	0.7	**2.9**	1.0	**2.9**	0.7	**2.6**	0.6
Willingness, motivation, and curiosity to learn	**3.0**	0.6	**3.0**	0.9	**2.7**	0.9	**2.5**	0.8	**3.1**	0.8	**2.5**	0.8
Self-monitoring	**3.0**	0.6	**2.8**	0.9	**2.8**	0.6	**2.4**	0.7	**2.5**	0.7	**2.3**	0.7
Self-reflection	**2.8**	0.8	**2.8**	1.0	**3.1**	0.8	**3.0**	1.1	**2.7**	0.9	**2.6**	0.9
Creating a learning plan	**2.6**	0.6	**2.0**	0.6	**2.5**	0.7	**2.4**	0.7	**2.2**	0.8	**2.0**	0.9
Lifelong learning	**3.2**	0.6	**3.2**	0.8	**2.9**	0.6	**2.5**	1.0	**2.8**	0.6	**2.6**	0.7

3.3 Longitudinal analysis of the pre and post-test

In Table 4 the mean scores for the importance variable can be compared between the pre and post test.

Table 4. Descriptive statistics of the importance variable

	Bachelor 1				Bachelor 2			
	Pre		Post		Pre		Post	
	M	SD	M	SD	M	SD	M	SD
Locating and scrutinizing information	**3.0**	0.4	**3.3**	0.7	**3.3**	0.9	**3.4**	0.7
Willingness, motivation, and curiosity to learn	**3.2**	0.6	**3.1**	0.6	**2.8**	0.8	**3.1**	0.8
Self-monitoring	**2.8**	0.7	**2.6**	0.6	**3.0**	0.8	**2.8**	0.9
Self-reflection	**3.0**	0.8	**2.7**	0.8	**2.3**	1.0	**2.8**	1.2
Creating a learning plan	**2.8**	0.8	**2.6**	0.6	**2.0**	0.7	**2.1**	0.6
Lifelong learning	**3.5**	0.8	**3.2**	0.6	**3.1**	0.9	**3.3**	0.8

The random intercepts model indicates a significant main effect of the student group for *creating a learning plan* ($t = -3.03$; $P < .01$) is found and can be recognised as the horizontal distance between the lines on Figure 1. This means that the students in bachelor 2 find *creating a learning plan* less important than the students in bachelor 1.

Further, a significant interaction effect of the student group and the timing (pre vs. post) for *self-reflection* ($T = 2.17$; $P < .05$) which can be recognised by the intersecting lines on Figure 1. This means that the attitude change for *self-reflection* from the pre to the post test depends on the bachelor year. In bachelor 1 there is a decrease in the perceived importance of self-reflection, but in bachelor 2 there is an increase.

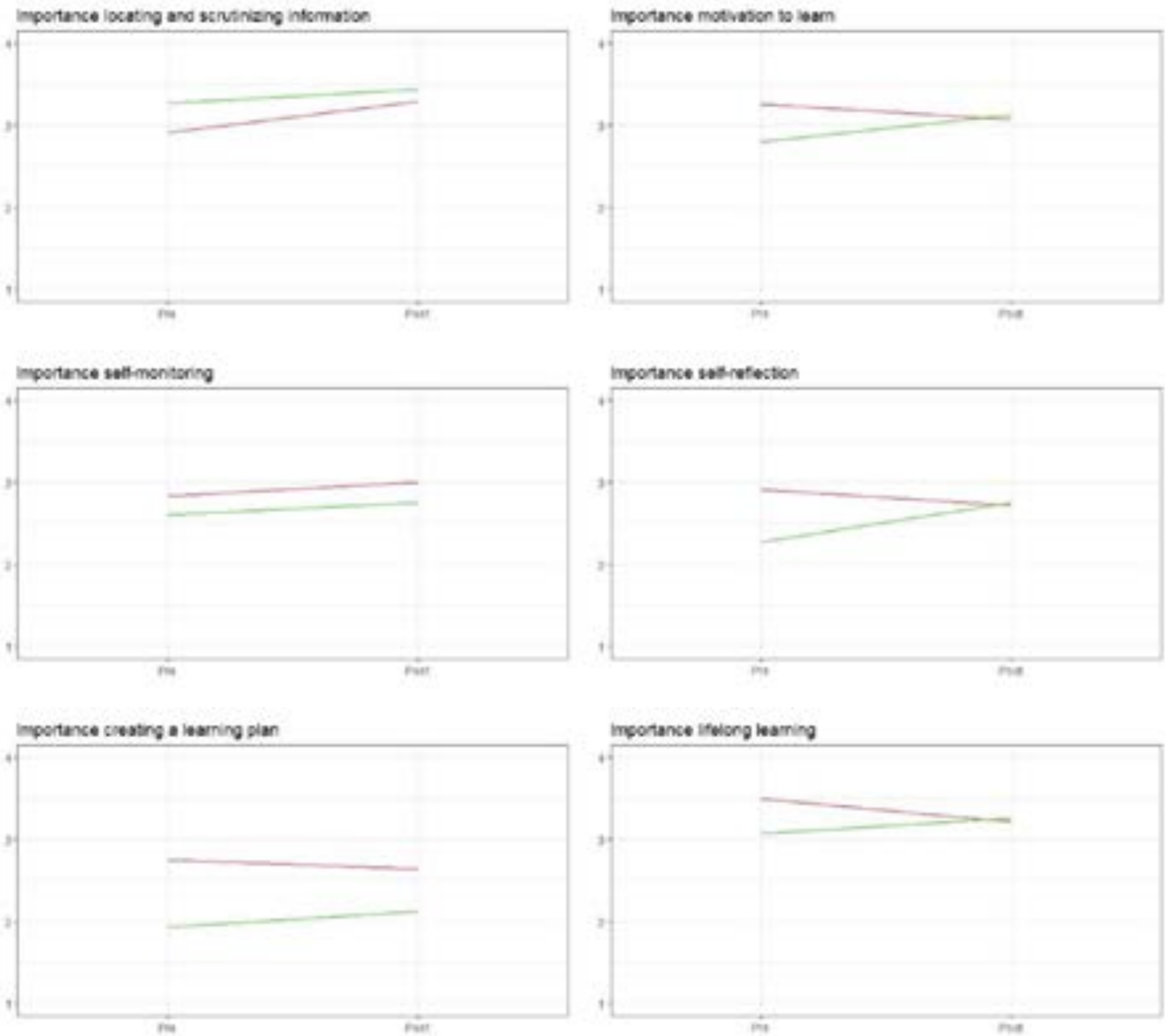

Fig 1. Visualisation of growth of importance. Pink = bachelor 1; green = bachelor 2.

4 DISCUSSION

4.1 Discussion of the results

To support the development of LLL competencies, an e-portfolio based on the PDP was implemented in an engineering technology programme. The effectiveness of this intervention was measured using attitude measures in a pre-post design.

In the pre-test, students of the first and second bachelor were asked about the LLL competencies and their importance, the extent to which they are taught and the extent to which they are assessed. The first bachelor students perceived the general lifelong learning competency to be the most important (M = 3.5), but not that extensively taught (M = 2.4) and assessed (M = 2.1). This decrease in scores from the importance to taught to assessed variable can also be identified for the LLL competencies. The data from the second bachelor contains a similar relationship between the variables, however, LLL is indicated to have the same importance as the LLL competencies. When zooming in on the taught and assessed variable it can be seen that locating and scrutinizing information as well as self-reflection are taught and assessed the most for both the first and second bachelor. This is in line with the fact that these competencies are included the most explicitly in the curriculum.

Analysis of the post-test shows similar results. Lifelong learning remains one of the most important competencies in engineering practice but is less present in engineering education. A new variable here is competency level variable (how competent do you think you are?) where the relatively modest answers of the students stand out (bachelor 1: 2.2 – 3.1; bachelor 2: 2.0 – 2.6). These means are around the midpoint of the scale and lie between ‘somewhat competent’ and ‘competent’ on the response scale. In previous research at the same university, the lifelong learner scale (Authors 2023) was used to measure LLL preparedness and this measurement painted a more positive picture with a mean score well above the midpoint of the scale (M = 3.44; Min = 2.57; Max = 4.57). Two different measures which aimed to measure a similar idea – LLL attitude vs. LLL preparedness – thus paint a slightly different picture.

The longitudinal analysis of the data points out that the second bachelor students find being able to create a learning plan significantly less important than the first bachelor students. It is notable how they find creating a learning plan to be only somewhat important while they indicate lifelong learning to be the second most important competency in the list. This finding aligns with other (currently unpublished) observations of ours on how students conceptualize lifelong learning as being open-minded and curious, and associate it with informal and unintentional learning, and thus without a learning plan. Meanwhile professionals seem to have a more formal idea of lifelong learning with employees taking on courses or doing direct self-study where a learning plan becomes more relevant. If this is the case, the discrepancy between students’ and professionals’ conceptualisation of lifelong learning can cause a misunderstanding between recent graduates and their employers. This line of research needs to be further inspected within our data and evaluated for generalizability.

A main effect of the time point – pre versus post testing – is not present in the data. Inspection of the visualisations in Figure 1 point out that a more complex effect might be at play here. The first bachelor students seem to go through a drop in attitudes between the pre and post test while the second bachelor students go through an increase. Only for self-reflection, this interaction effect is significant, but visually it can be identified for most other variables as well. This decrease in the first bachelor can be a consequence of students initially having less experience with these competencies and perceiving their importance to be very high. By engaging with the e-portfolio they initially become more critical (post-test, first bachelor), while the second bachelor’s are starting to recognize the importance of LLL and LLL competencies. This progression is similar to what is called the Dunning-Kruger effect (Dunning 2011) where people initially overestimate themselves because of a lack of knowledge and experience, but later, when they are more experienced, underestimate themselves.

4.2 Next steps

This final section includes some next steps in the implementation of the e-portfolio based on the results, including (1) changes to the e-portfolio for next academic year, (2) the measurement of LLL competencies, and (3) the research design of the next e-portfolio.

Currently, the PDP is present in the e-portfolio (Appendix A), but student go through multiple cycles in one semester. The time in between the cycles is too short to fully engage in self-monitoring. In a next version of the e-portfolio, students will go through only one PDP cycle per semester to increase the time for monitoring one's own learning process. Additionally, the different steps of the PDP as outlined by Patel et al. (2023), as well as the idea of the PDP as a process, will be made more explicit for students. Making competencies explicit seems to work, as can be seen in the higher scores for self-reflection and locating and scrutinizing information for the taught and assessed variables (as seen in section 3.1 and 3.2).

The competency level variable aimed to capture how students would estimate their competency level and the slightly different results we have found previously using a survey (LLS; Authors 2023) raise questions about their validity. Future research will have to point out which measures are better at predicting actual LLL behaviour or an increase in their actual mastery of the LLL competencies. A first step here will be to compare the self-reported measures with (1) grades on relevant assignments such as self-reflection exercises or learning plans in the context of the e-portfolio, and (2) interviews with students giving insight in how they answer these questions and how it relates to their competencies.

The effectiveness of the e-portfolio in this study is inconclusive because of a lack of a control group. Future studies using the more explicit PDP e-portfolio, as described above, will include a control group to compare the natural growth in LLL attitudes to the growth in a student group with an e-portfolio. Qualitative data collection will be used to further underpin conclusions.

5 ACKNOWLEDGEMENTS

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REFERENCES

Alam, Firoz, Harun Chowdhury, Alex Kootsookos, and Roger Hadgraft. 2015. "Scoping E-Portfolios to Engineering and ICT Education." *Procedia Engineering* 105 (Icte 2014): 852–57. https://doi.org/10.1016/j.proeng.2015.05.102.

Chaudhuri, Tushar, and Béatrice Cabau. 2017. *E-Portfolios in Higher Education: A Multidisciplinary Approach*. 1st ed. Springer Singapore. https://doi.org/10.1007/978-981-10-3803-7.

Cruz, Mariana Leandro, Gillian N. Saunders-Smits, and Pim Groen. 2020. "Evaluation of Competency Methods in Engineering Education: A Systematic Review." *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2019.1671810.

Authors. 2023.

Dunning, David. 2011. *The Dunning-Kruger Effect. On Being Ignorant of One's Own Ignorance*. *Advances in Experimental Social Psychology*. 1st ed. Vol. 44. Elsevier Inc. https://doi.org/10.1016/B978-0-12-385522-0.00005-6.

Galanis, Nikolas, Enric Mayol, Maria José Casañ, and Marc Alier. 2017. “Towards the Organization of a Portfolio to Support Informal Learning.” *International Journal of Engineering Education* 33 (2): 887–97.

Gutiérrez-Santiuste, Elba, Sonia García-Segura, María Ángeles Olivares-García, and Elena González-Alfaya. 2022. “Higher Education Students’ Perception of the E-Portfolio as a Tool for Improving Their Employability: Weaknesses and Strengths.” *Education Sciences* 12: 1–14. https://doi.org/https://doi.org/10.3390/educsci12050321.

Harun, Raja Nor Safinas Raja, Mohd Hafiz Hanif, and Goh Swee Choo. 2021. “The Pedagogical Affordances of E-Portfolio in Learning How to Teach : A Systematic Review.” *Studies in English Language and Education* 8 (1): 1–15. https://doi.org/https://doi.org/10.24815/siele.v8i1.17876.

Huang, Jeff J S, Stephen J H Yang, Poky Y F Chiang, and Luis S Y Tzeng. 2012. “Building an E-Portfolio Learning Model : Goal Orientation and Metacognitive Strategies.” *Knowledge Management & E-Learning: An International Journal* 4 (1): 16–36.

Patel, Santosh, Gareth Kitchen, and Janet Barrie. 2013. “Personal Development Plans - Practical Pitfalls.” *Trends in Anaesthesia and Critical Care* 3 (4): 220–23. https://doi.org/10.1016/j.tacc.2013.04.003.

Roger, G, and Anette Kolmos. 2020. “Emerging Learning Environments in Engineering Education.” *Australasian Journal of Engineering Education* 25 (1): 3–16. https://doi.org/https://doi.org/10.1080/22054952.2020.1713522.

Sankaran, Meenakshi, and Amiya Kumar Rath. 2021. “Assessing Undergraduate Engineering Programmes Using Alumni Feedback.” *Journal of Engineering Education Transformations* 34 (Special Issue): 733–41. https://doi.org/10.16920/jeet/2021/v34i0/157174.

Yap, Jiun Soong, and Jully Tan. 2022. “Lifelong Learning Competencies among Chemical Engineering Students at Monash University Malaysia during the COVID-19 Pandemic.” *Education for Chemical Engineers* 38 (September 2021): 60–69. https://doi.org/10.1016/j.ece.2021.10.004.

Appendix A Content of the e-portfolios in relation to the PDP steps

Portfolio Bachelor 1		Portfolio Bachelor 2	
Question	PDP step	Question	PDP step
Self-assessment on professional competencies[1]	Identify	Self-assessment on professional competencies[1]	Identify
Define one concrete action	Prepare	Define one concrete action	Prepare
(The project starts)	Act and monitor	(The project starts)	Act and monitor
Reflect on peer feedback	Reflect	Reflect on peer feedback	Reflect
Select one competency to work on	Identify	Select one competency to work on	Identify
Propose one concrete action	Prepare	Propose one concrete action	Prepare
(The project continues)	Act and monitor	Self-assessment on professional competencies[1]	Identify
Self-assessment of presentation skills after a presentation	Identify	Reflection about feedback during the semester	Reflect
Define two opportunities for growth	Prepare		
(The project continues)	Act and monitor		
Reflect on peer feedback	Reflect		
Select one competency to work on	Identify		
Propose one concrete action	Prepare		
Self-assessment on professional competencies[1]	Identify		
Reflection about feedback during the semester	Reflect		

[1] The professional competencies are following: presentation skills, written communication, being a team player, interacting with others, stress resilience, time management, organisation, ethical thinking, critical thinking, creativity, initiative and problem-solving.

"ONCE I FINALLY UNDERSTAND THE CONCEPT, I WON'T RETHINK AND REDO IT AGAIN, BECAUSE I NOW HAVE THAT VISUAL AND THAT ENTIRE CONCEPT IN MY HEAD TO THINK BACK ON": STUDENTS MENTAL MODELS WHEN USING MECHANICAL OBJECTS AS LEARNING AIDS

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Conference Key Areas: *Curriculum development and emerging curriculum models in engineering; Teaching technical knowledge in and across engineering disciplines*
Keywords: *mental models, think-aloud protocol, mechanical objects, conceptual understanding, thermodynamics*

ABSTRACT

This study employed a think-aloud methodology to delve into the intricacies of student cognition and problem-solving behaviors in the context of thermodynamics education, specifically focusing on the challenging domain of psychometrics. By elucidating the cognitive strategies employed by students with and without the use of physical objects, the study aimed to provide valuable insights into the efficacy of tangible learning aids in enhancing conceptual understanding and problem-solving proficiency in thermodynamics. The study findings reveal that the presence of a simple physical object facilitated the development of robust mental models in the participants from the group with the object, enabling a more intuitive grasp of problems and alignment with scientific principles. Suggestions for implications for engineering education and further research are shared in the conclusion of this paper.

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1 INTRODUCTION

The use of physical artifacts in STEM education has become a significant teaching strategy for demystifying complex and abstract concepts. By providing tangible representations of complex ideas, these artifacts offer students hands-on experiences that enhance understanding and memory (Koretsky et al., 2018; Mitropoulos et al., 2024). Especially in subjects like mathematics and physics, where learners often confront abstract theories, physical models, manipulatives, and simulations become critical for linking theoretical knowledge with practical application (Bain et al., 2014; Rogers, 2023). For example, in mathematics, tangible tools such as geometric shapes and algebraic manipulatives allow students to interact with abstract concepts in a visual and tactile manner, thereby promoting active learning and deeper comprehension (Kuhn, 2022).

Furthermore, these artifacts are essential for situating STEM concepts in real-world scenarios, making the theoretical knowledge more relevant and applicable (Koretsky et al., 2018; Kuhn, 2022). By mimicking real-life situations or natural phenomena, they help students bridge the gap between classroom learning and practical applications, emphasizing the real-world utility of STEM education (Mitropoulos et al., 2024). In the context of engineering education, the deployment of physical prototypes and lab equipment enables students to apply theoretical principles in the creation and testing of actual systems, fostering essential skills such as problem-solving, critical thinking, and experimentation—all crucial for success in STEM fields (Nottis et al., 2018; Rogers, 2023).

In engineering specifically, the abstract and complex nature of thermodynamics presents a considerable challenge for many students (Bain et al., 2014). Nevertheless, integrating physical artifacts into the learning process can significantly enrich students' educational experience in this area (Kuhn, 2022). Utilizing tangible objects like pistons and phase change models allows educators to concretely demonstrate key thermodynamic principles such as energy transfer and entropy. These physical models not only facilitate the visualization of abstract concepts but also enable hands-on exploration of variables and their effects, deepening students' understanding of thermodynamic principles (Bain et al., 2014; Rogers, 2023; Saricayir et al., 2016). Through these practical tools, educators can successfully bridge theoretical knowledge with its practical applications, preparing students to navigate the complexities of thermodynamics in real-world engineering contexts.

This paper discusses a portion of a broader study focused on evaluating the impact of physical artifacts on the learning experience within thermodynamics education. Specifically, it examines how these tools influence student cognition and the development of mental models during problem-solving tasks. Utilizing a think-aloud protocol, the study explores the cognitive strategies employed by students when faced with thermodynamics problems, with and without the aid of physical artifacts. The investigation centers on problem-solving sessions related to critical topics in thermodynamics: heat and work, entropy, and psychometrics. This paper particularly emphasizes the findings from sessions on psychometrics, aiming to uncover how tangible learning tools affect students' mental models and problem-solving approaches. Through this detailed analysis, we seek to highlight the value of physical artifacts in enhancing students' understanding and mastery of complex thermodynamic concepts, contributing to the literature on effective teaching strategies in STEM education.

1.1 Abstract and difficult topics in engineering thermodynamics

Thermodynamics is the branch of physics that deals with the relationships between heat, work, energy, and the properties of matter, explaining the principles governing the behavior of systems undergoing thermal processes (Drake, 2021; Steane, 2016). Abstract and difficult topics in engineering thermodynamics often present formidable challenges for students (Bain et al., 2014). Concepts within thermodynamics delve into the fundamental principles governing energy transfer, heat exchange, and the behavior of complex systems, posing significant cognitive hurdles due to their abstract nature and mathematical intricacy (Bain et al., 2014; Kuhn, 2022; Saricayir et al., 2016). Topics such as entropy, which quantifies the disorder or randomness of a system, and thermodynamic processes involving heat and work interactions, require students to grapple with theoretical frameworks that can be challenging to visualize and comprehend (Foroushani, 2019). Additionally, psychometrics, which deals with the properties of moist air and their applications in air conditioning and refrigeration, introduces complexities stemming from the non-linear relationships and multifaceted interactions inherent in air-water vapor mixtures (Foroushani, 2019; Steane, 2016). The abstract nature of these topics, coupled with their inherent complexity, underscores the need for innovative pedagogical approaches and effective instructional strategies to facilitate students' understanding and mastery of thermodynamic principles.

1.2 Conceptual understanding

Conceptual understanding lies at the core of effective learning in thermodynamics, providing students with a robust foundation upon which to navigate the intricate landscape of this discipline. Unlike mere memorization of formulas and procedures, conceptual understanding entails grasping the underlying principles, relationships, and phenomena that govern thermodynamic systems (Foroushani, 2019; Saricayir et al., 2016). It involves the ability to interpret and apply abstract concepts in diverse contexts, discern patterns and trends within complex data, and make connections between theoretical knowledge and real-world phenomena (Saricayir et al., 2016). A strong conceptual understanding enables students to not only solve problems algorithmically but also to reason critically, analyze situations holistically, and devise innovative solutions to novel challenges in thermodynamics. Through engaging in activities that promote conceptual understanding, such as inquiry-based experiments, modelling exercises, and collaborative problem-solving tasks, students can develop deep insights into thermodynamic principles, fostering enduring comprehension and proficiency in this intricate discipline (Ertikanto et al., 2023; Nottis et al., 2018; Rogers, 2023).

1.3 Mental models

Mental modelling is a cognitive process wherein individuals construct internal representations or mental simulations of external phenomena, systems, or processes to understand, predict, and interpret their behavior (Johnson-Laird, 1995). In the context of thermodynamics, mental models play a crucial role in how students conceptualize and make sense of complex phenomena such as heat transfer, entropy changes, and thermodynamic cycles (Ertikanto et al., 2023). By mentally constructing simplified versions of thermodynamic systems and processes, individuals can explore the relationships between variables, anticipate system behavior, and formulate hypotheses about outcomes. Mental models serve as cognitive frameworks that facilitate problem-solving, decision-making, and the interpretation of experimental data within the domain of thermodynamics (Hsu &

Thomas, 2002; Kirschner & Van Merriënboer, 2013). As students engage in learning activities, they continuously refine and adapt their mental models based on new information, experiences, and feedback, leading to a deeper understanding of thermodynamic principles and their applications.

Through the iterative refinement of mental models, students develop metacognitive awareness and self-regulation, enhancing their ability to transfer learning to novel contexts and apply acquired knowledge in practical situations (Nilson, 2013). Overall, the deliberate integration of mental models in education fosters active engagement, conceptual understanding, and metacognitive development, empowering students to become lifelong learners equipped with versatile cognitive tools for navigating the complexities of the world around them.

2. METHODOLOGY

This study employed a think-aloud protocol to investigate the cognitive processes and problem-solving strategies utilized by students in understanding and solving psychometrics problems in thermodynamics. Sixty students overall participated in the think-aloud protocol study. For the purpose of this study, the researchers worked with the transcripts of ten students who sat down for a think-aloud session that was focused on understanding the problem-solving mental models when students engaged in solving psychometrics-related problems. The think-aloud sessions were conducted a week later after the problem-solving section on psychometrics. Five students were selected from a group that used physical objects as aids during problem-solving sessions, while the other five were chosen from a group that did not utilize any objects. Each student engaged in a step-by-step verbalization of their problem-solving procedure while tackling the psychometrics problems. The think-aloud sessions were audio-recorded to capture the students' verbalizations in real-time and lasted approximately 45 minutes each.

Subsequently, the audio recordings were transcribed verbatim, and the transcripts were cleaned to remove any extraneous speech or irrelevant content. Thematic coding was then applied to the transcripts to identify emerging themes and patterns in the students' problem-solving approaches. The coding process followed Mettes et al. (1980, 1981) an established procedure tailored to the step-by-step method commonly used in problem-solving and recently adapted to the context of statics in Taraban et al. (2008). The codebook was further augmented to include student experiences and resource usage based on previous work done by McNeil et al. (2016). This systematic approach ensured consistency and rigor in the analysis of the think-aloud data, allowing for the identification of key insights into students' mental models and cognitive processes during psychometrics problem-solving.

This study’s codebook was based on the phases and subphases developed by Mettes et al. (1980, 1981) referred to as the Program of Actions and Methods (PAM) for systematic problem solving in science. The PAM is divided into 4 phases as illustrated in figure 1. Mettes et al. (1980, 1981) divided each phase into subphases that were used as 28 codes in this study, similar to what was done in Taraban et al. (2008). Figure 2 illustrates the conceptual model of student’s belief about engineering problem solving developed by McNeil et al. (2016). This study used the

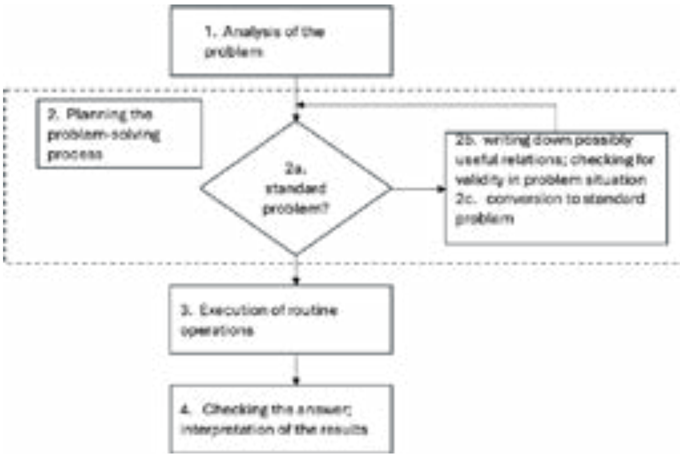

Fig. 1. Principal Phases of the PAM for systematic problem solving (Mettes et al., 1980)

elements of this model as 17 codes to further analyze the think aloud session transcripts.

3 RESULTS AND DISCUSSION

For this study, as well as the larger study, the researchers use Dedoose to code the think aloud session transcripts. The team looked into the code application tables as well as the co-occurrence matrix to investigate the potential themes arising from the coding process. Figure 3 represents the packed code cloud generated by Dedoose as a weighted representation of the codes present in the studied sample. It is important to mention that not all the codes have been observed in this first set of coding for this specific exercise given the nature of the posed questions.

The study results indicate that all participants present at the problem-solving session related to psychometrics engaged initially with the problem statements, an action likely influenced by the directive nature of the interviewer's prompt. This finding

Fig. 2. Student's Belief About Engineering Problem Solving (McNeill et al., 2016)

Fig 3. Packed Code Cloud

parallels the systematic problem-solving approach delineated by Mettes et al. (1980) and Taraban et al. (2008), which emphasizes the importance of the problem representation phase in the cognitive process of problem-solving. Moreover, analysis revealed a slightly more pronounced inclination among control group participants to draw upon personal and life experiences. This approach aligns with Johnson-Laird's (1995) mental models theory, suggesting that individuals rely on analogical reasoning, applying known experiences to unfamiliar problem contexts. Such strategies underscore the complexity of mapping personal experiences onto scientific principles.

The results also highlight that a subset of experimental group participants referenced mechanical objects during problem-solving, which corresponded with an enhanced use of intuition. This observation is supported by Koretsky et al. (2018) and Mitropoulos et al. (2024), highlighting the potential for tangible learning aids in fostering a deeper conceptual understanding. The reliance on intuition suggests a cognitive shift towards conceptual and principled reasoning, indicative of a deeper engagement with the material. For instance, one participant remarked, “I've always been a pretty conceptual learner, so when I can relate things to something tangible, or even just some fundamental concept, then I get it. I've never been good at remembering things at all. I can't just memorize things, so I have to really understand them.” This personal account vividly illustrates the study's findings, emphasizing the significant role that physical objects play in enhancing the intuitive grasp of complex principles for individuals predisposed to conceptual learning.

Participants from both groups eventually recognized key relationships among the variables, albeit with varying degrees of accuracy. This behavior demonstrates the cognitive effort to integrate provided information into a coherent understanding of the problem, as suggested by the coding rubric based on Mettes et al. (1980, 1981) and the conceptual model developed by McNeil et al. (2016).

Furthermore, it could be noted that participants in the experimental group sought to correlate the provided information directly with the problem or its model. This finding underscores the potential of physical artifacts to enhance the application of scientific principles to problem-solving, supporting the pedagogical value of tangible objects in abstract domains (Kuhn, 2022). Echoing this sentiment, one participant shared, “I had physically experienced all these things, so it just made a lot of sense. I think physical explanations of things have always been easier for me than, say, mathematical explanations of things." This reflection reinforces the value of experiential learning through physical artifacts, underlining how tangible experiences can demystify complex theoretical concepts, thereby catering to students who find abstract mathematical explanations challenging."

Moreover, both groups demonstrated a capacity to articulate conceptual understanding and identify key relationships. Notably, the experimental group exhibited a pronounced tendency to discern and articulate law-like principles. This distinction underscores the role of physical artifacts in promoting a more nuanced engagement with and application of fundamental scientific principles, echoing findings from Bain et al. (2014) and Rogers (2023).

Finally, the coding highlighted distinct patterns in how each group approached the psychometrics problems, revealing the potential influence of tangible learning aids on their cognitive processes. Participants from the group without objects predominantly leveraged personal or life experiences in their problem-solving endeavors, indicative of a reliance on analogical reasoning. This strategy suggests an attempt to bridge abstract thermodynamics concepts with familiar real-world contexts, a method that can offer intuitive insights but also risks inaccuracies when analogies do not fully align with scientific principles. Furthermore, these participants often resorted to guessing and subsequently recognizing mistakes—a hallmark of a trial-and-error approach. This behavior points to less developed mental models, where uncertainty in problem-solving steps is prevalent. Despite occasionally making assumptions to simplify problems and identifying key relationships and equations, these strategies were not predominant, suggesting a less systematic approach to understanding thermodynamics problems.

In contrast, the group with access to mechanical objects exhibited a more structured approach to problem-solving. Frequent references to conceptual understanding and intuition were observed, indicating that the presence of tangible aids likely facilitated a deeper, more intuitive grasp of thermodynamics concepts. This group demonstrated a strategic approach to problem simplification and a systematic

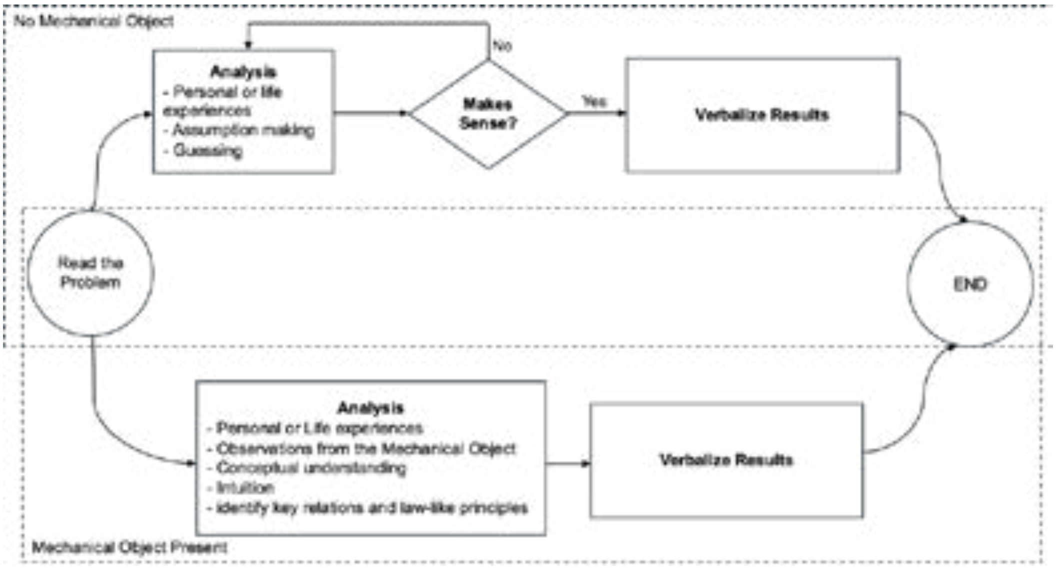

Fig 4. Simplified Student Mental Models of Problem-Solving for Each Group

breakdown of problems, behaviors that suggest well-developed, robust mental models capable of navigating complex problems with greater efficacy. The ability to identify key relations and law-like principles more frequently and accurately suggests that these participants' mental models were closely aligned with the scientific principles of thermodynamics, enabling a direct and effective approach to problem-solving as illustrated in Figure 4.

4 Conclusions and Future Works

This study, focusing on a set of ten students engaged in solving psychometrics problems, provided detailed insights into how the presence or absence of a simple physical object could influences individual problem-solving strategies and their mental models. Through the meticulous application of a think-aloud protocol, we captured the cognitive processes underpinning students' approaches to these challenges, revealing the nuanced impact of tangible learning aids on their problem-solving efficacy.

For the participants who had access to a physical object during the problem-solving sessions, there was a notable facilitation in the development of robust mental models. This select group of students demonstrated a more intuitive grasp of the problems at hand, aligning closely with scientific principles in their problem-solving efforts. Their strategies were characterized by a direct and strategic navigation through the complexities of psychometrics, contrasting markedly with their peers without such aids.

The group without physical objects leaned more heavily on personal experiences and analogical reasoning. Although creative, this approach led to a less structured problem-solving process. It was marked by a reliance on trial-and-error tactics and an observable uncertainty in applying abstract thermodynamics concepts.

This investigation's findings, while rich and informative, are contextualized within the experiences of these ten students and the specific domain of solving psychometrics-related problems. It draws attention to the potential benefits of integrating tangible objects into educational practices, suggesting that such aids could significantly impact students' understanding and problem-solving strategies. However, the observations and implications derived from this study are specific to this particular cohort and the unique set of problems they addressed.

Acknowledging the limited scope of this study—centered on a singular object and a focused problem-solving session—it was crucial to refrain from broad generalizations. The intention was to provide a detailed account of how tangible objects might influence problem-solving within a narrowly defined context. Future research is planned to extend beyond this preliminary exploration, aiming to code and analyze all think-aloud activities conducted across a broader array of topics and with a larger group of participants. This subsequent work will seek to validate, refine, or expand upon the findings presented here, offering a more comprehensive understanding of the role mechanical objects play in engineering education, specifically within the realm of thermodynamics and beyond.

REFERENCES

Bain, K., Moon, A., Mack, M. R., & Towns, M. H. (2014). A review of research on the teaching and learning of thermodynamics at the university level. *Chem. Educ. Res. Pract.*, *15*(3), 320–335. https://doi.org/10.1039/C4RP00011K

Drake, G. W. F. (2021). Thermodynamics. In *Encyclopedia Britannica*. https://www.britannica.com/science/thermodynamics

Ertikanto, C., Viyanti, & Hardini, S. N. (2023). Effectiveness of Guided Inquiry Learning Model on Thermodynamics Content in LMS-Based Blended Learning with Regard to Students' Higher Order Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11280–11288. https://doi.org/10.29303/jppipa.v9i12.4026

Foroushani, S. (2019). Misconceptions in engineering thermodynamics: A review. *International Journal of Mechanical Engineering Education*, *47*(3), 195–209. https://doi.org/10.1177/0306419018754396

Hsu, Y.-S., & Thomas, R. A. (2002). The impacts of a web-aided instructional simulation on science learning. *International Journal of Science Education*, *24*(9), 955–979. https://doi.org/10.1080/09500690110095258

Johnson-Laird, P. N. (1995). *Mental models: Towards a cognitive science of language, inference, and consciousness* (6. print). Harvard Univ. Press.

Kirschner, P. A., & Van Merriënboer, J. J. G. (2013). Do Learners Really Know Best? Urban Legends in Education. *Educational Psychologist*, *48*(3), 169–183. https://doi.org/10.1080/00461520.2013.804395

Koretsky, M., Keeler, J., Ivanovitch, J., & Cao, Y. (2018). The role of pedagogical tools in active learning: A case for sense-making. *International Journal of STEM Education*, *5*(1), 18. https://doi.org/10.1186/s40594-018-0116-5

Kuhn, S. (2022). *Transforming learning through tangible instruction: The case for thinking with things*. Routledge.

McNeill, N. J., Douglas, E. P., Koro-Ljungberg, M., Therriault, D. J., & Krause, I. (2016). Undergraduate students' beliefs about engineering problem solving. *Journal of Engineering Education*, *105*(4), 560–584. https://doi.org/10.1002/jee.20150

Mettes, C. T. C. W., Pilot, A., Roossink, H. J., & Kramers-Pals, H. (1980). Teaching and learning problem solving in science. Part I: A general strategy. *Journal of Chemical Education*, *57*(12), 882. https://doi.org/10.1021/ed057p882

Mettes, C. T. C. W., Pilot, A., Roossink, H. J., & Kramers-Pals, H. (1981). Teaching and learning problem solving in science: Part II: Learning problem solving in a thermodynamics course. *Journal of Chemical Education*, *58*(1), 51. https://doi.org/10.1021/ed058p51

Mitropoulos, T., Bairaktarova, D., & Huxtable, S. (2024). The utility of mechanical objects: Aiding students' learning of abstract and difficult engineering concepts. *Journal of Engineering Education*, *113*(1), 124–142. https://doi.org/10.1002/jee.20573

Nilson, L. B. (2013). *Creating self-regulated learners: Strategies to strengthen students' self-awareness and learning skills*. Sterling, Virginia.

Nottis, K. E., Vigeant, M., Prince, M., Golightly, A., & Gadoury, C. (2018). Computer simulations vs. Physical experiments: A gender comparison of implementation methods for inquiry-based heat transfer activities. *2018 ASEE Annual Conference & Exposition Proceedings*, 30214. https://doi.org/10.18260/1-2--30214

Rogers, T. R. (2023). Hands-on Model for Investigating Entropy and Disorder in the Classroom. *The Physics Teacher*, *61*(6), 439–443. https://doi.org/10.1119/5.0089761

Saricayir, H., Ay, S., Comek, A., Cansiz, G., & Uce, M. (2016). Determining Students' Conceptual Understanding Level of Thermodynamics. *Journal of Education and Training Studies*, *4*(6), 69–79. https://doi.org/10.11114/jets.v4i6.1421

Steane, A. M. (2016). *Thermodynamics: A complete undergraduate course*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198788560.001.0001

Taraban, R., Anderson, E., Craig, C., Fleming, J., DeFinis, A., & Brown, A. G. (2008). An assessment of problem solving processes in undergraduate statics. *2008 Annual Conference & Exposition Proceedings*, 13.175.1-13.175.14. https://doi.org/10.18260/1-2--3440

EDUCATORS' WELL-BEING IN THE LONG RUN

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ABSTRACT

Teacher burnout can be a severe problem in higher education, as it can affect the quality of education. In 2022, we started a career planning course based on Stanford's Design Your Life course (BurnettB and EvansD 2016; 2018; 2020), supplemented with positive psychological exercises, for the teachers and researchers of the Budapest University of Technology and Economics. 4 courses have taken place so far, in two types of organization (classic or intensive), with 53 participants. In the study below, we asked the previous participants to participate in a follow-up research, in which we asked about the usefulness of the course in terms of their well-being and burnout. We asked them for a subjective estimate in both areas and used an objective measurement. Their well-being was measured using the PERMA Questionnaire (ButlerJ and KernML 2016), and Maslach's Burnout Inventory (Maslach et al., 1996) was used to measure burnout. The PERMA Questionnaire was already known to them, as they filled it out at the beginning of the course and three months after the course, and it also showed positive results in the short-term follow-up (Authors 2023). One year later, based on the sample's responses (n=22), the course is particularly effective in terms of well-being, which is supported by medium and significant solid correlations. Based on this, we can conclude that the course is effective both in the short and long term, thus suitable for permanently improving the mental state of teaching colleagues.

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1 INTRODUCTION

In these challenging times, the competitiveness of a higher education institution is crucial. National and international rankings of universities deal partly with the staff's academic performance metrics, such as teaching excellence and rate of publications. The other indicators related to graduates also depend on the effectiveness of the faculty. After all, only prepared and dedicated teachers can train excellent professionals. We see in the literature that the burnout of employees works against the above process, while well-being supports it (RahmT and HeiseE 2019; BallantyneJ and RetellJ 2020; Smetackova et al. 2019).

1.1 Programs targeting decrease teachers' burnout and increase well-being

As Watts and Robertson (2011) emphasized in their review article, a decade ago, burnout among academic staff was spread out. Mironova and Slokta (2021) found in their recent meta-analysis that burnout among academic staff is a common state because university teachers face many stressors that can lead to burnout syndrome. To solve the situation, we must better understand the demands and resources of higher education staff, especially teachers (Khan et al. 2017). The stressors have changed and multiplied over the last few years. However, we see a lack of techniques that can solve the situation and improve academicians' well-being (HyattK 2022).

These two phenomena are interrelated (Kolomitro et al. 2020). Programs targeting the development of critical elements of well-being are complex to study empirically. Researchers focus on specific aspects of well-being in terms of the PERMA model, a widely accepted and well-known framework (Donaldson et al. 2022; Linton et al. 2016). According to Seligman's (2011) updated model, people have to fulfill five different components to reach the state of flourishing. These are positive emotions, engagement, (positive) relationships, meaning, and accomplishment (SeligmanM 2011). Furthermore, well-being considers other factors, such as physical health, absence of negative emotions and loneliness, and presence of the experience of happiness (ButlerJ and KernML 2016).

Several studies found that engagement, dispositional optimism (Barkhuzien et al. 2014), resilience (Johnson et al. 2019), more commitment, and better work-life balance (Fontinha et al. 2019) seem to be necessary for being well (KinmanG and JohnsonS 2019) and reduce burnout in direct and indirect ways.

1.2 A possible solution: The Designing Your Life program

Our Designing Your Life Program (DYLF) is based on Burnett and Evans's "Designing Your Life" and "Designing Your Work Life" methodologies (BurnettB and EvansD, 2016; 2018; 2020). Regarding the authors' idea, a well-designed life is the key to a well-lived life and well-being. The idea came up first as a class at Stanford University designed for design students. In this approach, they used techniques that fit designers' mindsets, which means it is suitable for people who like to solve problems (BurnettB and EvansD, 2016; 2018; 2020). We expected that the design thinking mindset would also fit in with the original thinking patterns of the Budapest University of Technology and Economics teachers (Authors 2023).

Without pretensions of completeness, the most crucial Design thinking mindset elements that we touched on in the DYLF program were (based on BrownT 2008; 2009):

- Empathy: Understanding the needs, desires, and motivations of others is fundamental to design thinking. In the DYLF program, the tasks helped the participants to be empathic about themselves.
- Creative Confidence: The significance of instilling confidence in individuals to unleash their creative potential and innovate.
- Iterative Thinking: advocates for an iterative approach to problem-solving, where ideas are continuously refined through prototyping and testing. In the DYLF program, for example, we organized Living Library with participants who have worked or worked at our university and have already achieved attractive results in several career segments.
- Mindful Observation: design thinkers cultivate the ability to observe the world around them keenly, uncovering insights and opportunities for innovation.
- Collaboration: design thinking is a team sport. Bringing diverse perspectives together and fostering collaboration is critical to unlocking innovative solutions.

We had exciting results based on the data we measured during the program and the short-term follow-up (Authors 2023). First, we saw a statistically positive effect at the short-term follow-up. As relationships are essential for well-being (SeligmanM, 2002; SeligmanM, 2011; KhawD and KernML, 2014) and the program has its' effect on the relationship scale, we could say that the Designing Your Life program seems appropriate for engineering university teachers. At the end of the course, the participants had concrete plans for the following months. They have tools to use daily and planning to be more accurate and flexible simultaneously. These tools and plans can lead them through the difficulties of academic career building so that they can set more appropriate achievements. Participants gave feedback from growing social networks and felt that the university cares more about them than they had felt before the program. We also found that the workshop design is familiar to engineers' thinking, and with these small changes, we adapted it to our university's circumstances (Authors 2023).

1.3 Research questions

Our previous research confirmed that the effect of the design thinking-based career planning course on the well-being of the participating teachers can be felt in the short term (Authors 2023). In the present research, we examine the long-term effects.

Burnout is a syndrome to avoid, while well-being is a generally desirable state. The course provided the tools to achieve and maintain this dual goal. After one year, we were curious to see if the participants used the knowledge they perceived and experienced a positive change in terms of their well-being along the PERMA factors.

This study aims to explore whether the course mentioned above is an appropriate tool for engineering educators in the stressful context of higher education to reach a state of well-being and avoid burnout in the long run, i.e., i.e., can the results of the course be felt 1-1.5 years after the program.

2 METHODOLOGY

2.1 Study design

We planned a follow-up study for those who participated in the carrier (re)planning course. In an online questionnaire, we asked for demographic and carrier-regarded data, attitudes about the efficiency of the course, their experiences about the course in the long run with extended text answer possibilities, and some retrospective opinions about their mental state in terms of burnout and well-being.

In addition to the qualitative part, we used quantitative tools. To measure former participants' well-being, we used the PERMA Profiler (ButlerJ and KernML 2016), which they already knew, and the Maslach Burnout Inventory (Maslach et al. 1996).

We shared the questionnaire with each former participant in February 2024, 0.5-1.5 years after they finished the course.

Before starting the course, we informed the participants that the program also has a research purpose. By voluntarily participating in the program, they gave informed consent, which they had the right to withdraw at any time. The participants anonymously filled out the course and follow-up questionnaires, but their data was not processed this way.

In this study, we only focus on one part of the data.

2.2 Sample description

We asked 53 former participants to complete the online survey, and 22 responded. In this section, we describe them.

Twelve were female and ten male, which is similar to the distribution of the courses. One was a professor and one associate professor, 10 were senior lecturers, four assistant research fellows, one technical assistant, and 5 PhD students.

Participants work at the university for an average of 8.27 years with a 5.08 years SD.

16 participated in a classical course setting, i.e., 5 times in a 6-week long period, and 5 participated in an intensive course setting, i.e., in a 2.5-day long weekend training.

After the first 3 run courses, we offered former participants a 2.0 course to develop themselves, and among our respondents, 11 attended that course too.

50% of the respondents attended the first course (May 2022), 22,7% participated in the second course (October 2022), 13,6% attended the third course (April 2023), and 13,6% participated in the fourth course (September 2023). That means that 53% referred to more than 1.5-1-years effects, 14% to short one-year effects, and only 13% had less than 1-year impact. The data is retrospective and self-reported based on former participants' memories and everyday experiences. In this sense, researchers have to trust respondents as psychological changes are the best experienced by the person themselves.

3 RESULTS

3.1 Effectiveness of the course – descriptives

Half of the sample (n=11) said they had significantly shifted their career since the course ended. Many of them got their degrees or started their doctoral plot (n=6), have successfully won tenders of excellence (n=3), and reached higher or better positions (n=4). However, it is interesting that there is no difference in any of the examined indicators between the participants who achieved progress and those who did not. From this, we can conclude that the later described changes in well-being are not the results of material changes associated with progress but the totality of the internal changes induced by the course.

On a 10-point Likert scale, participants reported the course's general efficiency at 8.32, which means excellent. We also asked them about the usefulness of the PERMA factors because the course tasks were related to the different aspects of well-being (see Authors 2023) on the same 10-point scale shown in Table 1.

Table 1. The usefulness of the course in terms of the PERMA factors

Well-being aspect	Mean	SD	Range
Positive shift in the emotional life (more positive and less negative emotions)	7.27	2.41	1-10
Engagement (finding the intrinsic motivation and one's own goals in work)	7.77	1.95	3-10
Relationships (better and more satisfying network, less feeling of loneliness)	6.55	2.32	2-8
Meaning (finding coherence, meaning, and long-term goals)	7.32	2.01	2-8
Accomplishment (reframing of challenging situations, setting SMART goals with higher demand level)	7	2.05	1-8

In addition, we asked participants to guess how much they were burnt out before attending the course. They referred, on average, 7.27 points on a 10-point Likert scale where one was not at all and 10 was completely burned out. In these terms, the participants were highly loaded and close to complete burnout.

Based on our data, we see that there are positive correlations between work experience (measured in years) and usefulness in positive emotions ($r=.473$, $p<.05$) and motivational changes ($r=.446$, $p<.05$).

3.2 Good practices are taken from the course

Participants shared the three words that came to mind regarding the course. In our translation, these were their primary cognitive and emotional experiences from the course. In Figure 1. we show the diverse answers.

Fig. 1. Answers to the question "What are the three words that come to mind concerning career planning?" The bigger the word is, the more people say it.

We asked the participants what practices or tasks they have used since the course ended. 17 of the respondents mentioned tasks from the original Carrier (re)planning course that they used (i.e., planned in the frame of Designing Your Life Program and directly related to PERMA factors) and pick-up tasks (i.e., come additionally to the tasks) too listed in Table 2. Many of the respondents mentioned more tasks.

Table 2. The usefulness of the course in terms of the PERMA factors (n=17)

Task	Type	Well-being aspect
Odyssey plan (to plant at least 3 different lives)	DYL	meaning
Good times diary (to collect flow activities)	DYL	positive emotions
Concrete action plan (to choose one goal and plan the way to reach it)	DYL	negative emotions
Work-life attitude (to write essays about values)	DYL	engagement
SMART goals (to learn how to write a SMART goal)	pick-up	accomplishment
mind-map making (to learn how to group ideas and tasks)	pick-up	meaning
physical to-do and done list (to feel success and capacity)	pick-up	accomplishment
breathing exercises (to learn physical techniques to cope with stress)	pick-up	health
5-minutes rule (to learn time management)	pick-up	engagement

From the advanced course, they referred to deeper self-knowledge tasks, such as DISC personality classification. However, the whole 2.0 course was a networking event, which weighted the relationship well-being factor.

Based on these results, we can say that they used the tasks as expected and extended the tasks to each well-being factor.

4 SUMMARY AND ACKNOWLEDGMENTS

At the beginning of the DYLF program, the university's main objective was to support colleagues in various critical career stages at a leading national technology university. This is based on preventing burnout and increasing well-being, according to Rahm and Heise (2019), Ballantyne and Retell (2020), and Smetackova and his colleagues (2019).

Critical stages are most often characteristic of periods around the transition of different career stages, for example, before a step forward and at the same time a more significant challenge, or after the step forward, entering a new unknown stage. One of the biggest challenges of the university career is that it typically consists of more significant milestones, with each stage spanning 3-10 years.

Awareness and appropriate human relations are necessary to maintain motivation. During the DYFL course, participants also practice planning short, mid, and long periods. If they become more successful, their commitment and awareness will also increase. The university is interested in providing a long-term perspective for its employees to reduce career-related stress. A better and more satisfying network and less loneliness give inspiration at the critical points.

This follow-up study shows that the DYFL course can support the university's primary goal of keeping and developing employees. So, it can answer the poor toolkit that Hyatt (2022) stated.

We consider the main result of the course that they felt burned out, but based on the follow-up study results', they experienced a positive shift in all areas of well-being elements, according to Seligman (2011), especially in engagement, which allows colleagues to find their intrinsic motivation and look for such goals that lead them to flow experiences as an essential aspect according to Berkhuzien and his colleagues (2014). They are more able to see the big picture, which helps them know the meaning of their huge efforts, strengthening resilience (Johnson et al. 2019; Fontinha et al. 2019). A motivational change appeared as a parallel, mutually reinforcing effect among colleagues with more work experience.

A remarkable result is that they use well-being techniques and exercise what they learned, which is a key to success, according to Kinman and Johnson (2019). This feedback means that they find the course valuable, and the practices fit into their original mindset, so they are familiar with it. This result strengthens the idea that the DYLF-based program is appropriate for the engineering field of higher education, strengthening the main idea that this Designing Your Life program was first dedicated to design students (BurnettB and EvansD, 2016; 2018; 2020).

Last but not least, a good quality of social network and increased collaborative skills are crucial. They mentioned various forms, and almost every time in the follow-up study, the teams at teamwork experiences which are crucial for well-being (SeligmanM, 2002; SeligmanM, 2011; KhawD and KernML, 2014).

However, the ecological validity of the results is limited to our university our former (Authors 2023), and current results are impressive and suggest that the modified DYLF program is a potential and innovative tool to strengthen the psychological capital of engineering educators.

4.1 Acknowledgments

We are grateful to the Budapest University of Technology and Economics, especially the Talent Support Council, for enabling and supporting the organization of the course.

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4.2 Limitations and Further Research Directions

Participation in the course was voluntary by the university lecturers, so in a certain sense, motivated staff participated in the study. Hence, the generalizability of the results is limited. It is also important to emphasize that we worked explicitly with teachers participating in engineering education at a university, which may limit the validity to other fields of higher education.

Since the sample size was relatively small, it was just enough for statistical tests; the conclusions are currently valid in our narrow area, i.e., engineering education. As a further research direction, it would be worthwhile to test the program's scenario widely initially with higher education instructors who volunteer and then expand it into a generally available university well-being development program. Our results are positive and perspectival. The empirical impact assessment of both programs is the task of the future.

REFERENCES

Ballantyne, J. and J Retell. “Teaching Careers: Exploring Links Between Well-Being, Burnout, Self-Efficacy and Praxis Shock.” *Frontiers in Psychology* 10:2255 (2020). doi: 10.3389/fpsyg.2019.02255

Barkhuzien, N, S., Rothmann and F.J.R. van de Vijver. “Burnout and work engagement of academics in higher education institutions: Effects of dispositional optimism.” *Stress & Health,* 30,4 (2014): 322-332. https://doi.org/10.1002/smi.2520

Brown T. “Design Thinking.” *Harvard Business Review,* 86,6 (2008): 84–92.

Brown T. *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation* USA: HarperCollins, 2009.

Burnett, B. and D. Evans. *Designing Your Life: How to Build a Well-Lived, Joyful Life.* New York: Clarkson Potter Publisher, 2016.

Burnett, B. and D. Evans. *The Designing Your Life Workbook: A Framework for Building a Life You Can Thrive In Diary.* New York: Clarkson Potter Publisher, 2018.

Burnett, B. and D. Evans. *Designing Your New Work Life: How to Thrive and Change and Find Happiness--and a New Freedom--at Work.* New York: Clarkson Potter Publisher, 2020.

Butler, J. and M.L. Kern. "The PERMA-Profiler: A brief multidimensional measure of flourishing*." International Journal of Well-being,* 6,3 (2016): 1-48. https://doi.org/10.5502/ijw.v6i3.526

Donaldson, S.I., van Zyl, L.E. and S.I. Donaldson. 2022. "PERMA+4: A framework for work-related well-being, performance and positive organizational psychology 2.0" *Frontiers in Psychology* 12:817244 (2022) doi: 10.3389/fpsyg.2021.817244

Fontinha, R.E. S. and D. Van Laar. (2019) "Overtime and Quality of Working Life in Academics and Nonacademics: The Role of Perceived Work-Life Balance." *International Journal of Stress Management,* 26,2 (2019): 173–183. https://doi.org/10.1037/str0000067

Hyatt, K. "Stressors in higher education that lead to burnout and solutions to avoid it." *Journal of Business and Educational Leadership,* 12,1 (2022): 110-125.

Johnson, S.J., Willis, S.M. and J. Evans. "An Examination of Stressors, Strain, and Resilience in Academic and Non-Academic U.K. University Job Roles." *International Journal of Stress Management,* 26,2 (2019): 162–172. https://doi.org/10.1037/str0000096

Khan, F., Rasli, A., Khan, Q. and A. Naz. "05 factors affecting academicians burnout in higher education institutions: A systematic review of literature." Biannual Journal of Gender and Social Issues, 16,1 (2017): 75-90. Retrieved from: https://jgsi.fjwu.edu.pk/jgsi/article/view/48/16

Khaw, D. and M.L. Kern. "A cross-cultural comparison of the PERMA model of well-being. Undergraduate." *Journal of Psychology at Berkeley, University* of California, 8,1 (2014): 10-23.

Kinman, G. and S. Johnson. "Special section on well-being in academic employees." International *Journal of Stress Management,* 26,2 (2019): 159–161. https://doi.org/10.1037/str0000131

Kolomitro, K., Kenny, N. and S. Le-May Sheffield. "A Call to Action: Exploring and Responding to Educational Developers' Workplace Burnout and Well-Being in Higher Education." *International Journal for Academic Development,* 25,1 (2020): 5–18. doi:10.1080/1360144X.2019.1705303.

Linton, M-J., Dieppes, P. and M-L. Antonieta. "Review of 99 self-report measures for assessing well-being in adults: exploring dimensions of well-being and developments over time." *BMJ Open* 6:e010641 (2016). doi:10.1136/bmjopen-2015- 010641

Maslach, C., Jackson, S.E. and M.P. Leiter. *Maslach Burnout Inventory.* 3rd edition. Palo Alto, CA: Consulting Psychologists Press, 1996.

Mironova, J. and B. Slokta. (2021): "Burnout of the teaching staff in the higher education institutions and it's influence on the teaching process." Paper presented at *XVI. IBANESS Congress Series on Economics, Business and Management,* I*stanbul, Turkey, 2021*. Retrieved from: https://www.researchgate.net/profile/Shiret-Elezi/publication/362068522_Impact_Of_COVID-19_Outbreak_On_Organizational_Performance_Evidence_From_North_Macedonia/l inks/62d53008fd347a451bc7428c/Impact-Of-COVID-19-Outbreak-On-Organizational-Performance-Evidence-From-North-Macedonia.pdf#page=102

Rahm, T. and E. Heise. “Teaching Happiness to Teachers - Development and Evaluation of a Training in Subjective Well-Being.” *Frontiers in Psychology* 10:2703 (2019). doi: 10.3389/fpsyg.2019.02703

Seligman, M.E.P. *Authentic happiness: Using the new positive psychology to realize your potential for lasting fulfillment.* New York: Simon and Schuster, 2002.

Seligman, M.E.P. *Flourish: A visionary new understanding of happiness and well-being.* New York: Free Press, 2011.

Smetackova, I., Viktorova, I., Martanova, P., Pachova, A., Francova, V. and S. Stanislav. “Teachers Between Job Satisfaction and Burnout Syndrome: What Makes Difference in Czech Elementary Schools.” *Frontiers in Psychology* 10:2287 (2019). doi: 10.3389/fpsyg.2019.02287

Watts, J. and N. Robertson. “Burnout in university teaching staff: a systematic literature review.” *Educational Research*, 53,1 (2011): 33–50. https://doi.org/10.1080/00131881.2011.552235

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PIONEERING PEDAGOGY: UNVEILING THE POTENTIAL OF PODCASTING IN ENGINEERING EDUCATION FROM EDUCATORS' PERSPECTIVE

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***Keywords**:* Multimedia, podcasts, educators, learning, technology

ABSTRACT

The rise of new teaching formats poses opportunities and challenges for educators. While promising enhanced content transfer and engaging learning experiences for students, they also bring added responsibilities and risks for educators, accountable for student outcomes. Podcasts, a novel tool in engineering education, illustrate this trend. Despite studies on student agreement, teachers' perspectives are often overlooked. This paper bridges this gap by examining educators' experiences with podcasting. Beyond assessing its didactic potential, it explores practical challenges and educational adjustments required. Recognizing teaching quality's reliance on educators' capabilities and resources, the study underscores the importance of holistic considerations in integrating podcasts. By highlighting educators' viewpoints, this research aims to guide successful incorporation of podcasts into education, informing future strategies and supporting pedagogical innovation.

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1 INTRODUCTION

New teaching formats are popular. They promise teachers a better transfer rate of their teaching content and students a welcome change in their everyday learning routine. Such new formats are often discussed in terms of their didactic potential for increasing learning outputs (Colis & Moonen 2001; Indahsari 2020). However, from the educators' point of view, who feel responsible for the learning success of their students, they always represent a risk, a great deal of effort in addition to the usual research and teaching load, and often also a personal challenge if the new formats require them to leave their comfort zone of familiar and proven roles and routines. Podcasting is a new format that is currently being experimented with in engineering education. A podcast is a digital audio or video program that is made available on the internet for downloading or streaming. A good podcast can serve as the basis for decision-making or as a synopsis for a listener to gain knowledge on a specific topic (Spina et al. 2017). Similar to screencasts and learning games, a medium traditionally associated with private use and entertainment is now being harnessed for targeted knowledge transfer within the realm of higher education. Initial studies on the acceptance and learning success of students as well as descriptions of different didactic objectives and integration into the course sequence are emerging (Peters, Hagedorn & Stark 2021; Engzell & Norrman 2023). What has not been considered so far is the perspective of the educators, whose professional background generally qualifies them neither as media producers nor as journalistic talk show hosts. Thus, this is the main focus of this paper. Past research has prioritized the perspective of students over that of educators (Cooper 2008; Farshi & Mohammadi 2013; Sabrila & Apoko 2022). However, learning success depends on the quality of teaching, e.g. teaching materials. This quality, in turn, depends on the educator and resources of the educator, especially in the case of newly developed formats. This paper therefore examines the experiences of educators, or teachers, who have ventured into podcast production as a teaching tool to find out what should be considered apart from the didactic potential when considering integrating this new format into teaching. This paper seeks to explore the issues of (a) *How do educators perceive the effectiveness of podcasting as a pedagogical tool in enhancing learning outcomes in engineering education? and (b), What practical adjustments and resources are necessary to support effective implementation?*

2 FRAME OF REFERENCE

Students learn in different ways, a fact that has been observed by e.g. Kolb (1984) among others, hence teacher need to take this into account when designing their lessons and learning materials. The term "blended learning" (cf. Garrison & Kanuka 2004; Ginns & Ellis 2007; Lopez-Perez et al. 2011) is a way to meet this as it integrates traditional face-to-face lecturing with digital learning platforms. Besides this, teachers also need to create (cf. König 2021; MacInnis et al. 2012; Zimba et al 2021) among the learners. Several studies show the importance of active learning designs (cf. Biggs 2003; Politis 2005; Gibb 2002) as they encourage deeper understanding. The "flipped classroom" model (Bergmann & Sams 2012) entails that the theoretical input is acquired by the students through e.g. literature, video lectures or podcasts ahead of a teacher-led activity. The benefit of this is that the students can acquire the knowledge and understanding needed at their own pace and then deepen their knowledge during the teacher-led activity. According to our experience, so-called podcasts, by means of pre-recorded audio tracks where course content is treated in the form of a dialogue between two or more parts, can be a great tool for teachers, both to enhance knowledge and understanding and to create inspiration to learn and understand more.

3 METHODOLOGY

The usage of case study methodology is a viable approach for delving into complex and less-explored subjects (Yin 1984). Various scholars have embraced case studies to explore podcasts in higher education from diverse angles (Cartney 2013; Lewis & Francis 2020). This study employs a multiple case-study approach to investigate the distinct differences and similarities among podcasts at two different universities. Our study comprises three different podcast cases. Multiple-case studies are known as more robust compared to single-case studies, as they offer the opportunity to observe and analyze a phenomenon across multiple contexts (Yin 1984). Thus, this approach not only facilitates comparison among different cases to yield similar results (literal replication) but also enables the exploration and validation of patterns identified in initial cases (theoretical replication). Hence, this methodology does not prescribe a fixed number of cases required to fulfill the replication strategy; rather, cases are chosen based on theoretical criteria established to identify podcasts for higher education (Laing & Wootton 2007; Sprague & Pixley 2008). These criteria, gleaned from the literature, are demonstrating the various perspectives of why students prefer them and how they are used in learning (Chester et al. 2011; Knowles 1975; König 2021). Cases were selected based on diversity and university (providing technology and engineering programs).

The data collection methods employed was in line with the multiple case-study approach. To ensure the validity and reliability of the study (Yin, 1984), diverse sources and extra materials were gathered for all three cases. These sources included university publications such as magazines, publications and websites, as well as podcasts and related audio materials that could be found at the universities.

Regarding data analysis, the cases were analyzed using variables such as e.g. didactic goal, didactic integration, role of the teacher, personal challenges, and practical challenges, thus enhancing reliability across all cases (Yin 1984).

Analysis was conducted searching for patterns, differences, and similarities. The authors did comparative reflection rounds in addition to doing a comparative analysis of the podcast material. In sum, this methodology enabled us to do triangulation of perspectives, evaluations, and other data through a comparative and inductive analysis (Eisenhardt 1989; Jick 1979).

Besides these, all the authors have produced podcasts and used them in their teaching. This have benefited our analysis.

3.1 Potential of podcasting: Three Case Studies

3.1.1 Case 1: Interviewing befriended scientists for making students experience effective learning strategies

In the first case, a teaching podcast at TU Berlin funded by ”Qualitätspakt Lehre” by the Z for Y, a cross-sectional bachelor course on ”Fundamentals of Industrial Information Technology for Engineers ” was chosen (for more detail see Peters, Hagedorn & Stark 2021). This course is mostly taken by young students during their first semester who in Germany usually start their studies with little experience in effective and self-organized learning after the strictly pre-structured learning routines of their school vitae. The podcast was intended to provide these students with learning experiences that would improve their self-learning skills by experiencing that 1. preparing oneself helps following the lecture and thus makes attending it more effective, 2. listening is not the same as active listening and learning, and 3. the effects of distributed learning over time. To accomplish this, a podcast episode relevant to the upcoming lecture topic was released one week prior to the lecture and was paired with a mandatory quiz that students needed to complete before attending the lecture. This way, the students went into the lecture prepared, were able to follow it more easily and were less likely to drift off. Continuous engagement with the topics made learning easier at the end of the semester. In addition, they learnt to recognize if they were actively listening or if they were listening but not processing information, as in the latter case they failed the quiz even though they had listened to the episode.

The podcast featured an assistant teacher, chosen for their familiar rapport with students. Research assistants from a partnering Fraunhofer Institute, well-versed in relevant topics through their PhD research, were selected as guests due to their close working relationships with the podcast producers. Their similar age to students and informal rapport with the interviewer aimed to cultivate a relaxed podcast atmosphere. Additionally, their proximity to TU Berlin's podcast studio facilitated easy participation and integration into existing collaboration routines. Collaboratively, a rough script was prepared for each episode to ensure alignment with lecture content. Five episodes were produced, initially recorded at TU Berlin 's studio and professionally edited. Later episodes adhered to COVID-19 regulations and were recorded via Zoom. Access to the podcast was restricted to TU Berlin's online platform, as some interviewees preferred limited accessibility, a deviation from the initial agreement.

3.1.2 Case 2: Engaging academia experts to offer theoretical insights to students from varied scientific backgrounds, disrupting conventional learning routines

The second case, from TU Berlin and funded by the "Freiraum" programme of the Foundation for Innovative University Teaching, addresses Master's students in a module on transdisciplinary technology development in the context of sustainable and fair urban mobility. The challenge here lies in the broad interdisciplinary composition of the participants with their heterogeneous learning habits. In order to favor no disciplinary group over the others, a format for providing theoretical input was needed that was equally unfamiliar and low-threshold for everyone. Thus, the podcast format was chosen. Interviewees were chosen according to their outstanding expertise on the episodes topics from other departments and other universities, some of them international. Thus, the teachers could expand vastly the sources of expertise that contributed to the course input and even integrating first-hand multiperspectivity. Also, the search for qualified dialogue partners resulted in a rapidly growing network of experts for the teachers and their departments that greatly facilitated access to the scientific community of "transdisciplinary research".

Extensive planning preceded the podcast's development, addressing various media aspects including interviewer role, audience relationship, language use, and interview structure, all aligned with didactic goals. The interviewer, also the course teacher, adopted an approachable persona, fostering student engagement through relatable dialogue devoid of technical jargon. This carefully crafted role aimed to establish a relaxed atmosphere, facilitated by the informal German "du" form of address. Pre-interview meetings were crucial in overcoming hierarchical barriers, ensuring a trust-based environment. However, logistical constraints led to remote interviews, with sound editing undertaken by the teacher using Audacity. Despite efforts, the lack of professional conditions extended editing time, indicating a need for improved post-processing in future endeavors. Two episodes were double-interviews with two interviewees at the same time, other interviewees contributed to more than one interview, so that eight interviewees were involved but not necessarily one per episode.

3.1.3 Case 3: Experimenting with academic colleagues for innovative teaching approaches

"The Auditory Classroom" was a one-year explorative project on how to create podcasts to complement and broaden the teaching in Linköping university courses and make the teaching more accessible and flexible. The incorporation was to meet the demands of modern learners and the dynamic nature of academic studies. Pedagogically, the project was based on the idea of the "flipped classroom" and the division into pre-, during, and post-teacher-led activities. By listening to a podcast before a specific course moment, students' learning is facilitated (Kelly et al 2022). The opportunity to listen afterwards can also deepen understanding. Students can take greater responsibility for their studies as they have already absorbed the material in advance, thus using classroom time to build on their knowledge, ask relevant questions, and thereby progress in their learning. The teacher can therefore more quickly delve into analysis/deepening of the subject in the learning process. The goal of podcast episodes was to create different episodes covering topics, theories, and models within the subjects of project, innovation, and entrepreneurship. The idea was also to inspire and motivate students. In total, 6 episodes were created in the project covering: entrepreneurship & intrapreneurship, NABC, Challenge-based-learning, business model and BMC, pitch, and environmentally driven innovation. Participating teachers edited and edited the episodes themselves, and the music was created by an external person; Teodor Miciol. Finally, this project has emphasized the importance of incorporating student input when selecting pedagogical tools for teaching. Podcasts are just one of many educational tools that can enhance blended learning approaches.

4 DISCUSSION

Comparing the three cases reveals significant differences in didactic objectives and integration, yet similarities in project conditions and experiences. Despite variation, each podcast produced a similar number of episodes: 5, 6, 8. This highlights the importance of meeting the minimum episode requirements to maintain consistency and engagement in a recurring podcast format. While maintaining regularity demands a minimum number of episodes, the extensive production process, alongside teaching and research commitments, constrains maximum episode output. Also, a limited number of episodes of a podcast can effectively deliver focused content, keeping listeners engaged without overwhelming them. This concise format also ensures manageable production, allowing for consistent quality and the opportunity to evaluate the podcast's impact before committing to a longer series. As confirmed by previous studies e.g. Yeh (2021) and McCarthy et al (2021), guest engagement involves familiarization, preliminary meetings, and format discussions. Additionally, logistical aspects such as studio bookings and scheduling coordination are crucial. All episodes require recording, editing, and integration into online platforms, often including supplementary information and links. For a teacher with little experience in audio editing, doing all of these things on his or her own can mean 15-20 hours of work for a 30-minute episode with guests. Thus, an effort such as podcast production is only possible with additional funding, which also has been confirmed by previous studies (Sellan & Solá 2019). This leads to the further commonality of the three cases in that they were all created as part of specifically funded projects aiming at developing innovative educational formats, although the level of funding varied greatly. Depending on the equipment available at the university, there are also costs for equipment and editing software. In two of the three cases, an external music producer was hired to produce a jingle to give the podcast a professional look. In Case 1 a research assistant got sponsored for three years to develop innovative approaches to teaching of which the podcast was one result. In Case 2 the didactic development and iterative testing of a new teaching module with new teaching methods was funded, paying two research assistants for two years, also covering the 3 months of podcast production and a little equipment. In Case 3, the production was supported as a pedagogical project.

The three cases discussed are also similar in the sense that the teachers had no prior experience in this area before engaging in podcast production. Therefore, in addition to the time commitment, such a project is also fraught with uncertainty due to the number of new roles that teachers must fulfill simultaneously. In addition to their roles as researchers and teachers, podcast producers are asked to act as journalists, producers, and entertainers ~~(see Fig. 1),~~ which is not usually part of their job description. For teachers and researchers, podcast production therefore means leaving their comfort zone, increasingly so the less familiar they are with the invited guests. If colleagues are interviewed, as in Case 1 and Case 3, only the new role of a journalistic interviewer is a challenge. If, on the other hand, external experts are sought, as in Case 2, it is necessary to make contact with actors who may be higher up in the hierarchical university system. Asking unknown, senior colleagues for something without any apparent quid pro quo can cause great internal tension. On the other hand, it can pay off to withstand the potential conflicts, as proven in case 2, where the teacher and her department could build a network of top experts on the podcast topic within four months. In Case 3, the multiple roles sparked diverse discussions and highlighted the necessity of prioritization to yield meaningful outcomes and avoid potential conflicts.

In all three cases, the instructors had at least partial professional support for the technical implementation. It is an advantage if the university has a central institution for digital teaching, which may even run a podcast studio. To produce a technically high-quality podcast, professional technical support is helpful and was actively sought in all three cases. However, the sound editing was only done by professionals in case 1. In cases 2 and 3, the teachers themselves learned to use editing programs.

From a didactic point of view, the three cases show the variety of possible uses of podcasts in teaching, which also has been outlined in previous research (Laing &

Wootton 2007). In case 1, the podcast is intended to create learning experiences for first-year undergraduate students that will encourage them to develop effective learning methods. In case 2, the podcast is intended to make theoretical input equally accessible to a large interdisciplinary group of students with very different learning habits typical of their discipline. In case 3, the podcast is intended to introduce students to cross-curricular themes and serve as an inspiration for the use of new teaching formats. Cases 1 and 2 are geared to a specific course and are therefore integrated into the course in terms of time and content, while case 3 is available as a permanent offer. Podcasts can therefore be used in the classroom for both general and very specific educational purposes. In the former case, there is a great deal of freedom in the production process in terms of topic selection and preparation. However, if the podcast is to cover course content, it is necessary to check the content for compatibility with learning goals, course structure, and exam content. Didactically, in cases 1 and 2, it has proven useful to couple such podcasts with subsequent quizzes to ensure that students have absorbed the content. As confirmed in previous studies e.g. Peters, Hagedorn & Stark (2021), this is one effective way of using podcasts in teaching to improve students learning. After all, most students listen to podcasts incidentally in their everyday lives, with divided attention, e.g. while exercising or on the move. If such an everyday medium is to be integrated into the classroom in a way that is relevant to exams, it is important to ensure that users develop appropriate usage patterns. Thus, for teacher the task of producing a podcast might be linked to further tasks of producing even more new learning materials such as quizzes, lists of show notes, graphic illustrations or scripts to embed the podcast in the course didactically.

5 RESULTS AND CONCLUSIONS

In the modern educational landscape, podcasts have emerged as multifaceted tools, offering educators various possibilities for enriching teaching methodologies. Drawing from our three cases, this study delves into the multifaceted uses of podcasts in teaching, emphasizing resource needs, personal commitment, and incentives for guest participation from the educators' perspective.

One main finding is that becoming involved with podcasts as a teaching medium presents educators with new challenges (e.g. using new structures or being more entertaining), significantly diverging from their professional identities as teachers and researchers. Educators embarking on podcast production must also actively cultivate expertise in new professional domains, including both journalistic practices and technical aspects of media production. This requirement introduces psychological, social, and professional dimensions that educators must navigate. The endeavor demands considerable resources in terms of time, energy, and even financial investment – i.e. it requires a substantial effort. ~~Consequently,~~ The educators may also find themselves pushed beyond their comfort zones. Yet, despite the challenges, engaging in educational podcast production offers manifold benefits, not least through the broadened palette of reaching out with their message. Through packaging the teaching in new formats, educators gain new experiences and competencies, which can enrich their personal growth. Podcasts may also extend their network and improve their collaborative skills. Finally, teaching effectiveness and expansion of the teachers professional networks, thus augmenting their impact within the educational sphere, can also be a result. Thus, while the undertaking demands substantial effort and adaptation, the rewards in terms of personal and professional development can be profound.

Also, the integration of podcasts in teaching requires educators to embrace self-reflection and personal commitment. Stepping out of one's comfort zone and embracing innovative pedagogical tools demand a willingness to adapt and evolve.

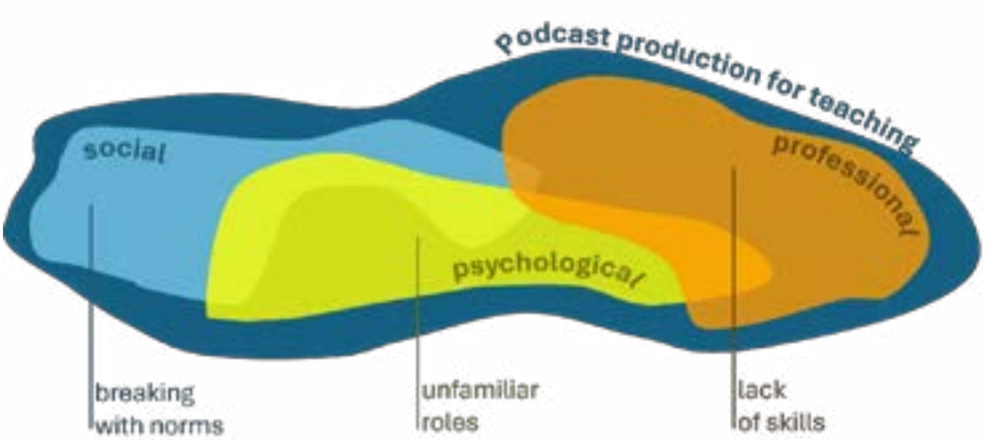

Fig. 1. Dimensions to consider when getting involved with podcasts as teaching medium

In conclusion, integrating podcasts enriches educational experiences dynamically. The comparison of podcast methodologies illustrates educators’ capacity to develop diverse episodes independently. It's crucial to recognize the considerable effort educators invest in content creation and podcast design tailored to their courses. However, the time-intensive nature of content creation, recording, and editing poses challenges, especially for educators balancing multiple roles. The article emphasizes educators’ capability to produce podcast episodes independently, with varying purposes across courses or contexts. Collaboration with podcast production and technology experts significantly enhances material quality and production efficiency. This collaborative approach played a pivotal role in improving podcast engagement and user-friendliness in the described cases.

REFERENCES

Bergmann, J., & Sams, A. (2012). Before you flip, consider this. *Phi Delta Kappan*, *94*(2), 25-25.

Biggs, J. (2003) Teaching for Quality Learning At University, 2nd ed., The Society for Research into Higher Education and Open University Press, Berkshire: England.

Cartney, P. (2013). Podcasting in an age of austerity: A way of both enhancing student learning and reducing staffing costs?. *British Journal of Social Work*, *43*(3), 446-466.

Chester, A., Buntine, A., Hammond, K., & Atkinson, L. (2011). Podcasting in education: Student attitudes, behaviour and self-efficacy. Educational Technology and Society, 14(2), 236–247.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of management review*, *14*(4), 532-550.

Engzell, J., & Norrman, C. (2023). Podcasts As A Learning Method In Engineering Education. In *51st Annual Conference of the European Society for Engineering Education, SEFI 2023 Dublin 11 September 2023 through 14 September 2023* (pp. 398-405). European Society for Engineering Education (SEFI).

Garrison, D. R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. Internet and Higher Education, 7(2), 95-105. Retrieved from

Gibb, A. (2002). "In pursuit of a new 'enterprise' and 'entrepreneurship' paradigm for learning: creative destruction, new values, new ways of doing things and new combinations of knowledge", International Journal of Management Reviews. Sep, Vol. 4 Issue 3, p. 213. 19p.

Ginns, P., & Ellis, R. (2007). Quality in blended learning: Exploring the relationships between on-line and face-to-face teaching and learning. *The Internet and Higher Education*, *10*(1), 53-64.

Indahsari, D. (2020). Using podcast for EFL students in language learning. *JEES (Journal of English Educators Society)*, *5*(2), 103-108.

Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative science quarterly*, *24*(4), 602-611.

Kelly, J. M., Perseghin, A., Dow, A. W., Trivedi, S. P., Rodman, A., & Berk, J. (2022). Learning through listening: a scoping review of podcast use in medical education. *Academic Medicine*, *97*(7), 1079-1085.

Knowles, M. S. (1975). Self-directed learning: A guide for learners and teachers.

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development (Vol. 1). Englewood Cliffs, NJ: Prentice-Hall.

König, L. (2021). Podcasts in higher education: teacher enthusiasm increases students' excitement, interest, enjoyment, and learning motivation. Educational Studies, 47(5), 627–630.

Laing, C., & Wootton, A. (2007). Using podcasts in higher education. *Health information on the internet*, (60).

Lewis, S. L., & Francis, R. W. (2020). Podcasting as a Mode of Motivation in Online and Blended Learning. Learning in the Digital Age.

Lopez-Perez, V., Perez-Lopez, C. & Rodriguez-Ariza, L. (2011) Blended learning in higher education: Student's persseptions and their relation to outcomes, Computers and education, vol 56, pp 818-826.

McCarthy, S., Pelletier, M., & McCoy, A. (2021). Talking together: using intercollegiate podcasts for increased engagement in marketing education. *Marketing Education Review*, *31*(2), 125-130.

McInnis, C., Ramsten, P. & Macoinachie, D. (2012) Executive leadership of learning and teaching in higher education. Office for learning and teaching, Sydney

Mnatzaganian, C. L., Singh, R. F., Best, B. M., & Morello, C. M. (2020). Effectiveness of providing video podcasts to pharmacy students in a self-study pharmaceutical calculations module. *American Journal of Pharmaceutical Education*, *84*(12), ajpe7977.

Peters, I., Haedorn, L. & Stark, R. (2021) A structured digital offer for developing learning strategies as add-on for higher education engineering classes. In H-U. Heiß, H-M. Järvinen, A. Mayer, A. Schulz, A. Wipper, & U. Schumann (Eds.), Blended Learning in Engineering Education: Challenging, enlightening and - lasting?: Proceedings of SEFI 49th Annual Conference (pp. 1149-1159). SEFI: European Association for Engineering Education.

Politis, D. (2005) The process of entrepreneurial learning: a conceptual framework, Entrepreneurship theory and practice, july, pp 399-424.

Sprague, D., & Pixley, C. (2008). Podcasts in education: Let their voices be heard. *Computers in the Schools*, *25*(3-4), 226-234.

Sabrila, R. A. P., & Apoko, T. W. (2022). The Effectiveness of Podcast on Listening Skill for Vocational School Students. *IDEAS: Journal on English Language Teaching and Learning, Linguistics and Literature*, *10*(2), 1177-1186.

Yeh, H. C., Chang, W. Y., Chen, H. Y., & Heng, L. (2021). Effects of podcast-making on college students' English speaking skills in higher education. *Educational Technology Research and Development*, *69*, 2845-2867.

Yin, R. (1984). *Case study research, design and methods.* Beverly Hills, CA: Sage.

Zimba, Z. F., Khosa, P., & Pillay, R. (2021). Using blended learning in South African social work education to facilitate student engagement. *Social work education*, *40*(2), 263-278.

APPENDIX

Variables	Case 1	Case 2	Case 3
Level of experience teachers? students?	No experience of neither teachers nor students to use podcasts in edu	No experience of neither teachers nor students to use podcasts in edu	Little previous experience of teachers Little experience of students to use podcasts in edu
Format of podcast	One Podcast, 5 Episodes	One Podcast, 8 episodes planned to be expanded	One podcast, 6 episodes
Purpose	To create learning experiences for freshmen to implicitly collect experiences with important learning	To replace classical disciplinary media for providing theoretical input in a broadly interdisciplinary course to provide just	To introduce students to a certain topic

	techniques without addressing it as such	accessibility to all students	
Didactic plan	Bi-weekly with additional online quiz Didactic Goals Content: Illuminating and deepening the topics of each lecture from a different perspective Competence: implicitly showcasing useful short-term and long-term learning strategies	Synchronization with the students' project working phases 90% of theoretical input via the podcast pluralization of knowledge sources on the teachers' side	Not included in the didactic plan, extra resource
Who is the receiver of the podcast	Early bachelor students	Advanced master students	Students e.g. engineering programs
Who is the speaker	Teacher (research assistant, not professor)	Teacher (research assistant, not professor)	Teachers
Guest(s) in the podcasts	Colleagues from a partnering Fraunhofer-Institute	Highly experienced (external) scientific experts on the respective topics	Teachers
Relationship between speaker and guest	Colleagues	Strangers	Know each other since before
Ambitious level of group			Vary depending on the role
Level of professionalism Quality of sound etc.	Project as Experiment accompanied by professional technical assistance but inexperienced staff; main focus: avoid discrepancies with the lecture while	Main focus: content and atmosphere (journalistic professionalism)	High expectations on sound, quality and content

	providing new learning experiences		
Funding and resources	Funded by the national Ministry for Education and Research (one educational researcher for 3 years, no equipment funds)	Funded by the German Foundation for Innovation in Higher Education (one educational researcher to develop the didactic for a module on transdisciplinary for 2 years)	Pedagogical project, very limited resources
Content	Specific topics related to Industrial Information Technology	Theory and practice of transdisciplinary research for sustainable urban mobility	Broad topics related to entrepreneurship, innovation and project management
Role of the moderator	1 moderator Interviewing colleagues from the field as additional teaching input	1 moderator identifying with the students, going on a quest to understand the topics together	Rotating the role as moderator
Dynamics of people in the studio			Structured and flexible at the same time
What can we gain? Is podcasts worth the effort from a teacher perspective?	Offer learning experiences, especially with “deep listening” vs. just being physically present	To provide students with different learning backgrounds (interdisciplinary student group) with material equally accessible to all reach students with specific learning styles or disadvantages (e.g. reading disorder or impaired vision) Offer expert knowledge from the best instead of the best knowledge of one teacher (distributed first hand knowledge resources) scientific network	To formulate and package content, to provide students with knowledge in another format

Surprises at Work: A STUDY OF EARLY CAREER ENGINEERS

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ABSTRACT

Early-career engineers encounter various surprises in engineering practice when they transition from being students to becoming early-career professionals. Studies on employability identify transition issues, and in our present study the guiding research question is: what can come as a surprise to early-career engineers when

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entering engineering practice? In this article, we analyse qualitative data collected from interviews and identify several aspects that surprise early-career engineers. Our findings indicate that generic competences, and the importance of generic competences, may be surprising to early-career engineers. This raises questions about engineering education and whether degree programmes should take steps to better prepare students for engineering practice. Although technical competences remain the bedrock on which engineering practice rests, generic competences are identified as central in order to successfully collaborate and communicate, and therefore remain a vital component of employability alongside of areas such as the multiple roles an early-career engineer will take on, the parallel projects they must navigate, and the mutual dependency they will experience. As this article will show, these areas of concern play an important role in ensuring that early-career professionals are able to do their jobs satisfactorily.

1 INTRODUCTION

Employability is a journey, not a destination. This is the fundamental characteristic of employability, and (much like journeys) employability can be changed and developed by proactive choices as well as other factors, including personal attributes and attitudes. Employability encompasses a wide field of potential areas of interest; in this context, we use Yorke's definition to establish a baseline understanding, not least since it considers different interests:

[…] a set of achievements – skills, understanding and personal attributes – that makes graduates more likely to gain employment and be successful in their chosen occupation, which benefits themselves, the workforce, the community and the economy. (Yorke, 2006)

In line with this, Clarke (2018) insists that there are six key dimensions to a broad framework of employability: human capital, social capital, individual attributes, individual behaviors, perceived employability, and labor market forces. While some aspects relevant to an applicant's professional background may be tangible (i.e., does the applicant know the relevant software or programming language?), other central skills may be less easy to identify, and/or difficult for graduates themselves to articulate in a manner that assists their own employability. Some of these include adaptability, curiosity, proactivity, conscientiousness, goal-orientation, and more.

Furthermore, there is an expanding list of desirable competencies that employers look for, and many of these depend on a mix between professional skillsets and personal attributes. These skills are also reflected in Yorke's oft-cited employability definition which highlights the combination of both professional capabilities, disciplinary knowledge, and gainful personal attributes.

Many research projects have explored the attributes and capabilities that members of the workforce are required to demonstrate. These include teamwork, conflict management, written-, verbal and non-verbal communication, confidence, resilience, flexibility, and stress management skills (Stagnitti, School & Welch, 2010; Walker et al., 2013, Friedrichsen et al, 2023). Recent research has listed an additional set of contemporary proficiencies that graduates require, including a design mindset, virtual collaboration skills, cross-cultural competency, novel and adaptive thinking, new media literacy, social intelligence, epistemic fluency and emotional intelligence

(Davies, Fidler, & Gorbis, 2011; Goodyear & Ellis, 2007; Little, 2006; Higgs, 2009) Furthermore, it is noteworthy that transversal skills and self-awareness are highlighted as key areas, particularly given the fact that these may not immediately seem as crucially important for an engineer (Craps, 2017).

In a similar vein, Creasey stresses the importance of being able to reflect in an effort to showcase how one's experience, achievements, and skills positively influence employability. Improving employability skills, "requires students to record their achievements and to reflect on these." (Creasey, 2013, p. 18). This is a pertinent reminder that numerous skills and competences exist that influence employability, but self-awareness and reflection are required to create a realistic representation of an individual's current abilities and their employability. Whether several of these areas can or should be taught at universities is a complex issue. It is clear, however, that graduates are expected to perform on parameters beyond just the technical, and that employability relates to several different and expanding areas – some of which are surprisingly intricate and rely on personal development as much as on professional competences.

A Danish study on engineering students' perception of what is important at different stages of their studies showed a kind of instrumental turn with an increased focus on mono-discipline related engineering skills such as engineering analysis, engineering tools, and data analysis (Kolmos & Holgaard, 2019). This study indicates a situation where engineering students becomes oriented towards the disciplinary; this resonates badly with calls for generic competences and personal attributes in more differentiated employability contexts, e.g. as proposed by Clarke (2018).

In this study, we aim to characterize some of the areas related to employability in engineering education by asking early-career engineers to elaborate on their expectations about work while studying compared to their actual experience after being employed. Our research question is as follows:

What can come as a surprise to early-career engineers when entering engineering practice?

2 METHODOLOGY

2.1 Data collection

This study is based on 8 interviews with early-career engineers. The study is inductive in its approach which allows the interviewer to explore unexpected and relevant aspects of the conversation. The interviews are based on probing questions as well as emerging questions (Kvale & Brinkmann, 2009). The qualitative data was collected in October 2023. The following table (Table 1) details the educational backgrounds of the participants. Each interview was collected individually and was approximately one hour in duration. The interviews were semi-structured (Creswell, 2017) and explored the experiences and understandings of early-career engineers cf. engineering practice and their expectations in this context. The qualitative methodology (Patton, 2015) provides insights that help clarify experiences; this helps researchers' understanding based on actual experiences and subjective framings.

All interviews except one were conducted in Danish and any quotes have been translated by the authors. Participants were from three different universities: one

Japanese university, and two Danish universities. One of the Danish universities uses a PBL model, the other does not.

Table 1. Educational backgrounds, years of experience, and gender of participants

Particip ant ID	Country in which degree was obtained	Educational background	Years of experience	Gender
P1	Japan	PhD, polymer science & organic chemistry	3	M
P2	Denmark	Civil engineer (chemistry)	6 months	F
P3	Denmark	Materials technology & nano technology	3	M
P4	Denmark	Chemical engineering	10 months	M
P5	Denmark	Civil engineering (chemistry)	2	F
P6	Denmark	Chemical engineering	2	M
P7	Denmark	Chemical engineering	5	M
P8	Denmark	AP Automotive Technology	4	M

The interview data was transcribed using Whisper and afterwards double-checked and corrected by the authors. The interviews were coded in Nvivo, and the coding was guided by the following themes: generic competences, interdisciplinary, experiences, transition, and employability.

3 RESULTS

In the following we outline four surprises experienced by early-career engineers in the transition from engineering education to work. Although the interviews contain much interesting and relevant data, the scope of this article is limited to the following surprises.

3.1 Surprise number 1: The value of generic competences

The first citation describes the value of generic competences and highlights how P7 was specifically surprised at how crucial it is to develop strong generic competences.

I think it is quite clear that it is the generic skills that have the greatest impact. As in, when we actually get to work. Those are the ones I have used the most, and they are probably the ones that have had the least direct focus on in my degree programme. I definitely think it's something that develops over time, and it's a bit hidden, but they come as part of a lot of other things at university. But they are *definitely the ones I feel are the most important. [...] So those generic things about how you learn. (P7).*

It is noteworthy how P7 also mentions *how* a person learns, stressing the importance of the ability to learn in new situations. The impact of generic competences as described here is an interesting phenomenon, and the following quote specifically highlights communication and teamwork.

Yes, but there is clearly much more communication than one is accustomed to at university. Also with people from other companies or other countries. (P2).

P2 was surprised at the extent to which communication, and people generally, influence engineering practice, and how this differed from their experiences at university. Furthermore, P2 highlights intercultural competences, and this is noteworthy because cultural competences are not a significant part of many engineering programmes.

Inclusion of generic competences in engineering education does not only mean that generic competences is to be known and acted on by the students. Boelt et al (2022:1415) argued, based on a literature review of studies of generic competences in a problem-based learning environment (PBL), that even though generic skills and competences are seen as a remedy for increasingly complex and interconnected world and highly integrated in the PBL approach, the movements towards inclusion of these competences in engineering education is instrumental rather than critical and reflective. In engineering education, it would be beneficial for course content and the overall education to transcend the purely instrumental.

As mentioned in the introduction, generic competences are strongly emphasized in relation to the employability discourse. In the following, we point to other surprises that engineers got in their transition from education to work.

3.2 Surprise number 2: The many different roles

The following surprise focuses on different roles and how engineering practice turned out to be different from the interviewee's assumptions. P3 describes the small disconnect between their expectations and the reality of their many roles.

I had expected that I would sit somewhere and do some office technical work, do a lot of calculations on things that I learned at university, and then test them in reality, and figure out how it all practically fits together, and then be involved in implementing it. Making some documentation updates and talking to some project managers who poke at me. I hadn't expected that I would have to be both an advisor and project manager, and purchaser and engineer and documentation [specialist]… that's not how I expected it to be. (P3)

The surprise mostly concerns the sheer number of different roles and the different tasks involved with each role. This particular interviewee had anticipated to primarily use what Ravensteijn et al (2005: 67) call instrumental competence which requires thorough technical knowledge and capability. Instrumental competences are seen in contrast to strategic competences which embrace social know-how, and in contrast to communicative competences which are related to the necessity of creating a social consensus for innovations. However, engineering practice turned out to involve more tasks – several of which are not strictly instrumental engineering.

The same pattern emerges from the next quote in which the interviewee was unsure about what a career even is or includes, and we see surprise expressed at how few engineers focus solely on stereotypical engineering work.

For me, I wasn't really aware of what a career was, or what it would mean, or whether one is a specialist, or a project manager, or a manager, etc. It's only something I learned later, after entering the workforce, that there's actually a whole aspect of this that some people focus on called motivation, etc. And then I think… at least from what I've seen, what I've learned, is that what I consider classic engineering work is not something that many engineers do. (P8)

Another early-career engineer (P6) also said that they definitely expected more "hardcore" engineering work, with more calculations and sitting by oneself and solving problems related to a larger project. The reality turned out to be slightly different.

3.3 Surprise number 3: Work across multiple projects

One way in which engineering practice may surprise concerns projects and collaboration across projects. As the following will highlight, project work plays a significant role in engineering practice, and an engineer may be involved in several projects at the same time instead of focusing solely on one big project.

I believe that the group work we use out there is insanely important, but it's also what we use a lot to explain how we work. It's not the same, because you're not just working on one project for six months, and that's it. It's often several things where you're involved in ten different projects, and some of them get stopped, and some of them run for five years. (P7).

This sentiment was shared by other interviewees who also mentions that an engineer may not simply work across multiple projects, but also collaborate with multiple different project managers. This necessitates specific generic competences in other to manage one's workload and the different situations involved.

I feel that there has been a lot of interdisciplinary work in terms of putting things into perspective, the projects one had, especially projects at the university. But I don't think there has been as much in terms of... What do you call it? Yeah. I mean, there hasn't been specifically as much collaboration across projects. (P4)

In an engineering education context, Kolmos et al (2024) stress the need for cross-group work in what they identify as inter-team, system and M-project (which includes mega- or mission driven projects).The three project types include a higher degree of interdisciplinarity: from cross team collaboration within an engineering program (inter-team); across engineering programs (system); and across engineering and humanities and social science programs (M-projects). This is an example of a framework that can help engineering education institutions prepare students to work across multiple projects.

3.4 Surprise number 4: The degree of mutual dependency

Mutual interdependence is an interesting topic because, as early-career engineers learn, their own progress and ability to conclude tasks will depend on other people, other departments, and many factors more or less outside of their control, including time, money, and resources. The following quote highlights this, paying particular attention to the influence other people's work has on one's own work.

Yes, and then there are all sorts of factors with time and money and resources and colleagues, and it matters in a different way than as a student. [...] The thing is, one thing is that I have to deliver the piece of work that I now have to, but the quality of that piece of work also depends, as most often as not, on others' work. (P5)

The same interviewee goes on to describe the transition from one project to the next, and how the quality and overall result of one project will influence other projects. This relates to Mathieu et al (2018) and their work on multi-team systems. This is an interesting difference compared to sequential university projects. Furthermore, these other projects are linked to other people, and this influence of other people is a recurring theme. Another interviewee describes how engineering practice is influenced by the interests of other people and stakeholders.

I always ask this question myself, because when we are a student, right, we always think about professional. So it's more like how quick, how deep, how creative idea, how good idea you can think about it. Right. Back to a reality right now, I don't think like in the job, in the society, there's so many different people. There's so many people. Right. And sometimes even you have good idea, but in reality, it's really hard to put it to you to use it (P1).

This is related to what P3 also argued, namely their surprise that they could not simply work on what they wanted, but had to ensure that their work always creates some kind of value for the company. While this may seem self-evident, it was nevertheless described as a surprising change from life as a student where projects more easily initially can be based on personal interest.

4 CONCLUSION

This study points to four surprises that early-career engineers identify when comparing their study life with work life (see figure 1). As illustrated, each surprise addresses the need for coping strategies to prepare graduates for work and positive influence their employability.

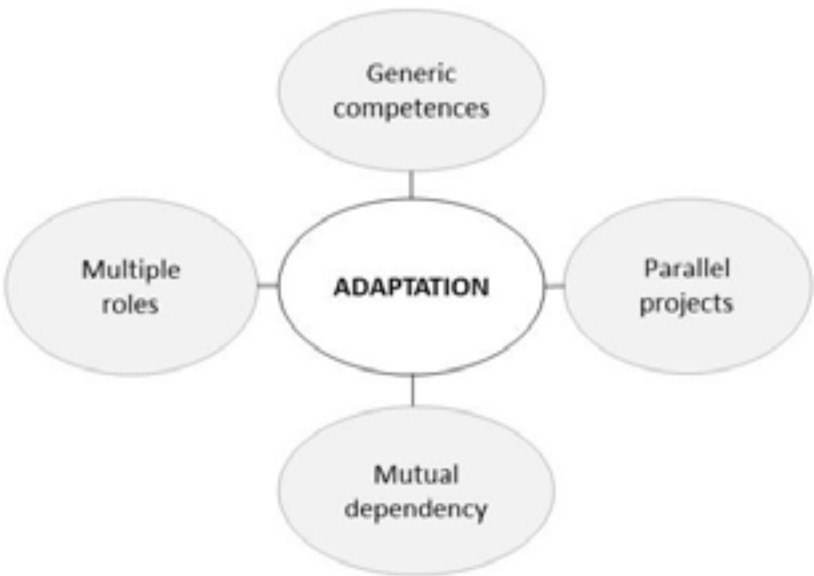

Fig. 1. Adaptation strategies

There are limitations to the study, parly connected to the number of interviewees. Our hope is that this will inspire further research into the transition to work. Additionally, more surprises can arise from other contexts of study (such as gender perspectives), but it is our hope that the simple framework presented in Figure 1 leads to reflections on the educational design in different engineering institutions. The question is whether such coping strategies are needed in the different educational contexts and, if so, whether this should lead to a redesign of engineering education programs. More fundamentally, which surprises should engineering education allow engineering graduates to encounter in their transition from engineering education to work?

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REFERENCES

Boelt, A., et al. (2022). "Literature review of students' perceptions of generic competence development in problem-based learning in engineering education." European Journal of Engineering Education 47. 6: 1399-1420.

Clarke, M. (2018). "Rethinking graduate employability: the role of capital, individual attributes and context." Studies in Higher Education 43(11): 1923-1937.

Craps, S., Pinxten, M., Saunders, G., Leandro Cruz, M., Gaughan, K., Langie, G. (2017). Professional Roles and Employability of Future Engineers. Proceedings of the 45th SEFI Annual Conference. Azores, Portugal, Education Excellence for Sustainability.

Creasey, R. (2013). "Improving Students' Employability." Engineering Education, 8:1, 16-30.

Creswell, J. W. and J. D. Cresswell (2017). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches 4th edition, Sage, Newsbury Park.

Davies, A., Fidler, D., & Gorbis, M. (2020). Future Work Skills. Palo Alto, CA.

Friedrichsen, D., et al. (2023). The Need for Interdisciplinarity: A Case on Employees' Perspectives. European Society for Engineering Education (SEFI).

Goodyear, P. and R. Ellis (2007). "The development of epistemic fluency: learning to think for a living." Sydney University Press.

Higgs, J., et al. (2019). "Learning for Future Possibilities." Education for Employability 2.

Kolmos, A. and J. E. Holgaard (2019). Employability in Engineering Education: Are Engineering Students Ready for Work? The Engineering-Business Nexus: Symbiosis, Tension and Co-Evolution. S. H. Christensen, Delahousse, B., Didier, Chistelle., Meganck, M., Murphy, M., Springer: 499-520.

Kolmos, A., et al. (2024). "Interdisciplinary project types in engineering education." European Journal of Engineering Education 49, 2: 257-282.

Kvale, S. and S. Brinkmann (2009). Interview: Det kvalitative forskningsinterview som håndværk.

Little, B. (2006). "Employability and work-based learning." The Higher Education Academy York, England.

Mathieu, J. E., Luciano, Margaret M., DeChurch, Leslie A. (2018). The SAGE Handbook of Industrial, Work & Organizational Psychology, SAGE Publications Ltd.

Patton, M. (2015). Qualitative Research and Evaluation Methods 4th edition, Sage Publications, Thousand Oaks.

Stagnitti, K., Schoo, D., & Welch, D (2010). " Clinical and fieldwork placements in the health professions." Melbourne, Australia: Oxford University Press.

Tripp, B. and E. E. Shortlidge (2019). "A Framework to Guide Undergraduate Education in Interdisciplinary Science." CBE - Life Sciences Education 18(ES3): 1-12.

Tymon, A. (2013). "The student perspective on employability." Studies in Higher Education 38:6: 841-856.

Walker, A., Yong, M., Pang, L., Fullarton, C., Costa, B., & Dunning, A. M. T. (2013). "Work readiness of graduate health professionals." Nurse Education Today, 33 (2), 116-122.

Wim Ravesteijn, E. D. G., Otto Kroesen (2011). "Engineering the future: the social necessity of communicative engineers." European Journal of Engineering Education 31:1: 63-71.

Yorke, M. (2006). "Employability in Higher Education. What it is, what it is not " Learning and Employability Series 1.

Development of the Differential Equations Concept Inventory to Assess Conceptual Understanding

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ABSTRACT

Differential equations (DEs) are an important mathematical concept for a wide variety of disciplines in engineering. Hence, students need to develop a good understanding of the basic concepts of DEs. To assess student conceptual understanding, Concept Inventories (CIs) are commonly used in engineering disciplines. They also serve to evaluate instruction especially when new teaching methods are tried out.
The Differential Equations Concept Inventory (DECI) was developed to be used to evaluate the average basic understanding. In a first stage it shall be used to compare the impact of different teaching methods. Existing frameworks were used to develop the DECI and statistical methods to assess its validity and reliability for the given purpose.

The DECI shows a good level of support to measure students' overall understanding of the concepts addressed by the DECI. It is not yet recommended to determine individual students' understanding of specific concepts, their difficulties or common errors. For this purpose, higher statistical standards would need to be met and individual influencing factors like gender or ethnicity would have to be investigated.

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Hence, the DECI can be used by instructors to examine the impact of their teaching and new teaching methods on the conceptual understanding of students in the field of differential equations.

1 INTRODUCTION

Differential equations (DEs) are an important mathematical concept for a wide variety of disciplines in engineering. Students must not only acquire (some) procedural skills but also a deep understanding of the basic concepts of DEs and their solutions. They need to be able to assign meaning to DEs, use them in the correct way and utilize their knowledge for complex problem solving. However, there is substantial research showing that many students have conceptual difficulties and do not achieve these goals (Zandieh and McDonald 1999; Habre 2000; Rasmussen 2001; Rowland and Jovanoski 2004; Trigueros 2004; Rasmussen and Kwon 2007; Raychaudhuri 2008; Mallet and McCue 2009; Arslan 2010; Camacho-Machín, Perdomo-Díaz, and Santos-Trigo 2012a; 2012b; Czocher, Tague, and Baker 2013; Camacho-Machín and Guerrero-Ortiz 2015; Hyland, Van Kampen, and Nolan 2018; 2021; Sijmkens et al. 2022; Habre 2023).

The term *difficulties* and not *misconceptions* is deliberately used, as students might not have conceptions about some of the addressed concepts at all. The difficulties are subdivided in those connected to (i) a severe lack of prior knowledge from algebra and calculus, (ii) the DE itself and (iii) the solution to the DE (Fuhrmann and Kautz 2022). For lecturers it can be challenging to successfully address students' difficulties in their teaching and provide for a good basic conceptual understanding.

To evaluate both, instruction and individual students' performance, Concept Inventories (CIs) are becoming increasingly popular in different fields of STEM education (e.g., Force Concept Inventory (Hestenes, Wells, and Swackhamer 1992)). CIs make one or more of the following claims about students' conceptual understanding and common student difficulties (Jorion et al. 2015): Students' CI scores can be used to indicate their overall understanding of all concepts identified in the CI, to indicate their understanding of specific concepts, and / or to indicate their propensity for difficulties or student errors. In this paper we discuss the design, reliability and validity of the Differential Equations Concept Inventory (DECI).

2 METHODOLOGY

2.1 Design of the DECI

The DECI was designed along the ten-step process laid out by Crocker and Algina (1986) which are in agreement in the essential aspects with Adams and Wieman (2011) and the AERA-Standards (2014).

Table 1. Ten-Step process for the design of the DECI (Crocker and Algina 1986)*. The steps are discussed in detail in the results section.*

Step 1	Define the purpose of the test
Step 2	Identify the concepts to be tested
Step 3	Define the test specifications

Step 4	Create an initial pool of items
Step 5	Have items reviewed by experts
Step 6	Hold preliminary item try-outs
Step 7	Field-test the items on a large representative student sample
Step 8	Conduct item analysis
Step 9	Design and conduct reliability and validity studies for the final test
Step 10	Develop guidelines for administration, scoring, and interpretation of the test scores

2.2 Statistical considerations

The most fundamental considerations for developing and evaluating a CI are its validity and reliability. The *Standards for Educational and Psychological Testing* (2014) define validity as the degree to which evidence and theory support the interpretations of test scores for the proposed uses of the inventory. They use the term reliability (precision) in the more general notion to denote consistency of the scores across instances of the testing procedure. Validity and reliability of the inventory can be tested through quantitative statistical and qualitative methods, e.g., external measures like interviews, measures from classical test theory (CTT), and item response theory (IRT).

Validity can only be assessed for the specific proposed interpretations of test scores and therefore for the given purpose, target population, and setting. Qualitative measures were used to examine the four types of validity (face, content, criterion, and construct validity).

To asses reliability the following measures (table 2) were used (Direnga 2021):

The **average of score** $\bar{x}$ is calculated using equation (1) and the **standard error of the average** σ_{mean} is given for experimental data with unknown mean and standard deviation by (2). **Cronbach's-**α is a measure of internal consistency of the inventory and calculated using (3). Only given answers were included in the calculation of the variance, i.e., if an item was not answered by a student, it was not included rather than classified as being wrong. The **difficulty index** diff_j is a measure of "easiness" and ranges between 0 (always answered wrong; "difficult" item) and 1 (always answered correctly, "easy" item). The **discrimination index** disc_j compares the subgroup difficulty indices $\mathrm{diff}_{\mathrm{j,H}}$ of the 27 % high scorers (H) of that item to the one $\mathrm{diff}_{j,L}$ of the 27 % low scorers (L) and is defined by (5). Here, again, only students that answered the item of interest, are included in the calculation.

The **ability** of a student is defined as a (normalized) measure that predicts (or explains) the students' performance on the inventory (Hambleton, Swaminathan, and Rogers 1991). It also depends on parameters of the items, e.g., their difficulties and abilities to discriminate between students. Since the item parameters are not known and since not all items are in their final form yet, it was decided to calculate the **normalized score** ϑ as a simplified method to estimate a students' ability (6). ϑ does not take into account characteristics of the items. It therefore has a midpoint of 0 and a standard deviation of 1. The **probability** of answering an item correctly increases

Table 2. Equations used to calculate statistical measures.
n - number of test takers, x_i - score of each test taker, k - number of items on the test, $Var(\chi_j)$ - variance of item j, $Var(\chi)$ - variance of the entire test, $n_{j,correct}$ - fraction of test takers who responded to item j correctly, $n_{j,correct} + n_{j,incorrect}$ - pool of students that answered item j, x_n - score of individual n, σ_x - standard deviation of scores.

$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$	(1)	$\mathrm{diff_j} = \frac{n_{j,\mathrm{correct}}}{n_{j,\mathrm{correct}} + n_{j,\mathrm{incorrect}}}$	(4)
$\sigma_{\mathrm{mean}} = \sqrt{\frac{1}{n} \cdot \frac{1}{n-1} \cdot \sum_{i=1}^{n} (x_i - \bar{x})^2}$	(2)	$\mathrm{disc}_j = \mathrm{diff}_{j,H} - \mathrm{diff}_{j,L}$	(5)
$\alpha = \frac{k}{k-1} \cdot \left(1 - \frac{\sum_{j=1}^{k} \mathrm{Var}(\chi_j)}{\mathrm{Var}(\chi)}\right)$	(3)	$\vartheta = \frac{x_n - \bar{x}}{\sigma_x}$	(6)

monotonically as the level of ability increases. This relationship can be shown in the item characteristic curve.

3 RESULTS

In the following, the relevant data for the DECI is presented along the steps of the design process as stipulated by Crocker and Algina (1986) and shown in table 1.

3.1 Definition of the purpose of the test

The Differential Equations Concept Inventory (DECI) was designed to measure students' basic conceptual understanding of DEs and their solutions. In a first stage it is intended to assess the success of instruction and instructional methods, meaning that the test scores indicate an overall understanding of all concepts identified in the DECI. Test score interpretation for individual students' learning is limited, since construct-irrelevant components (e.g., gender, ethnicities, or age) could influence the total score and were not investigated up to now. Also, higher levels of validity and reliability would have to be met. The DECI shall not be used as a placement tool, formative assessment tool, or to discover unknown difficulties. However, it can inform about the frequency of certain false ways of reasoning.

3.2 Identification of the concepts to be tested

Student difficulties and key concepts with DEs were identified through literature, and complemented and partially confirmed by semi-structured interviews with 9 students (Fuhrmann and Kautz 2022). They were grouped, when necessary, and six concepts were chosen for the inventory based on the following criteria:

- **Completeness**: If all of the concepts covered by the inventory are understood by a student, the student may be considered as having gained a basic conceptual understanding of DEs. The inventory encompasses all essential concepts of DEs.

- **Parsimony**: If even one of the concepts covered in the inventory is not understood, one may not conclude, that this student gained a basic conceptual understanding of DEs. The inventory contains only essential concepts of DEs.

- **Testability**: It must be possible to test for the concepts with a multiple-choice questionnaire. E.g., it is hard to test for difficulties concerning the differences and similarities between functions, DEs and solutions of DEs with multiple choice questions since there has to be one definitely correct answer and four definitely incorrect ones with no room for interpretation.

The concepts included in the DECI are:

1) Recognition of DEs from a text-based problem

Students decide whether a text-based problem can be described by a DE and base their decision on correct arguments.

2) Formulation of a DE from a text-based problem

Students can formulate a DE from a text-based problem or associate the problem with an appropriate DE.

3) Understanding the meaning of variables and terms involved in the DE

Students are able to interpret the variables and terms involved in a DE, such as y, $\dot{y}$, x, and constants.

4) DEs and graphical representations (diagrams)

Students relate DEs and graphical representations of functions in diagrams. They interpret and draw conclusions from the graphical representation of a DE or its solution.

5) Application of solution methods and verification of solutions of DEs

Students decide for and use a correct solution method to solve basic-level DEs. They provide proper justification, using mathematically correct arguments, for determining whether a given solution can correspond to a given DE.

6) Prior knowledge

Students understand basic mathematical concepts that are considered to be important for the topic of DEs. Our choice was the understanding of functions, derivatives, infinitesimal quantities and graphical representations / diagrams.

Concepts regarding the topics of equilibrium solutions or homogeneous and inhomogeneous DEs were not considered by the test designers to be very basic concepts but themselves require a basic conceptual understanding of DEs. Therefore, they were not included in the DECI.

3.3 Definition of the test specifications

The DECI is designed to be administered as a post-test and should be paired with an appropriate pre-test as a reference for students' prior knowledge. It cannot be used as a pre-test, as the concepts are unlikely to be familiar to students from prior mathematical courses or everyday life experiences. When administering the DECI, students are expected to have covered the relevant materials on DEs in their study programs, but it can be implemented at any subsequent point in time.

Any CI that covers basic mathematical skills, including the understanding of functions, limits, derivatives, infinitesimal quantities, and integrals can be used as a pre-test (e.g., the Calculus Concept Inventory (Epstein 2013; Gleason et al. 2019) when ensured that the relevant concepts have been covered in the university courses beforehand).

The implementation is similar to other CIs (Madsen, McKagan, and Sayre 2017). The DECI has to be performed during class time (!) and lasts 30 min. An online form is possible, e.g., to ensure easy handling, comparability and data transfer between institutions. No tools are allowed except the test environment in the electronic device if administered online.

The DECI is a multiple-choice questionnaire for various reasons. In this way it is highly objective, allows for automated and fast scoring, enables assessing large student groups, and is feasible for the application of test-theoretical methods for validation and reliability checks. The concepts 1) to 5) relating to DEs are assessed with three items each, prior knowledge with four items, resulting in 19 items. The number of items per objective was guided by the principle of providing at least three items per concept (Engelhardt 2009) for a reliable and valid inventory while ensuring that the DECI remains within reasonable length constraints.

3.4 Creation of an initial pool of items

The questions were inspired by existing multiple-choice and open-ended questions from literature and online resources (e.g., http://mathquest.carroll.edu/de.html). For each of the concepts 1) to 5), three items were developed. The creation of distractors was based on known difficulties and students' typical thought patterns from literature and semi-structured interviews. The distractors may be more strongly linked with one of other concepts tested for in the DECI rather than the specific concept intended in the question. Prior knowledge was assessed with four items taken from the Calculus Concept Inventory.

3.5 Item review by experts and item revision

Four experts (i.e., professors and lecturers of mathematics) reviewed the items with a focus on ensuring mathematically correct wording and completeness of the items. They assured that the items encompassed all relevant concepts and were solvable with a basic conceptual understanding of DEs. Additionally, the authors strove to minimize complexity and facilitate understandability of the items for students.

3.6 Preliminary item try-outs and item revision

This step was omitted because we found it to be of limited value in this development process due to the greatly diverse target group at Universities of Applied Sciences. Therefore, a first field test followed the item review with more field tests to come.

3.7 Field-test of the items on a large representative student sample

The DECI was used at different Universities of Applied Sciences in Germany. In contrast to traditional Universities or Technical Universities, the students' background is often more heterogeneous concerning their educational background and mathematical knowledge. We strongly believe, that the DECI is also valid in other types of universities, but did not yet test for it.

The DECI was carried out in six mathematics courses at five Universities of Applied Sciences with second semester students (Darmstadt, Landshut, Merseburg, Rosenheim, Regensburg). 121 students participated. No bonus points or rewards were given to students for participation.

3.8 Item analysis and item removal or revision

Based on the statistical analysis in section 3.9, test items will be rephrased and slightly rearranged before unrolling the 2nd version of DECI.

3.9 Design and conduct of reliability and validity studies

Reliability and validity of the DECI are assessed as far as possible in section 4.

3.10 Develop guidelines for administration, scoring, and interpretation of the test scores

Administration is equivalent to other CIs, as shown in section 3.3. Comparative scoring values need to be assessed for the final version.

4 RESULTS OF RELIABILITY AND VALIDITY STUDIES

General Statistical Considerations

The distributions of the total scores and of the number of answers are shown in Fig. 1 and Fig. 2. On average, 18.65 ± 0.12 items (out of 19) were answered and 7.30 ± 0.33 correct answers given (with standard errors of the mean as indicated). Fig. 3 and Fig. 4 show the percentage of test takers that did not answer each item and the percentage that answered an item correctly, respectively.

Reliability Considerations

Cronbach's-α is 0.728 and therefore larger than 0.7 which indicates that the DECI is sufficient for group measurements (Engelhardt 2009; Jorion et al. 2015). For each item of the DECI, α was also computed for the entire test without the given item. α should then be lower compared to the entire test. For items 1, 6, 10, 15 and 18 it was greater ($0.73 < \alpha < 0.74$), indicating the need for revision of these items.

In Fig. 5 the scatterplot of item difficulty and item discrimination is shown. Most of the items meet the recommended criteria for CIs intended for instructional (as opposed to individual) use, with the difficulty ranging between 0.2 and 0.8 and the item

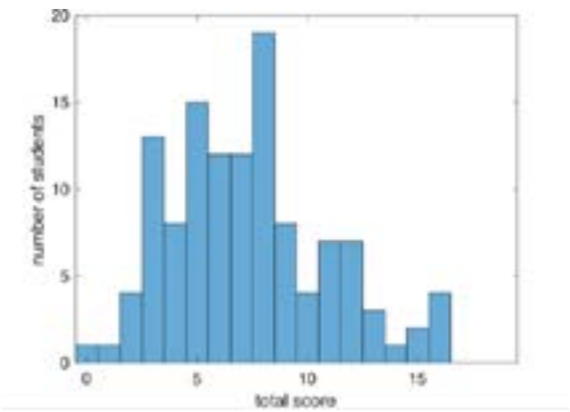

Fig. 1. Distribution of students based on the total scores, which is equal to the number of correct answers.

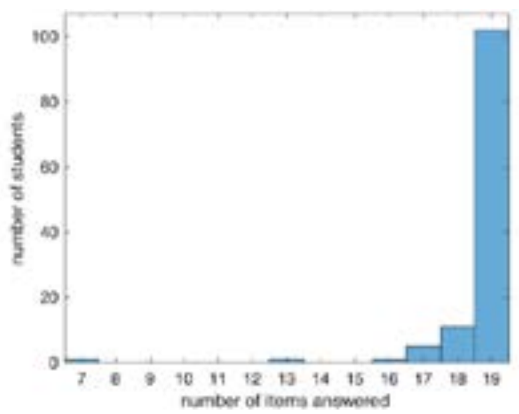

Fig. 2. Distribution of students based on the number of answers given in the DECI.

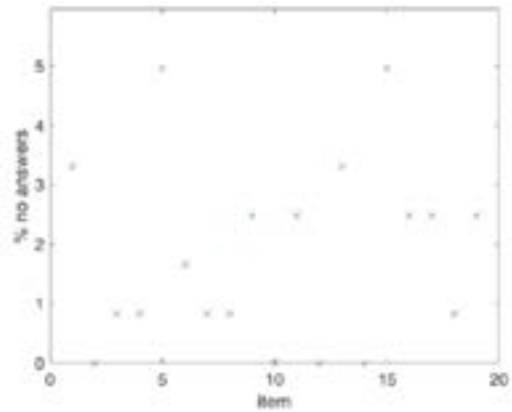

Fig. 3. Percentage of students that did not give an answer for each item.

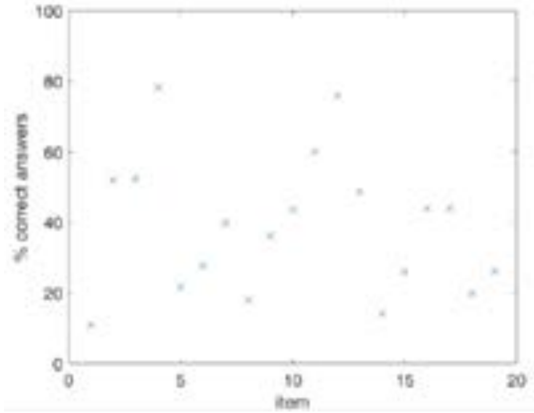

Fig. 4. Percentage of students that gave correct answers in relation to the number of students answering each item.

discrimination being larger than 0.8 (Jorion et al. 2015). The diagram indicates the need for revision for items 1, 8, 14 and 18. A rarely chosen option in item 6 will be removed leaving 5 answering options and leading to a better alignment with the other items with mostly five options.

For each item, the item characteristic curve (ICC, e.g., Fig. 6) and the distribution of chosen answer options was assessed. ICCs were constructed by grouping students in 10th percentiles (i.e., aggregating 12 to 13 students per data point on the ICC). This methodology facilitated the collection of 10 data points for each ICC and allowed for a comprehensive examination of item quality. The observed slopes for the correct answers across all items were positive, showing that students with a higher total test score were more likely to answer each item correctly. Despite attempts at curve fitting and model validation, such as utilizing a 3-parameter logistic model, these efforts were impeded by the limited amount of data available as well as the necessity for slight adaptions in certain items.

The process of assessing the ICC and the given answers is illustrated using item 3. The question and answer options are shown in Fig. 6. Even though the correct option a) is the first response option and the only one with a derivative of y, only 52 % of students chose this answer. Option b) was chosen by 26 % of students and may result from two possible ways of thinking. First, for some students, DEs are inextricably linked to exponential functions. Second, some students do not or not

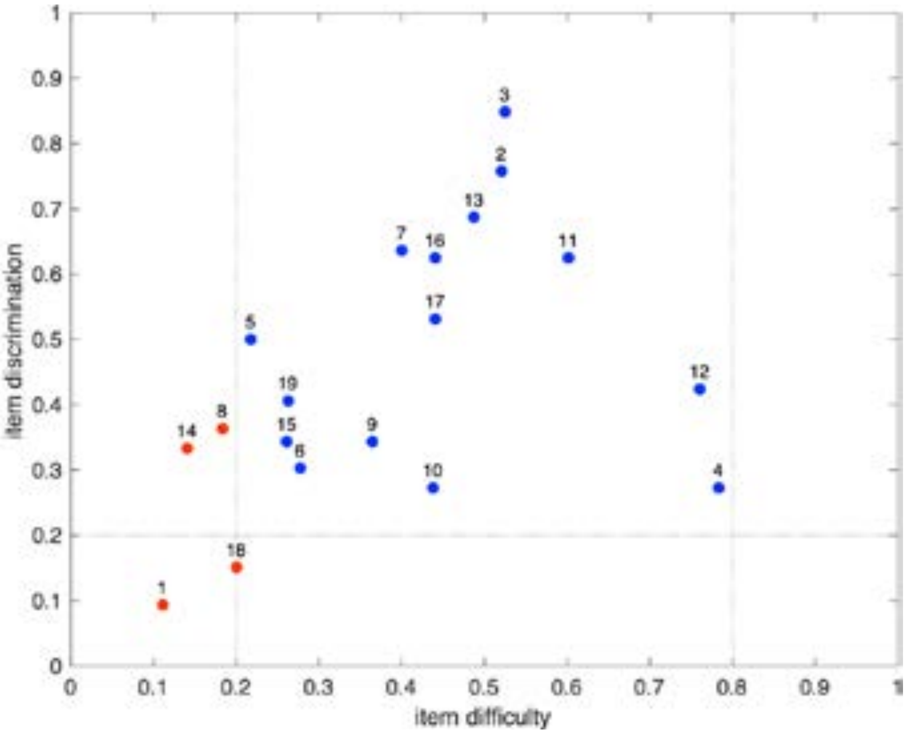

Fig. 5 Scatterplot of item difficulty and item discrimination. Recommended minimum and maximum values are denoted by the dotted lines. Three items (1,8,14) did not meet the recommended minimum item difficulty of which two had a good discrimination index.

sufficiently distinguish between a DE and its solution. Option b) is a very well-known solution for students to the stated problem. Option c) (7.4 %) might be selected by students who do not have a deep understanding of the meaning of the variables and terms involved in a DE. They may see that the rate of change, which they think of as the dependent variable, is proportional to the number of rabbits, which they consider to be the independent variable. Therefore, a linear function results. Option d) (6.6 %) was included as an option for students who reason similarly but might additionally think that the answer must be more "complicated" than a linear function. Option e) was designed to attract students who build an isolated, completely decoupled knowledge about DEs and think of them as something "totally different" to what they have learned before. For those students it can be nonsensical to write down a DE (part of the new knowledge) for an everyday, well-known phenomenon (part of the previous knowledge).

If the following problem can be described by a differential equation, which differential equation can correspond to the problem ($a, b \in \mathbb{R} \setminus \{0\}$)?

A small number of rabbits are located in a very large open area without predators. The rate of change in the number of rabbits is proportional to the number of rabbits present.

a) $\dot{y}(t) = a \cdot y(t)$

b) $y(t) = a \cdot e^{bt}$

c) $y(t) = a \cdot t$

d) $y(t) = a \cdot t^2$

e) The problem is not described by a differential equation.

Fig. 6: Item 3 with the correct answer being a).

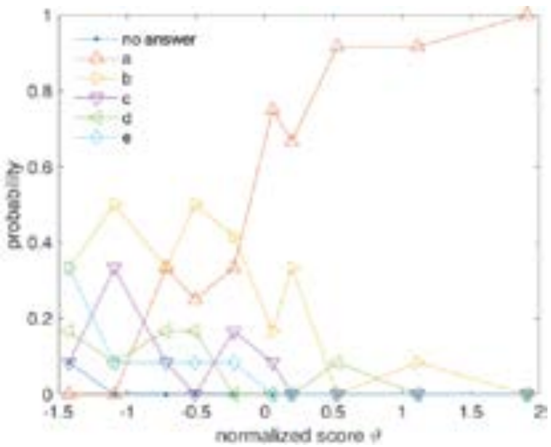

Fig. 7. Item Characteristic Curve of item 3. The probability of giving a specific answer is shown for all answer options. The correct answer is a.

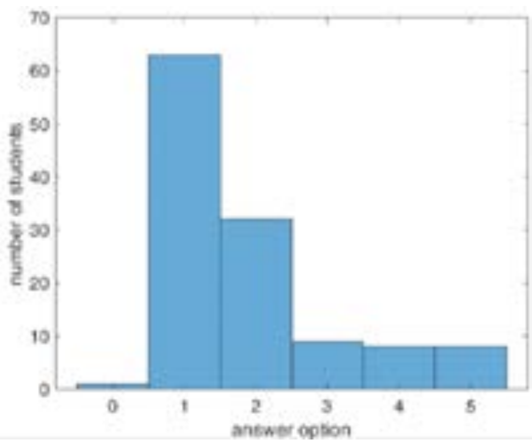

Fig. 8. Distribution of student responses: index 0 indicates the count of students who did not respond to the item, indices 1 to 5 correspond to options a to d.

In Fig. 7 it can be seen, that the probability for answering item 3 correctly increases for students with a higher normalized score. This is the preferred characteristic for an item in a Concept Inventory. Fig. 8 shows, that the correct option is the preferred one, but also, that all options were chosen by students. Therefore, all options appeal to students and no option has to be exchanged.

Validity Considerations

***Face Validity**:* Mathematicians (experts) verified that the DECI appears to measure the intended constructs.

***Content Validity**:* During steps 2 and 5 of the design process, attention was devoted to ensuring that the concepts and items of the DECI fully represent the overall construct, namely, the basic conceptual understanding of DEs. However, for a final version of the DECI, interviews with experts should be conducted.

***Criterion Validity**:* The results of the DECI cannot be compared to other quantities since there is no "gold standard" inventory available (concurrent validity). Due to strong data protection regulations in Germany, the DECI was performed anonymously, asking students only for self-generated identity codes (SGICs, (Timmermann et al. 2016)). Therefore, it cannot be correlated to e.g., exam results (predictive validity) or other measures.

***Construct validity**:* Construct validity assesses whether the DECI and its individual items measure the intended overall construct. Some questions were given to students in semi-structured interviews in a modified form. The students' reasoning was then observed and analyzed, suggesting that the questions were correctly interpreted by the students. However, the exact questions of the DECI were not given to students in interview settings.

5 CONCLUSIONS

The Differential Equations Concept Inventory (DECI) is not in its final form yet, but our data indicate that it is a valid and reliable instrument to assess students' basic conceptual understanding of DEs and their solutions. Accordingly, it can be utilized to compare the effectiveness of different teaching methods.

REFERENCES

Adams, Wendy K., and Carl E. Wieman. 2011. "Development and Validation of Instruments to Measure Learning of Expert-Like Thinking." *International Journal of Science Education* 33 (9): 1289–1312. https://doi.org/10.1080/09500693.2010.512369.

American Educational Research Association, American Psychological Association, and National Council on Measurement in Education. 2014. *Standards for Educational and Psychological Testing*. Washington, DC: American Educational Research Association.

Arslan, S. 2010. "Do Students Really Understand What an Ordinary Differential Equation Is?" *International Journal of Mathematical Education in Science and Technology* 41 (7): 873–88. https://doi.org/10.1080/0020739X.2010.486448.

Camacho-Machín, M., and C. Guerrero-Ortiz. 2015. "Identifying and Exploring Relationships between Contextual Situations and Ordinary Differential Equations." *International Journal of Mathematical Education in Science and Technology* 46 (8): 1077–95. https://doi.org/10.1080/0020739X.2015.1025877.

Camacho-Machín, M., J. Perdomo-Díaz, and M. Santos-Trigo. 2012a. "An Exploration of Students Conceptual Knowledge Built in a First Ordinary Differential Equations Course (Part I)." *The Teaching of Mathematics* 15 (1): 1–20.

Camacho-Machín, M., J. Perdomo-Díaz, and M. Santos-Trigo. 2012b. "An Exploration of Students Conceptual Knowledge Built in a First Ordinary Differential Equations Course (Part II)." *The Teaching of Mathematics* 15 (2): 63–84.

Crocker, Linda M., and James Algina. 1986. *Introduction to Classical and Modern Test Theory*. New York: Holt, Rinehart, and Winston.

Czocher, Jennifer A., Jenna Tague, and Greg Baker. 2013. "Where Does the Calculus Go? An Investigation of How Calculus Ideas Are Used in Later Coursework." *International Journal of Mathematical Education in Science and Technology* 44 (5): 673–84. https://doi.org/10.1080/0020739X.2013.780215.

Direnga, Julie. 2021. "Assessing the Effectiveness of Research-Based Active Learning Materials for Introductory Engineering Mechanics." Hamburg University of Technology. https://doi.org/10.15480/882.3229.

Engelhardt, Paula V. 2009. "An Introduction to Classical Test Theory as Applied to Conceptual Multiple-Choice Tests." *Getting Started in PER* 2 (1): 1–40.

Epstein, Jerome. 2013. “The Calculus Concept Inventory–Measurement of the Effect of Teaching Methodology in Mathematics.” *Notices of the American Mathematical Society* 60 (08): 1018. https://doi.org/10.1090/noti1033.

Fuhrmann, Tina A., and Christian Kautz. 2022. “Understanding of Differential Equations in a Highly Heterogeneous Student Group.” In *Towards a New Future in Engineering Education, New Scenarios That European Alliances of Tech Universities Open Up*, 288–97. Universitat Politècnica de Catalunya. https://doi.org/10.5821/conference-9788412322262.1280.

Gleason, Jim, Spencer Bagley, Matthew Thomas, Lisa Rice, and Diana White. 2019. “The Calculus Concept Inventory: A Psychometric Analysis and Implications for Use.” *International Journal of Mathematical Education in Science and Technology* 50 (6): 825–38. https://doi.org/10.1080/0020739X.2018.1538466.

Habre, S. 2000. “Exploring Students’ Strategies to Solve Ordinary Differential Equations in a Reformed Setting.” *The Journal of Mathematical Behavior* 18 (4): 455–72. https://doi.org/10.1016/S0732-3123(00)00024-9.

Habre, S. 2023. “Qualitative Aspects of Differential Equations in an Inquiry-Oriented Course.” *International Journal of Mathematical Education in Science and Technology* 54 (3): 351–64. https://doi.org/10.1080/0020739X.2021.1954250.

Hambleton, Ronald K., Hariharan Swaminathan, and H. Jane Rogers. 1991. *Fundamentals of Item Response Theory*. Measurement Methods for the Social Sciences Series 2. Newbury Park, Calif: Sage Publications.

Hestenes, David, Malcolm Wells, and Gregg Swackhamer. 1992. “Force Concept Inventory.” *The Physics Teacher* 30 (3): 141–58. https://doi.org/10.1119/1.2343497.

Hyland, D., P. Van Kampen, and B. Nolan. 2021. “Introducing Direction Fields to Students Learning Ordinary Differential Equations (ODEs) through Guided Inquiry.” *International Journal of Mathematical Education in Science and Technology* 52 (3): 331–48. https://doi.org/10.1080/0020739X.2019.1670367.

Hyland, D., P. Van Kampen, and Brien C. Nolan. 2018. “Outcomes of a Service Teaching Module on ODEs for Physics Students.” *International Journal of Mathematical Education in Science and Technology* 49 (5): 743–58. https://doi.org/10.1080/0020739X.2017.1410736.

Jorion, Natalie, Brian D. Gane, Katie James, Lianne Schroeder, Louis V. DiBello, and James W. Pellegrino. 2015. “An Analytic Framework for Evaluating the Validity of Concept Inventory Claims.” *Journal of Engineering Education* 104 (4): 454–96. https://doi.org/10.1002/jee.20104.

Madsen, Adrian, Sarah B. McKagan, and Eleanor C. Sayre. 2017. “Best Practices for Administering Concept Inventories.” *The Physics Teacher* 55 (9): 530–36. https://doi.org/10.1119/1.5011826.

Mallet, Dg, and Sw McCue. 2009. “Constructive Development of the Solutions of Linear Equations in Introductory Ordinary Differential Equations.” *International Journal of Mathematical Education in Science and Technology* 40 (5): 587–95. https://doi.org/10.1080/00207390902759626.

Rasmussen, C. 2001. “New Directions in Differential Equations: A Framework for Interpreting Students’ Understandings and Difficulties.” *The Journal of Mathematical Behavior* 20 (1): 55–87. https://doi.org/10.1016/S0732-3123(01)00062-1.

Rasmussen, C., and O. N. Kwon. 2007. “An Inquiry-Oriented Approach to Undergraduate Mathematics.” *The Journal of Mathematical Behavior* 26 (3): 189–94. https://doi.org/10.1016/j.jmathb.2007.10.001.

Raychaudhuri, Debasree. 2008. “Dynamics of a Definition: A Framework to Analyse Student Construction of the Concept of Solution to a Differential Equation.” *International Journal of Mathematical Education in Science and Technology* 39 (2): 161–77. https://doi.org/10.1080/00207390701576874.

Rowland, D. R., and Z. Jovanoski. 2004. “Student Interpretations of the Terms in First-Order Ordinary Differential Equations in Modelling Contexts.” *International Journal of Mathematical Education in Science and Technology* 35 (4): 503–16. https://doi.org/10.1080/00207390410001686607.

Sijmkens, Elien, Nico Scheerlinck, Mieke De Cock, and Johan Deprez. 2022. “Benefits of Using Context While Teaching Differential Equations.” *International Journal of Mathematical Education in Science and Technology*, March, 1–21. https://doi.org/10.1080/0020739X.2022.2039412.

Timmermann, D, J Direnga, J Lund, and C Kautz. 2016. “Design and Application of Self-Generated Identification Codes (SGICs) for Matching Longitudinal Data.” In *Proceedings of the 44th SEFI Annual Conference*. Tampere, Finnland.

Trigueros, M. G. 2004. “Understanding the Meaning and Representation of Straight Line Solutions of Systems of Differential Equations.” In *Proceedings of the Twenty-Sixth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, 127–34.

Zandieh, M., and M. McDonald. 1999. “Student Understanding of Equilibrium Solution in Differential Equations.” In *Proceedings of the 21st Annual Meeting of the Northern American Chapter of the International Group for the Psychology of Mathematics Education*, 253–58. Columbus, OH: ERIC.

LEVERAGING GENERATIVE AI FOR ASSESSING STUDENT REPORTS IN ENGINEERING EDUCATION

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Conference Key Areas: *Digital tools and AI in engineering education; Engineering skills, professional skills, and transversal skills*
Keywords: *Large Language Models (LLMs), Generative Artificial Intelligence (GenAI), Engineering Education, Educational Assessment.*

ABSTRACT

This paper examines the application of Generative AI (henceforth GenAI), specifically OpenAI's advanced Large Language Models (LLMs), in evaluating student reports within challenge-based courses with focus on Sustainability and Ethics (S&E). Traditional grading methods, heavily reliant on manual effort and subject to human biases, present a significant workload for educators and often lack consistency. By integrating LLM into the grading process, this study explores the

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feasibility of automating assessment tasks, aiming to achieve more objective and efficient evaluation while reducing evaluators' workload. The research method entails preprocessing and anonymizing student reports, *promptifying* existing rubrics for LLM compatibility, and analyzing the AI-generated assessments against human-graded benchmarks. Preliminary findings suggest that LLMs can complement human grading by providing consistent evaluations under certain conditions, such as when reports are text-based and rubrics are clearly defined. However, limitations such as the model's reasoning capabilities and handling of non-textual information indicate areas for future research. This research contributes to ongoing discussions on the potential of GenAI in education, underscoring the need for further exploration into AI-assisted assessment tools that could enhance the transparency and efficacy of grading practices in engineering education.

1 INTRODUCTION

The rapidly growing field of Generative AI (henceforth GenAI), particularly in the development of Large Language Models (LLMs), catalyzes a range of potential applications across diverse sectors, including Healthcare, Business, Finance, Banking, Sales, Marketing, Content Creation, and Education (Bahrini et al. 2023; Ray 2023). The integration of Gen AI into the evaluation process of student reports presents a novel pathway for enhancing educational assessment methodologies (Tobler 2024). This paper explores the use of Gen AI to assess student reports on Sustainability and Ethics (S&E) topics, utilizing a custom methodology to emulate the grading approach of course professors. By incorporating contextual knowledge in the form of a rubric into the LLM, the study seeks to explore whether the assessment process could be streamlined, thereby supporting evaluators in reducing the time spent on grading and minimizing human errors and unconscious biases.

Challenge-based courses, especially those with group work, present unique assessment challenges. Fair assessment for individual students in capstone projects requires criteria beyond the final output to meet project objectives (Farrell et al. 2012). One method is determining the final grade by consensus in department meetings (Schramm and Chan 2013), although rubrics and IT tools are commonly used (Schramm and Chan 2013; Tio et al. 2014). Evaluations typically include class participation, peer assessment, group presentations, and final reports, which are often unrestricted in format and length. This freedom, while pedagogically valuable, increases the assessment workload for faculty (Valenti, Neri, and Cucchiarelli 2003), as the open-ended nature of assignments demands considerable time and effort in grading, especially with many students and complex reports.

Recent literature on AI for student assessment highlights its application to specific topics or domains (González-Calatayud, Prendes-Espinosa, and Roig-Vila 2021). AI has been used to assess English report quality with non-linear regression models (Liu et al. 2017) and evaluate programming exercises by measuring answer similarity with edit distance, categorizing answers, and identifying errors (Grivokostopoulou, Perikos, and Hatzilygeroudis 2017), among others. These approaches highlight the limitations of applying AI to broader domains without precise assessment tool design.

GenAI has shown exceptional ability in synthesizing extensive texts (Sallam 2023), responding to specific questions based on the text or integrating contextual or broad knowledge bases through techniques like Retrieval Augmented Generation (RAG) (Nashid, Sintaha, and Mesbah 2023). These systems offer a consistent approach to interpreting and evaluating text, presenting a solution to the subjective nature of essay grading, which often results in students perceiving unfairness due to grading variability by different human assessors (Valenti, Neri, and Cucchiarelli 2003). Utilizing automated assessment tools could improve consistency in grading and decrease the workload associated with the comprehensive evaluation of student reports. This shift towards automated systems seeks to reduce the risks of human biases and errors, which are likely when grading a large volume of submissions.

Exploring GenAI’s potential to streamline assessment in challenge-based courses is logical and promising. The application of LLMs in this domain could extend beyond reducing faculty's grading workload. It also has the potential to offer valuable feedback for refining and iterating existing rubrics. Such enhancements to the grading criteria can improve transparency and understanding for students, providing them with clearer expectations and requirements before they complete their reports. Ultimately, the incorporation of GenAI into the academic evaluation process heralds a substantial advancement in engineering education, promising a more efficient, objective, and enriching learning and teaching experience.

2 METHODOLOGY

This research uses GenAI, particularly OpenAI's advanced LLM, to simulate standard human grading processes. Subsequent sections detail the workflow from report selection to ground truth validation. This process is illustrated in Figure 1.

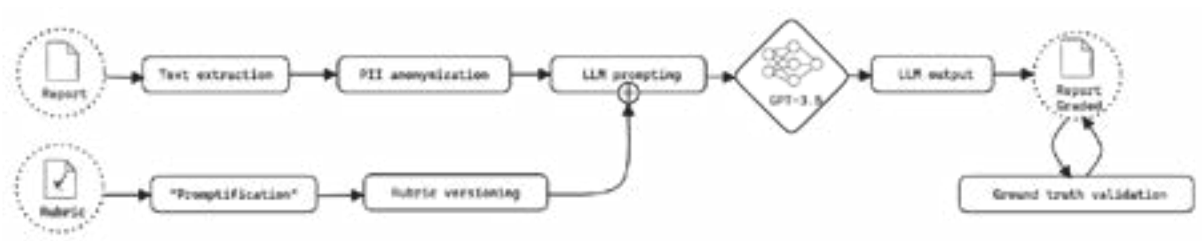

Figure 1. Methodology diagram

2.1 Reports Preprocessing and Anonymization

The initial stage of our methodology involves the compilation and preparation of student reports from the “Advanced Engineering Project" course, a capstone requirement for final-year ICT Engineering students at Telecos-BCN, the ICT Engineering School of Universitat Politècnica de Catalunya (UPC) in Barcelona, Spain. This is the third project-based course of our curriculum and follows the Product Development Project (PDP) model, which can also be assimilated to the New Product Development model (Cobb et al. 2016). In this course, relatively big students’ teams (8-12 students) carry out the design of a complete product or service, including its business model. They also perform the S&E analysis and an intellectual property search and patent proposal. The teams generate the requirements and specifications of the product or service from the initial interaction with the stakeholders, define the system block structure and the work packages and then distribute them among subgroups of 2-3 students. They must design, implement and test the subsystems, integrate them, define a business model based on the product or service and perform the S&E analysis. Since 2011, more than 1650 students have passed this compulsory course, working in more than 170 different projects. Currently, 75 % of the challenges are proposed by external agents: companies, hospitals, foundations, NGOs,… A more detailed description can be found in (Bragós Bardia, Aoun, Charosky Larrieu-Let, et al. 2022) and a comparative study of the performance of the student teams according to the kind of stakeholders (internal/external) and other features of the projects has been reported in (Bragós Bardia, Aoun, Bermejo, et al. 2022).

Bridging the academic framework with our analytical approach, over the course of three semesters from September 2022 to January 2024, we gathered a collection of 18 reports. We extracted the chapters focusing on S&E from these reports and these amounted to 156 pages to be assessed, averaging 9 pages per report. We used a Python script with regular expressions to preprocess the reports, removing escape characters and formatting issues for cleaner analysis. Following the extraction and cleaning, we utilize the Presidio library[2], an open-source tool, to perform the anonymization of Personal Identifiable Information (PII). This step was executed locally to ensure that sensitive information, such as personal and organization names or email addresses, would not be part of the prompt to the LLM. The result was a sanitized dataset ready for interaction with the LLM without compromising the privacy of any individual or entity involved.

2.2 Rubrics Promptification and Versioning

The rubrics for the “Advanced Engineering Project” course, originally formatted in a spreadsheet, underwent a process of *promptification* to make them suitable for use with an LLM. This term refers to the conversion of the existing rubric into a text-only format that encapsulates the grading criteria in a manner that is self-explanatory and it is able to properly instruct a LLM. This step was needed so the rubric would seamlessly integrate into the LLM operational framework as a part of the prompts used, as depicted in the next section.

To examine how rubric specificity influences the LLM's grading reliability, we developed two versions. The detailed v1 provided explicit grading instructions for each report section, while the less prescriptive v2 allowed for broader interpretive leeway by the LLM, Table 1 highlights the contrast. This comparative approach aimed to measure grading variance with repeated assessments, shedding light on the stability and dependability of the LLM's grading influenced by rubric design.

2.3 LLM Prompting and Output Parsing

The core of the assessment process involves prompting the LLM with the anonymized report text alongside the *promptified* rubrics. Upon receiving the prompts, the LLM generated assessments for each report. These outputs were then carefully parsed to separate the grading and feedback into formats that could be analyzed both quantitatively and qualitatively.

[2] https://microsoft.github.io/presidio/

Table 1. Comparison of rubric versions for a given question

Rubric v1	Rubric v2
F.EN.D. (Environmental Design) **Question:** Evaluate the project's approach to environmental sustainability, including the quantification and reduction of environmental impacts, the use of sustainable materials, supplier compliance with environmental standards, and the application of the cradle-to-cradle philosophy. **Criteria to grade from 0 to 10:** - Assign 2 points for specific quantification of environmental impact reductions. - Assign 2 points for detailing actions taken to reduce impacts with measurable outcomes. - Assign 3 points for using sustainable materials and ensuring supplier compliance with environmental standards. - Assign 3 points for incorporating the cradle-to-cradle philosophy with clear examples.	**F.EN.D. (Environmental Design)** **Question:** Evaluate the project's approach to environmental sustainability, including the quantification and reduction of environmental impacts, the use of sustainable materials, supplier compliance with environmental standards, and the application of the cradle-to-cradle philosophy. **Criteria to grade from 0 to 10:** Consider the depth of environmental impact analysis, efforts to reduce those impacts, the integration of sustainable materials, supplier compliance, and the cradle-to-cradle philosophy's application.

For our experiment, we used the *gpt-3.5-turbo-0125* model, known for its balance of performance and cost-effectiveness. Although OpenAI offers more advanced models like gpt-4, gpt-3.5 was sufficient for our task and more economical, crucial for large-scale research. The model's token window of over 16,000 tokens accommodated our combined prompt, which included the student's report S&E sections, the rubric, and framing instructions.

We provided clear instructions to the LLM to present grades in brackets "[ ]" for easy tabulation, with any deviations triggering a reiteration of the grading process. Extensive trials were needed to refine this response format. The final Python script, shown in Table 2, illustrates how we interacted with the OpenAI API and handled non-compliant responses.

Table 2. Pseudocode for Assessing Reports with LLM

Pseudocode for Assessing Reports with LLM

```
function load_reports(folder)
  reports <- read_pdf_texts(folder)
  return reports
end function

function build_prompt(report, rubric)
  anonymized_report <- anonymize(report)
  prompt <- concatenate(anonymized_report, rubric)
  return prompt
end function

function infer_grades(reports, rubric, iterations)
  all_grades <- []
  for report in reports
    for i from 1 to iterations
      prompt <- build_prompt(report, rubric)
      grade <- LLM_inference(prompt)
      if not is_valid(grade)
        retry LLM_inference
      all_grades.append(grade)
  end for
  return all_grades
end function

function summarize_results(all_grades, rubrics)
  summary <- compute_stats(all_grades)
  compare_rubrics(summary, rubrics)
  plot_results(summary)
  return summary
end function
```

2.4 Results Summarization and Ground Truth

In the final stage, we compared LLM-generated results with human evaluator grades to gauge accuracy. Additionally, we aimed to examine the level of consistency across multiple assessments of the same report. The generation of the final dataset for this study was completed on April 1st. To avoid potential rate limits, the dataset was processed sequentially in blocks of five reports, which translated to a minimum of 100 API calls, assuming no repeats were necessary due to incorrectly formatted LLM responses. The entire operation spanned approximately 1 hour and 15 minutes, entailing 559 API calls. It used 1,075,000 tokens—795,000 for prompting and 280,000 generated by the LLM in responses—and incurred a total cost of $0.82. On average, each report required 31 API calls, indicating a 50% increase over the ideal scenario with no retries.

With the collected data, we aimed to detect any significant grading deviations using boxplots. These visualizations, as depicted in Figure 2, were designed to quickly pinpoint reports with notable discrepancies in grading across iterations for either version of the rubric. By averaging the grades assigned per question, we could aggregate a score that reflected the LLM assessment behavior.

Further, in Table 3, we presented the aggregated data of all reports, segmented per question and rubric version. This granular approach allowed us to spot potential deviations in how the LLM assessed specific questions, which could indicate areas where the LLM setup in our experiment was more or less adept at grading.

3 RESULTS

The comparative analysis of rubric-based grading shows that Rubric v1, with its explicit criteria, results in more consistent grading than the less explicit v2. In 11 out of 18 reports, the interquartile range (IQR) was narrower for v1, indicating a tighter consensus across iterations. Additionally, the overall grading range was smaller for v1 in 13 out of 18 reports, highlighting the impact of clear criteria on grading consistency. However, a 46% overlap in IQRs between the two rubric versions suggests that other factors besides rubric design also affect grading outcomes.

These findings emphasize the value of detailed rubrics in achieving consistent evaluations and indicate the need for further work to minimize subjectivity in grading.

Other factors contributing to the lower percentage of overlap and the presence of outliers in the boxplots include the limited content in some reports (e.g., report 16, which is less than 3 pages) and content embedded in tables or images within the reports that cannot be extracted from the PDF format (e.g., report 11 and 16).

The data in Table 3 reveals that the 'Resource Utilization and Efficiency' question has the lowest average grade, suggesting students may find this topic more challenging or the grading criteria might be more stringent. Additionally, higher standard deviations for 'Economic Reevaluation' and 'Social Reevaluation' indicate varied interpretations of these questions, hinting at potential ambiguity in the rubric or diverse student approaches to these topics. This underscores the necessity for clearer guidelines or enhanced focus in teaching these areas.

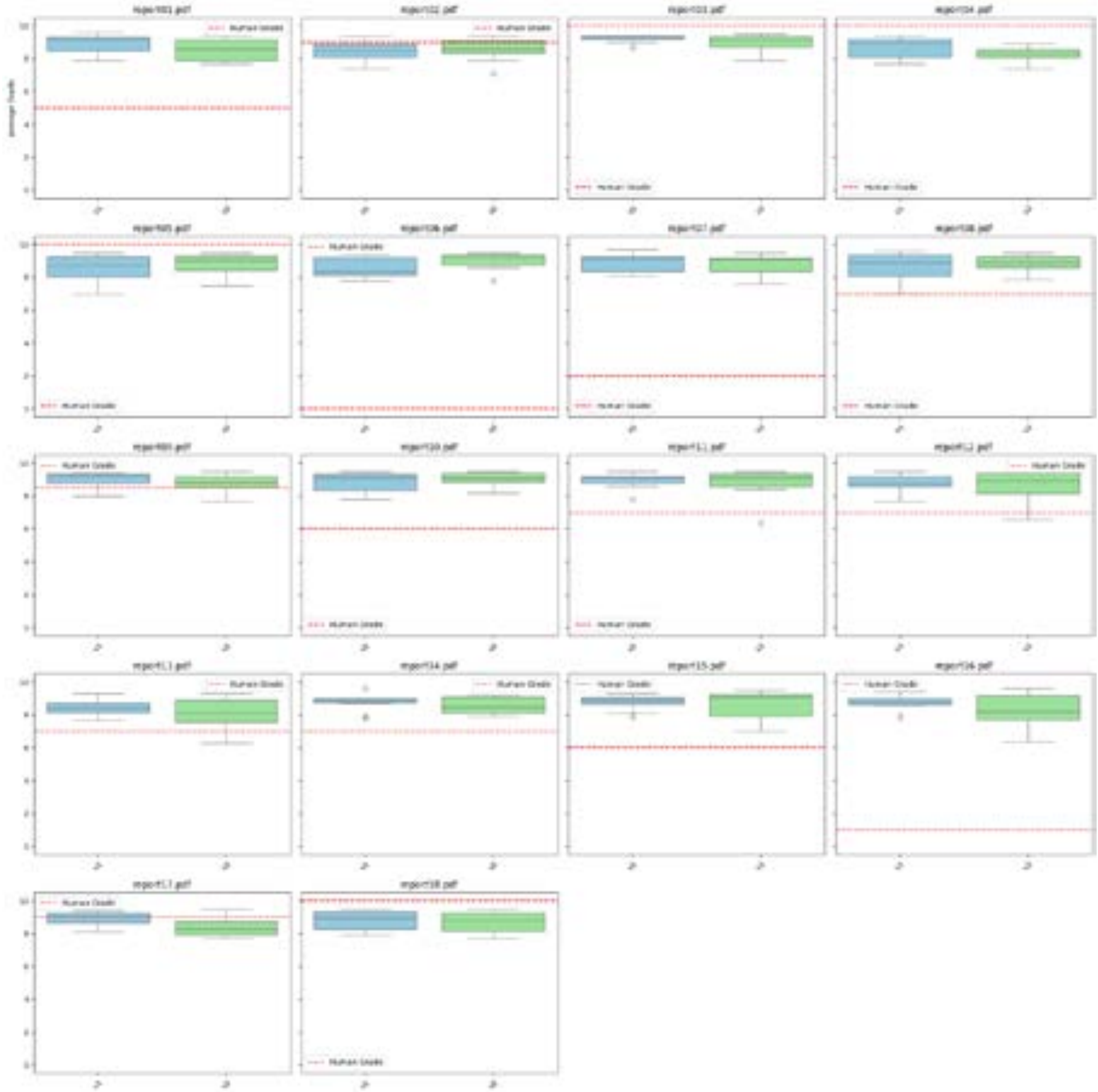

Figure 2. Boxplot grid for each report grades across the 10 iterations per rubric version

When it compares to actual human grading, reports 6, and 17 represent an outlier that should be further included in subsequent iterations of this automatic assessment fine tuning as in those cases, the human evaluator introduced values that are far from the tool assessed. The main reason behind, is that the evaluator used several threshold concepts (Baillie, Goodhew, and Skryabina 2006). There were some basic calculations and report formats that were basic requirements of the course and were not met. Those requirements were not reflected in the rubrics we used in the automatic assessment due to limitations on their definition. This issue helped us to realize that the rubrics may lack some requirements that are just assumed. This is not a problem if there is only an evaluator but would be if there is more than one. Therefore, the process of validating rubrics to be used in LLM-assisted assessment may help to make them more robust.

Table 3. Aggregated data statistics per question.

Question	RubricVersion	Grade mean	Grade std	Grade min	Grade max
F.EN.D. (Environmental Design)	v1	8.37	0.69	5	10
	v2	8.24	0.91	4	10
F.EN.X. (Resource Utilization and Efficiency)	v1	7.68	0.86	5	10
	v2	7.59	0.81	5	10
F.EN.R. (Resource Reevaluation and Reduction)	v1	7.74	0.91	5	9
	v2	7.56	1.01	5	10
F.EC.D. (Economic Design)	v1	8.89	0.94	6	10
	v2	8.79	1.01	6	10
F.EC.X. (Economic Execution)	v1	8.24	0.99	5	10
	v2	8.13	0.99	6	10
F.EC.R. (Economic Reevaluation)	v1	8.97	1.15	5	10
	v2	8.83	1.37	5	10
F.SO.D. (Social Design)	v1	9.32	0.94	6	10
	v2	9.13	1.11	5	10
F.SO.X. (Social Execution)	v1	9.57	0.81	7	10
	v2	9.51	0.82	7	10
F.SO.R. (Social Reevaluation)	v1	9.21	1.04	7	10
	v2	9.01	1.18	5	10
ETH (Ethical Considerations)	v1	9.82	0.46	8	10
	v2	9.73	0.57	6	10

3.1 Conclusions and limitations

While our experiment revealed variations in grading across multiple iterations by the LLM, it's important to note that such fluctuations also happen when multiple human evaluators grade the same reports using an identical rubric (Brookhart and Chen 2015; Tio et al. 2014). In essence, discrepancies in final grades among evaluators are to be expected. This observation underscores that, under specific conditions—namely, when rubrics are clearly defined and objectively detailed, and when student reports are structured primarily in text (as opposed to non-textual formats like images)—an LLM-based tool can effectively serve as a co-pilot. It offers a means to cross-check and validate grades assigned by human evaluators. However, it is fair to state that this AI tool is not positioned to replace human judgment in the grading process, at least not in the current state of technological advancement.

The limitations of this experiment highlight significant areas for further research and underscore the current constraints of technology. Refining the integration of rubrics with prompt generation for greater specificity remains a challenge, including improving prompt strategies for more accurate LLM responses and the LLM's inability to interpret non-textual content, indicating the potential need for computer vision models. Additionally, the current LLM's lack of reasoning skills, especially its inability to perform basic calculations, reveals a crucial gap in assessing certain concepts that human rubrics can, which state-of-the-art LLMs cannot yet bridge without the use of external tools as an addon to the LLM (Zhuang et al. 2023). These challenges point to the need for ongoing development in GenAI, suggesting that consistent grading with detailed rubrics and the successful application of GenAI in educational assessments require careful consideration of report content and format.

REFERENCES

Bahrini, Aram, Mohammadsadra Khamoshifar, Hossein Abbasimehr, Robert J. Riggs, Maryam Esmaeili, Rastin Mastali Majdabadkohne, and Morteza Pasehvar. 2023. “ChatGPT: Applications, Opportunities, and Threats.” arXiv. https://doi.org/10.48550/arXiv.2304.09103.

Baillie, Caroline, P. Goodhew, and Elena Skryabina. 2006. “Threshold Concepts in Engineering Education—Exploring Potential Blocks in Student Understanding.” *International Journal of Engineering Education* 22 (January).

Bragós Bardia, Ramon, Louay Aoun, Sandra Bermejo, Josep Pegueroles, and Guido Charosky. 2022. “Analysis of Students’ Performance in Capstone Projects,” 622.

Bragós Bardia, Ramon, Louay Aoun, Guido Charosky Larrieu-Let, Sandra Bermejo Broto, Francesc Rey Micolau, and Josep R. Pegueroles Vallés. 2022. “Correlation Study between the Access Mark and the Performance in Project-Based and Standard Courses.” In *SEFI 50th Annual Conference of The European Society for Engineering Education*, 151–59. Universitat Politècnica de Catalunya. https://doi.org/10.5821/conference-9788412322262.1168.

Brookhart, Susan M., and Fei Chen. 2015. “The Quality and Effectiveness of Descriptive Rubrics.” *Educational Review* 67 (3): 343–68. https://doi.org/10.1080/00131911.2014.929565.

Cobb, Corie L., Jonathan Hey, Alice M. Agogino, Sara L. Beckman, and Sohyeong Kim. 2016. “What Alumni Value from New Product Development Education: A Longitudinal Study.” *Advances in Engineering Education* 5 (1).

Farrell, Vivienne, Gilbert Ravalli, Graham Farrell, Paul Kindler, and David Hall. 2012. “Capstone Project: Fair, Just and Accountable Assessment.” In *Proceedings of the 17th ACM Annual Conference on Innovation and Technology in Computer Science Education*, 168–73. Haifa Israel: ACM. https://doi.org/10.1145/2325296.2325339.

González-Calatayud, Víctor, Paz Prendes-Espinosa, and Rosabel Roig-Vila. 2021. “Artificial Intelligence for Student Assessment: A Systematic Review.” *Applied Sciences* 11 (12): 5467. https://doi.org/10.3390/app11125467.

Grivokostopoulou, Foteini, Isidoros Perikos, and Ioannis Hatzilygeroudis. 2017. “An Educational System for Learning Search Algorithms and Automatically Assessing Student Performance.” *International Journal of Artificial Intelligence in Education* 27 (1): 207–40. https://doi.org/10.1007/s40593-016-0116-x.

Liu, Ming, Yuqi Wang, Weiwei Xu, and Li Liu. 2017. “Automated Scoring of Chinese Engineering Students’ English Essays.” *International Journal of Distance Education Technologies (IJDET)* 15 (1): 52–68. https://doi.org/10.4018/IJDET.2017010104.

Nashid, Noor, Mifta Sintaha, and Ali Mesbah. 2023. “Retrieval-Based Prompt Selection for Code-Related Few-Shot Learning.” In *2023 IEEE/ACM 45th International Conference on Software Engineering (ICSE)*, 2450–62. Melbourne, Australia: IEEE. https://doi.org/10.1109/ICSE48619.2023.00205.

Ray, Partha Pratim. 2023. “ChatGPT: A Comprehensive Review on Background, Applications, Key Challenges, Bias, Ethics, Limitations and Future Scope.” *Internet of Things and Cyber-Physical Systems* 3 (January):121–54. https://doi.org/10.1016/j.iotcps.2023.04.003.

Sallam, Malik. 2023. “ChatGPT Utility in Healthcare Education, Research, and Practice: Systematic Review on the Promising Perspectives and Valid Concerns.” *Healthcare* 11 (6): 887. https://doi.org/10.3390/healthcare11060887.

Schramm, Cheryl, and Adrian D. C. Chan. 2013. “Capstone Project Evaluation – Towards a Student-Centred Approach.” *Proceedings of the Canadian Engineering Education Association (CEEA)*, June. https://doi.org/10.24908/pceea.v0i0.4840.

Tio, Flex, Joelle Kong, Ryan Lim, and Edmund Teo. 2014. “Developing and Applying Rubrics for Comprehensive Capstone Project Assessment.” In *Proceedings of the 10th International CDIO Conference*, 16–19. http://staging.cdio.org/files/document/cdio2014/49/49_Paper.pdf.

Tobler, Samuel. 2024. “Smart Grading: A Generative AI-Based Tool for Knowledge-Grounded Answer Evaluation in Educational Assessments.” *MethodsX* 12 (June):102531. https://doi.org/10.1016/j.mex.2023.102531.

Valenti, Salvatore, Francesca Neri, and Alessandro Cucchiarelli. 2003. “An Overview of Current Research on Automated Essay Grading.” *Journal of Information Technology Education: Research* 2 (1): 319–30.

Zhuang, Yuchen, Yue Yu, Kuan Wang, Haotian Sun, and Chao Zhang. 2023. “ToolQA: A Dataset for LLM Question Answering with External Tools.” *Advances in Neural Information Processing Systems* 36 (December):50117–43.

EMPOWERING WOMEN IN STEM: AN INNOVATIVE STUDY ORIENTATION PROGRAM WITH A FOCUS ON NEW TECHNOLOGIES TO STRENGTHEN THE CREATIVE POTENTIAL AND SELF-EFFICACY OF WOMEN

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Keywords: *STEM Study orientation, STEM education, Women in STEM, VR/AR, Game-based Learning*

ABSTRACT[1]

This article presents the initial results of theory-based concepts for an innovative study orientation program designed for female 11th and 12th grade students in Germany. The focus is specifically on motivating young women for engineering and strengthening their self-confidence and creative potential. Using the design-based research (DBR) method, the first step was to analyse possible requirements with the help of a systematic literature review and 25 qualitative interviews. Based on the results a concept was designed and successfully transferred into practice. The program was tested for the first time in January 2024 with 61 grade 11 and 12 students at Leuphana University. A variety of technical workshops were developed,

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whereby the modular structure of the Virtual Reality (VR) and Augmented Reality (AR) workshop is presented in this paper. Initial results show that the program was very well received by the students. Further runs of the intervention as well as an effectiveness analysis of the program are pending.

1 INTRODUCTION

Digitalization, decarbonization and demographic change are creating strong pressure for transformation worldwide. Qualified professionals with different skills are needed. However, the current developments show otherwise. In April 2023, a labour shortage of 308,400 people in the STEM sector was reported in Germany (Anger et al. 2023). STEM expert occupations representing the largest bottleneck group. This is further boosted by demographic change, which results in 64,700 STEM academics leaving the labour market in Germany every year. The trend is rising (ibid.). As a result, demand and the labour shortage are increasing significantly. The simultaneously declining number of new STEM graduates will further exacerbate this problem. Educational measures to increase skills and motivation in the STEM sector are urgently needed to counteract. A closer look at the gender distribution in STEM professions show a strong underrepresentation of women (ibid.). Furthermore, it is notable that women do leave the STEM sector more frequently than men (Solga and Pfahl 2009). According to Anger et al. (2023), in order to master the structural challenges of the future, opportunities in the education system must be improved, digitalization in educational institutions must be promoted, STEM education must be strengthened and the potential of women must be raised through stereotype-free career and study orientation (ibid.).

This is where this contribution links in. This paper is intended to provide initial insights into the design of a study orientation program for female students in grades 11 and 12 in Germany in order to increase the proportion of women and strengthen the creative potential and self-efficacy of women in the STEM field. After discussing the research goals and methodology, chapters 4 and 5 deal with the results of the analysis of requirements of a STEM study orientation program as well as the design and implementation of a designed program. Chapter 6 describes the exemplary structure and implementation of a module on the topic of "Virtual and Augmented Reality" as an example of a game-based approach to introducing the field of new technologies. The orientation program was carried out for the first time in January 2024 with 61 female students. Initial results will be presented.

2 RESEARCH GOALS

The design, implementation and evaluation of a study orientation program for female high school students is part of a three-year research project of the German Federal Ministry of Education and Research (BMBF) titled "Hybrid STEM study orientation program for women in the context of digital transformation". The design-based research project aims to provide evidence-based and transferable findings on successful STEM study choice orientation for women in the context of digital transformation and, at the same time, a sustainable implementation as a regional STEM education measure. In addition, the development of self-efficacy, initiative and creative potential of young women is considered. Further positive effects are expected with regard to actively shaping the transition from school to university. The existing network between universities and schools is to be further expanded in order to contribute to securing the next generation of skilled workers in the technical sector. Three implementations of the program and an evaluation of its effectiveness are planned within the three-year term. This paper is intended to provide initial insights into the theory-based concept of the program and explain the structure and implementation of an exemplary workshop. Initial results and feedback from the first participants will be presented.

3 METHODOLOGY

Design-based research (DBR) according to McKenney and Reeves (2013) was chosen as the methodological approach for the research project. This is a methodological approach that aims to gain research-based insights into both the theoretical understanding of teaching and learning and pedagogical practice (McKenney and Reeves 2013; Kelly 2013). The model is shown in Fig. 1 and illustrates the three main stages of the process model for DBR: analysis, design and evaluation. The three stages are interdependent and require the implementation of the respective approaches. The results are delivered in two ways, both for theoretical understanding and for intervention in classroom practice. Feedback loops enable continuous improvement and adaptation (McKenney and Reeves 2018).

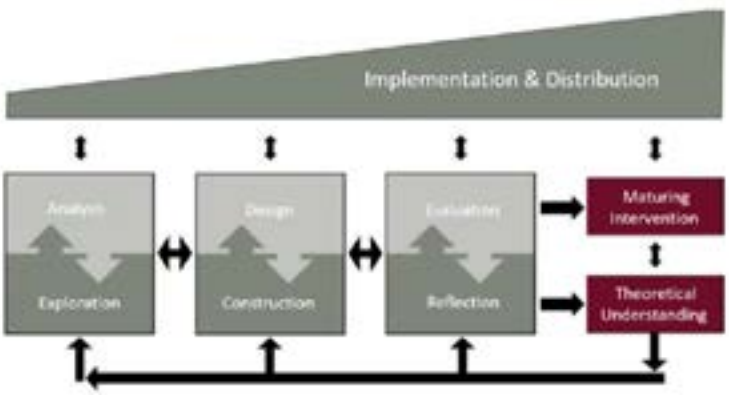

Fig. 1. DBR approach, illustration based on McKenney and Reeves (2013)

In the *analysis phase*, the problem is analysed and defined (McKenney and Reeves 2018). In this phase of the research project, a total of 25 qualitative interviews were conducted with female high school students, bachelor and master students from the field of engineering (Mayring 2022 and Kuckartz 2018). A systematic literature review was conducted (Moher et al. 2009). The aim was to collect recommendations for the ideal concept design in a theory-based manner. The results of the analysis phase are briefly outlined in Chapter 4.

In the *design phase* of the DBR approach, a solution is designed. A concept for an educational intervention or a learning environment is created, which must be implemented and tested. Based on the results of the analysis phase, two theory-based program proposals were developed. Eight schools in the region were contacted, three of which agreed to a rapid implementation. This enabled the final design and development of the program, incorporating digital tools, future technical fields (e.g. Sustainability, Industry 4.0, AI) and suitable remote units for a one-week program including a project phase of several weeks.

Finally, a complex effectiveness analysis is planned in the *evaluation phase*, in which the data from the three interventions will be evaluated. The program will be examined for its influence on the decision to study, the strengthening of self-efficacy and the initiative of the participating students. In addition to pre-post surveys, interviews and learning diaries, accompanying observation will be used (Mummendey 1999; Kromrey 1995).

4 RESULTS OF THE ANALYSIS OF THE REQUIREMENTS OF A STEM STUDY ORIENTATION PROGRAM

To generate a theoretical basis, a systematic literature review and qualitative interview studies were conducted in order to draw up recommendations for motivational projects for female students in engineering. In addition to the systematic analysis of 18 research papers (Moher et al. 2009), 25 qualitative interviews were carried out and evaluated (Mayring 2022 and Kuckartz 2018). For the interviews, eight female Bachelor's and three female Master's students from Leuphana University as well as 14 female pupils were interviewed. The aim of the systematic literature review was to filter previously researched framework conditions for motivational projects in the STEM field. The qualitative interview study aimed to obtain further individual opinions and the current status quo of the region. Both studies were analysed under the main categories "Target group", "Integration into the school system" "Timeframe and format", "Topics", "Teaching methods" "Role models", and "Learning atmosphere". Figure 2 shows the most important results and recommendations of the analyses.

According to the results of the analysis, the design of a six-month program is recommended. The program should be carried out in presence and be designed to be multifaceted. It should address topics relevant to the future, such as automation, digitalisation, Industry 4.0 or sustainability, and include a diverse range of teaching methods, such as laboratory experiments, excursions or mentoring programs. Addressing career planning and possible training paths to engineering proved to be an essential topic. In addition, a supportive and encouraging learning atmosphere as well as space for consultation and feedback should be created. A further component of a motivation program should be the presentation of the very diverse occupational profiles and in particular the demonstration of gender diversity and the countering of stereotypes in engineering. Finally, the inclusion of role models from different professions is recommended, preferably involving young female role models.

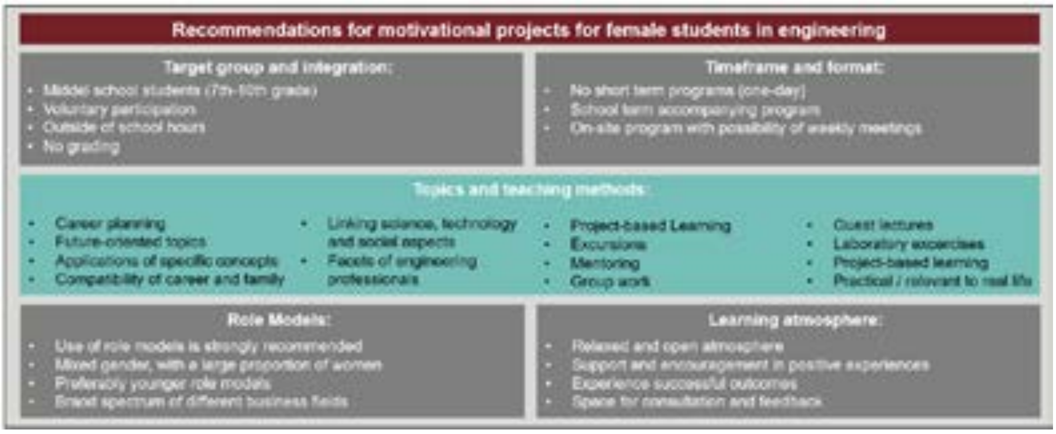

Fig. 2. - Recommendations for motivational projects for female students in engineering, own illustration

5 DESIGN AND IMPLEMENTATION OF THE THEORY-BASED CONCEPT

A suitable program was developed based on the results of the analysis phase. Contrary to the recommendation to design the program for the middle school, the upper school was chosen as the transition from school to university is imminent and the project funding was aligned to it (Stringer et al. 2020). A one-week program was developed at Leuphana University followed by a project phase, resulting in a total duration of about three months (Salto et al. 2014; Christensen et al. 2008). Figure 3 shows the timetable and the main topics of the individual days of the project week consisting of the future-relevant topics “New Technologies”, “Industry 4.0”, “Insights into Professional Practice”, “Sustainability” and “Student Orientation”. Different workshops on the respective main topic are planned for each day. This means that a wide range of topics can be covered within a week, such as VR/AR, robotics, excursions or study orientation offers. Section 6 presents an exemplary technical workshop on VR/AR. In addition, female engineering students and female professionals are involved as role models to demonstrate the variety of opportunities and career paths in STEM professions (Stringer et al. 2020). In the subsequent project phase, further workshops, panel discussions and the implementation of individual projects are planned.

Project - Week - Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
8 am - 3 pm	Main topic: New technologies	Main topic: Industry 4.0	Main topic: Insights into professional practice	Main topic: Sustainability in Engineering	Main topic: Study orientation

Fig. 3. Schedule with main topics of the project week at Leuphana University, own illustration

The developed program was tested for the first time in January 2024. A total of 61 students from three different schools visited Leuphana University for one week between 15.01.24 and 26.01.24 to take part in the program. Most of the participants were in grades 11 and 12. Four students from a vocational school also took part, resulting in an age range of 16 to 24 years.

6 PRESENTATION OF THE DESIGN AND IMPLEMENTATION OF THE "VIRTUAL AND AUGMENTED REALITY WORKSHOP"

The workshop on the topic of VR and AR, which was used as one of three modules on the "New Technologies" day, is presented below. The approach of game-based learning in combination with a modular structure was chosen.

The aims of the workshop included learning about the development of VR, familiarising participants with various theories and areas of application and autonomously learning the difference between VR and AR using game-based learning.

VR is a computer-generated reality with images (3D) and, in many cases, sound. It is transmitted via large screens, in special rooms (CAVE) or via a head-mounted display (Bendel n. D). As the technology evolved, the term "virtual reality" was coined to describe devices that create an immersive, interactive environment with visual realism (Boyles 2017). AR is a hybrid form of visualisation that combines the real and virtual worlds (Choi 2016). The study of Silva et al. (2017) concluded that immersive educational gaming experiences have great motivational potential. As one of many studies, it shows that the use of VR is an effective educational tool that increases motivation.

The VR and AR workshop is designed for a maximum of 25 participants and can be flexibly adapted depending on the number of participants, available headsets and further materials. For this workshop, there were six VR headsets available, which were used as the primary basis for the structure of the concept. The duration of the workshop is 120 minutes as standard, but can be adapted flexibly.

Figure 4 shows the structure of the workshop for participant groups with fewer than twelve (1) and more than twelve (2) participants. Version (2) in particular is explained below, with possible adaptations for a smaller number of participants (1).

The workshop was started with a short introduction and explanation of each activity. The participants were divided into four groups, which rotated to a next station every 25 minutes.

Station 1: Presentation
Station 1 included an introductory presentation on the topic of "Virtual reality, augmented reality, mixed reality - theory and areas of application". The differences between VR, AR and MR were explained and their historical development, functions and areas of application, such as industrial production, medicine and entertainment media, were discussed. The aim of this station is to provide participants with theoretical knowledge and to differentiate between the various concepts. Participants should become aware that VR & AR is already part of their everyday lives and that many of them have already used various functions of it in apps and games such as *Snapchat* or *Pokemon Go*. The potential of these new technologies should be explored.

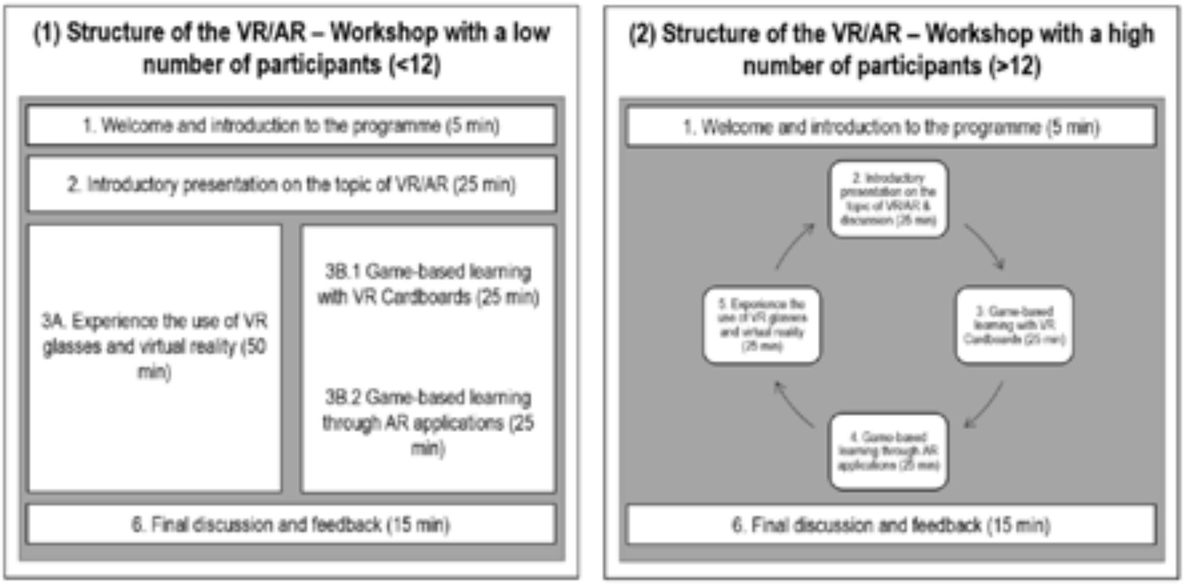

Fig. 4. - Structure of the VR/AR Workshop depending on the number of participants, own illustration

Station 2: VR Cardboards

At station 2, participants have the opportunity to learn selected content in greater depth through game-based learning and at the same time experience virtual reality with the help of cardboards and smartphones. The applications *"VR Tube (for iOS)"*[2] *a*nd *"YouTube (for Android)"* are used for this purpose. The videos can be selected from a variety of videos, ranging from engineering lab tours and city tours to popular skydiving experiences. After watching the videos, a short "*Kahoot"* survey follows to check understanding.

Figure 5 - Station 2 Cardboards and Station 3 Merge Cubes

[2]VR Tube:
https://play.google.com/store/apps/details?id=com.canturkgames.vrtube&hl=gsw&gl=US&pli=1

Station 3: Merge Cubes
Using Merge Cubes and the *"Merge Object Viewer"*[3] application, this station illustrates the difference between virtual and augmented reality. Participants can choose from various categories, such as Genetics, Human Anatomy, Solar System, Viruses, Space Science and many more, and take a closer look for example at the human heart or the James Webb Telescope. Predesigned exercises ensure that the participants understand and can apply these new concepts.

Station 4: VR headsets
Participants have the opportunity to test real VR headsets and try out various games at this station. In our case, the applications *"Beat Saber"* (rhythm game), *"IEYTD - Home Sweet Home"* (a virtual escape room) or *"Wooorld"* (a journey to different places in the world) were offered. The number of headsets influences the structure of the workshop and the amount of time the students have to try out one or more of the games. With 25 participants, each person had around 25 minutes to test the headset, whereas with only ten participants, each person had 45 minutes.

The structure and modular division of the workshop depends on the number of VR headsets available. In our case, six VR headsets were available. Structure (1) was chosen for a group with twelve or fewer participants (see Fig. 3). In this case, station 1 is an introduction and presentation for everyone. Two subgroups are then divided. While one group tests the VR headsets at Station 4, the other group works on Stations 2 and 3 simultaneously. The groups then switch before having a final discussion and feedback. If there are more than twelve and up to 25 participants, the group is divided into four subgroups and rotated until each group has been to every station. Appropriate supervision is particularly necessary for Stations 1 and 4, while Stations 2 and 3 can also be carried out as self-study, depending on the age of the participants.

The game-based workshop was successfully tested twice with 25 students each and once with a group of ten students from grades 11 and 12. The first evaluations of the feedback shows a positive perception of the workshop by the participants. On a Likert scale of 1 to 5, they rated the workshop with an average of 4.2 and 4.5 respectively in terms of their knowledge gain, which indicates a high level of satisfaction. The entire week was also rated very positively, as evidenced by the fact that 95.65% (N=46) would recommend participation to their friends.

7 RESULTS AND OUTLOOK

This contribution presents the initial results of theory-based concepts for an innovative study orientation program designed for female 11th and 12th grade students in Germany. The concepts developed were successfully transferred into practice. A variety of technical workshops were developed, whereby the modular structure of the VR/AR workshop is emphasized in this paper. The implementation of the project week met with an extremely positive response from the students, with 95.65% stating that they would recommend participation to their friends or want to participate again themselves. The effectiveness of the program will be evaluated after the project is completed, focusing on the development of skills and orientation

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[3]Merge Object Viewer:
https://play.google.com/store/apps/details?id=com.MergeCube.ObjectViewer&hl=de&gl=US

for STEM studies. At least two further interventions are planned in order to optimize the concept.

ACKNOWLEDGEMENTS

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REFERENCES

Anger, C., and Betz, J., and Axel, P. *MINT-Frühjahrsreport 2023: MINT-Bildung stärken, Potenziale von Frauen, Älteren und Zuwandernden heben.* Köln: Institut der deutschen Wirtschaft Köln e. V, 2023.

Bendel, O. “Virtuelle Realität” Last modified April 07, 2024. https://wirtschaftslexikon.gabler.de/definition/virtuelle-realitaet-54243.

Boyles, B. "Virtual reality and augmented reality in education." *Center For Teaching Excellence*, United States Military Academy, West Point, Ny 67 (2017).

Choi, D. H. *Emerging Tools and Applications of Virtual Reality in Education*. IGI Global, 2016.

Christensen, A., and Nott, W., and Edwards, D., and Yoder, L., and Ho, C., and Flanagan, S., and Hurd, S., Usselman, M., and Llewellyn, D., and Rosen, J., et al. “Service Learning Oriented Pre Engineering Programs And Their Impact On Non Traditional Engineering Students”. Paper presented at *ASEE Annual Conference & Exposition*, *Pittsburgh, 2008*. https://doi.org/10.18260/1-2—3300

Kelly, A.E. “Design-Based Research in Engineering Education.” In*: Cambridge Handbook of Engineering Education* Research, 2013, 497-518. New York: Cambridge University Press.

Kromrey, H. *Empirische Sozialforschung*. Opladen: Leske + Budrich, 1995.

Kuckartz, U. *Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunter-stützung.* 4th Edition. Beltz, 2018.

Mayring, P. *Qualitative Inhaltsanalyse: Grundlagen und Techniken*. 13th Editiion. Beltz, 2022.

McKenney, S.E., and Reeves, T.C. “Systematic review of design-based research progress: Is a little knowledge a dangerous thing?”, *Educational Researcher* 42, 2(2013): 97–100.

McKenney, S.E., and Reeves, T.C. *Conducting Educational Design Research*, 2nd Edition. Milton: Routledge, 2018.

Moher, D., and Liberati, A., and Tetzlaff, J., and Altman, D. G. “Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement.” *Annals of Internal Medicine*, 151,4 (2009): 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135.

Mummendey, H.D. *Die Fragebogen-Methode.* Göttingen: Hogrefe, 1999.

Salto, L. M., and Riggs, M. L., and Delgado De Leon, D., and Casiano, C. A., and de Leon, M. “Underrepresented minority high school and college students report STEM-pipeline sustaining gains after participating in the Loma Linda University Summer Health Disparities Research Program”. *PloS one*, 9, 9, (2014): https://doi.org/10.1371/journal.pone.0108497.

Silva, T.S., and Marinho, E.C.R., and Cabral, G.R.E., and Gama, K.S. “Motivational Impact of Virtual Reality on Game-Based Learning: Comparative Study of Immersive and Non-Immersive Approaches”. Paper presented at *IEEE 2017 19th Symposium on Virtual and Augmented Reality (SVR)*, *Curitiba, 2017*. doi:10.1109/SVR.2017.28

Solga, H., and Pfahl, L. “Doing gender im technisch-naturwissenschaftlichen Bereich”. In *Förderung des Nachwuchs In Technik und Naturwissenschaf, edited by* J. Milberg, Berlin, Heidelberg: Springer, 2009.

Stringer, K., and Mace, K., and Clark, T., and Donahue, T. “STEM focused extracurricular programs: who’s in them and do they change STEM identity and motivation?” *Research in Science & Technological Education*, 38, 4 (2020): 507–522. https://doi.org/10.1080/02635143.2019.1662388.

THE IMPLEMENTATION OF THE UAS STRATEGY AS PART OF THE DEVELOPMENT OF COMPETENCE-BASED CIRCULAR ECONOMY EDUCATION

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ABSTRACT

Education is an instrument for cultivating innovative methods, practices, and skills. Higher education is undergoing significant transformations, necessitating changes in educational institutions as well. Strategic management principles are one of the most common ways to manage transformation. Within the realm of strategic management, it is crucial to identify not only the imperative for change but also the internal and external environmental factors shaping current and future operations. Furthermore, the strategy formulation process must consider the interests of stakeholders, along with the means and resources to enact the strategy at the operational level. Active engagement of staff members holds particular significance.

This article presents the process how LAB UAS's circular economy education is responding the observed shifts in the operating environment and UAS´s strategic principles. The analysis is centred on two degree programmes: Environmental Technology (in Finnish) and Sustainable Solutions Engineering (in English). During the development process, a PESTE analysis, which encapsulates the key political, economic, social, and environmental drivers influencing circular economy education, was conducted. The PESTE environmental analysis served as the foundation for competency-based curriculums and has been instrumental in shaping the content and pedagogical framework of the examined study programmes to meet evolving adaptive competency requirements and aligning them with UAS´s strategic objectives.

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1 INTRODUCTION

1.1 Strategic Management in Higher Education: Navigating Change and Complexity

The central objective of strategic management is to guide the organisation and its personnel towards the desired strategic direction, enabling the achievement of profitability, continuity, and developmental goals in a changing internal and external operational environment (Tirronen 2014; Kamensky 2014, 15; Faulkner and Campbell 2009). The importance of strategic management increases as the operational environment becomes more complex (Faulkner and Campbell 2009; Hassanien 2017). The starting point for the strategy should be an understanding of the changes in the organisation's operating environment (both internal and external), based on which strategic objectives and action plans are selected and prioritised. (Yüksel 2012; Kamensky 2014, 16, 19).

In strategic management, an organisation should primarily be viewed through an individual and human-cantered lens, emphasising processes, individuals, and the actual activities, in what is known as the "*strategy-as-practice*" approach. This approach strongly emphasises extending strategic thinking beyond the organization itself and integrating it into everyday operations (Tirronen 2014). This is crucial to consider because, particularly from the perspective of the organization's employees, understanding the significance of strategies and their direct impact on practical tasks is often found to be limited (Kamensky 2014, 15–16, 18).

We are living in a rapidly changing world where global megatrends such as climate change, sustainability crises, digitisation, and globalisation have already had and will continue to have a significant impact on the principles of organisational operation and the skills required in the workplace (Ministry of Education and Culture 2017, 7; Dailey-Hebert and Dennis 2015; Tirronen 2014).From the perspective of an organisation's success, it is crucial to proactively prepare for changes so that they can be anticipated before they become mandatory (Kamensky 2014, 32–33). Strategic management and setting a course for the future, where very little is certain, represent one of the most challenging yet essential tasks for leadership. The complexity of the strategy process is further heightened by the interests, assumptions, and perspectives of various stakeholders and experts who have different objectives related to teaching, research, and service activities (Faulkner and Campbell 2009; Kamensky 2014, 33; Tirronen 2014; Williams 2020). Successful strategic dialogue, in line with the theory of a learning organisation, involves trust, commitment, and perceived fair treatment (Ranki 2016, 28).

The changes are so extensive that individual and organisational transformations alone are insufficient; systemic changes are required in all aspects of society (Sitra 2019). Various levels of political and economic control mechanisms are significant tools for directing activities and resources. Societal goals related to education, entrepreneurship, and sustainability have been outlined in Finnish, European Union, and global action programmes and objectives. These should be considered in the strategic work of organisations, leadership, and, consequently, directed operational activities. (Dailey-Hebert and Dennis 2015; Frølich et al. 2018). All these factors will reshape the traditional, relatively stable role of universities in regional development, as well as the pedagogical methods, models of education delivery, and contents.

Higher education policy instruments also aim to promote the effectiveness of education as part of competence-based economic growth. Higher education institutions are expected to contribute more to societal competitiveness, impact, adaptability, higher quality, and internationalisation (Dailey-Hebert and Dennis 2015; Kolmos et al. 2016; Kamp 2020, 3–4). Future professionals are expected to have not only strong subject-specific knowledge but also a sufficiently broad interdisciplinary competence (Dailey-Hebert and Dennis 2015). Changes should not be seen solely as threats but also as opportunities to leverage the good reputation and relatively dynamic adaptability of the Finnish education sector thus far.

1.2 Trends in Higher Education and the Utility of PESTE Analysis

Strategic management in higher education is characterised by a long-standing culture rooted in discipline-specific goals and values (Tirronen 2014). Therefore, it is essential to consider not only the personnel but also environmental factors, as well as the numerous perspectives, interests, needs and demands of students, personnel, and stakeholders. Changes in the external operational environment affecting the higher education sector include requirements related to knowledge-based economies, digitalisation, globalisation, and government means of control. (Tirronen 2014). At both individual and organisational levels, one of the key prerequisites for success is the ability to innovate both in terms of operations and skills. Micro-work, advanced revenue models, organisational forms, shifts in values, and networked activities are also increasingly shaping the future of the workforce (Ministry of Education and Culture 2017, 7). In the future, success will require greater adaptability in work that is independent of time and place, as well as an entrepreneurial attitude and approach (Miller 2015), including engineers (Byers et al. 2013). Future skills needed should be an integral part of education development since they directly affect how work is done, the sources of income and the structure of industries (Pucciarelli and Kaplan 2016). The need to implement sustainability, environmental and circular economy aspects into the education and curriculums is also highlighted (UNESCO 2016, Memon et al. 2015, Mulá et al. 2017)

At a general level, the trends affecting higher education, according to Pucciarelli and Kaplan (2016), include increased internationalisation and global distribution of knowledge, the mismatch between education and the workplace, diverse learning needs of millennials and the workforce, growing student numbers, student heterogeneity, the need for external funding, and reduced regulation. Changes in the education market and skill requirements have brought new competitors into the field. Additionally, information and communication technology and digitisation have significantly transformed the landscape of education. (Pucciarelli and Kaplan 2016.) Competition of skilled students and workforce is increasing, while at the same time public funding is under economic pressure (Frølich et al. 2018). Therefore, higher education institutions should invest even more in enhancing educational content and implementation methods (de Haan 2013).

One of the most common tools for observing the external business environment is the PESTEL or PESTE (Political, Economic, Socio-cultural, Technological, Environmental, and Legal) analysis, which provides organisations with information about the state of the environment, especially at the macro level (Yüksel 2012). It is suitable for various purposes and organisations of different sizes. PESTE analysis can also be used as part of other strategic processes. Through PESTE analysis, factors affecting the attractiveness and market potential of a product or service can be identified, and factors and trends that influence market success can be predicted. (Perera 2017.)

2 Methodology

2.1 Aims of the study and PESTE environmental analysis

LAB University of Applied Sciences (LAB) was established in 2020 by merging the two universities of applied sciences located in different cities in Finland. The complexity of the work was increased by the extensive transformation process taking place at LAB, which involves merging the practices and cultures of two universities of applied sciences in a changing operational environment. Dozens of teams have been involved in this transformation, and numerous workshops have been held to ensure the implementation of the strategy as part of the measures taken by the units, RDI focus areas, various target groups, and the personnel.

At the same time, as structural and cultural change, the development of two new study programmes began. The author actively participated in different development workshops arranged for internal and external stakeholders and reviewed guiding documents and research. During this work, efforts were made to identify globally and regionally influential change and environmental factors affecting higher education, particularly in engineering and circular economy education. These factors include, among others, macroeconomic and political factors, industry environment, stakeholders, and various networks. In the applied PESTE analysis, special attention was paid to factors influencing the content of curriculum: political and economic, social/societal, technological, and ecological environmental factors. The analysis also considered key players in the industry (customers, competitors) and other stakeholders (such as owners, public sector, network partners). The PESTE analysis thus encompasses a multitude of different subject areas, perspectives, and components, of which the most relevant ones for this work are presented in Figure 2.

One of the objectives of this work was to increase, through participatory action research, the knowledge at both individual and organisational levels about existing information, regulations, and plans. Through this knowledge, models and content can be developed to enhance the competence in these themes for Finnish and international degree and continuing education students.

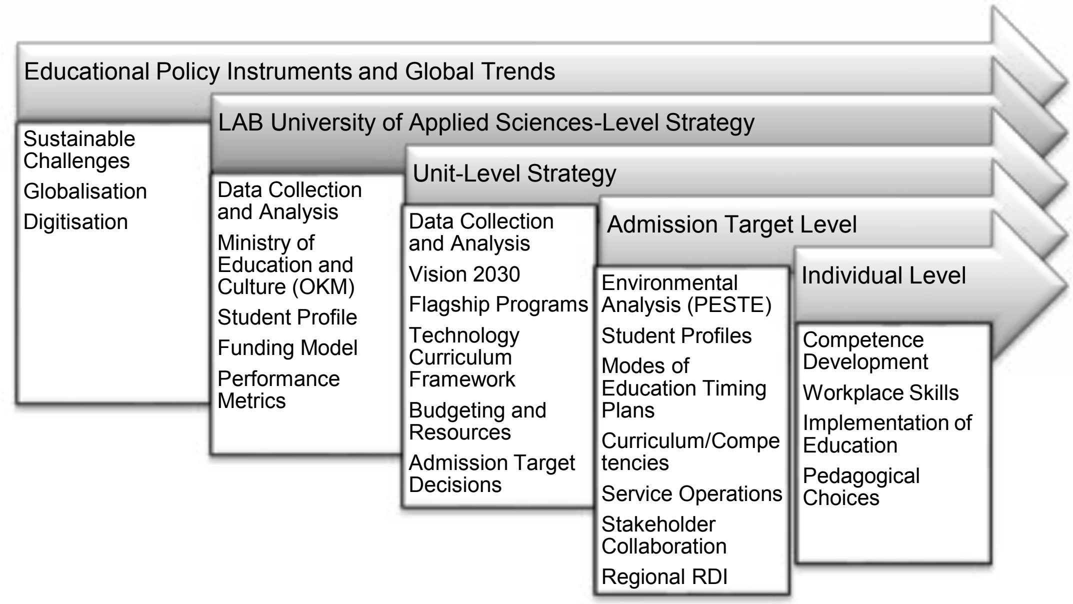

Fig. 1. Reviewed strategic levels and main influencing factors evaluated during study.

2.2 Profiling and Curriculum Work Related to Circular Economy Education

The process to develop the competence-based curriculums and the coordination of network-based collaboration for the English-taught Sustainable Solutions Engineering and Environmental Technology blended-learning programmes along with its competence objectives lasted about half a year, each.

The planning of a curriculum involved various stages and components (Kolmos et al. 2016). These methods included gathering information from various written sources, actively participating in seminars and workshops related to the topic, conducting internal and external workshops. The curriculum development process requires a multidisciplinary and multidirectional approach (du Toit et al. 2010). To gain a comprehensive understanding, the author consulted various national and international reports and forecasts, alumni surveys, thesis and clients, as well as engaging in discussions with industry representatives through interviews conducted over several years as part of futures study courses. Additionally, EU, national, regional, and organisational-level research and development strategies and supporting projects played a crucial role in supporting the curriculum development work.

Furthermore, the curriculum planning process considered organisational and national-level strategies, technology unit guidelines, collaboration with other universities, competitor analysis, network collaboration with various entities within the organisation, nationally, and internationally. It also considered continuing education needs and offerings, student´s and student organisation´s statements, existing online offerings, integrating expertise gained through organisational RDI projects into teaching, implementation possibilities, and existing learning environments (including laboratories). All these factors assisted in determining the competence needs required for the future labour market and the constraints that need to be considered in the curriculas. Each of LAB´s engineering study programmes´ curriculas were self- and cross-evaluated during workshops arranged among study programme coordinators. The aim was to figure out how the curriculas and the implementation methods align with LAB´s educational and technology unit strategic guidelines. The results of these evaluations for circular economy education programmes are presented in Tables 1 and 2.

In curriculum development, it was also necessary to consider the profiles of two parallel study programmes. The skills required for graduates of international, English-language programme, and for Finnish-language students, were identified. Cost-effectiveness was pursued by avoiding duplicate courses with the same content in these two study programmes. This approach provides students with more freedom to deepen their expertise by taking courses from other study programmes as part of their complementary studies.

3 RESULTS

3.1 The most Significant Environmental Factors Confirmed in the PESTE Analysis

The most important factors influencing the circular economy curriculum work, as observed during the completion of this work, have been compiled in Figure 2. Many environmental factors identified in the analysis are relevant across multiple categories or have mutually reinforcing and supportive significance. Overarching themes in all areas of the environmental analysis include requirements for change, digitalization, and the green transition. LAB's circular economy education aligns with the findings of the environmental analysis conducted. Additionally, the actions taken within the technology unit to implement the strategy and define future guidelines are in line with the environmental analysis.

Political and Economic Environmental Factors

Ministry of Education and Culture's Outcome Control: Increased emphasis on external funding's
EU Directives, Action Plans, and Financing: Alignment with policies, programs, and funding opportunities.
Entrepreneurship Policy Guidelines: Entrepreneurship education, initiatives by the Ministry of Economic Affairs and Employment, Business Finland's programs.
Environmental Policies: Internationalisation and cross-cutting societal functions, holistic examination of emissions, systemic change.
Trade Policy Measures: Harmonisation, regulations, standards, common rules, growth of digital services
Economic Instruments: Allocation of subsidies towards circular economy and green transition, shifts in taxation focus, emissions trading, and carbon tariffs.
Educational Policy Measures: Internationalisation, increased competition, raising the educational level, lifelong learning, strengthening RDI, innovation, collaboration, entrepreneurship education.
Government Program Values and Interests: Alignment with the values and interests outlined in government programs.
Competition for Talent: The competition for skilled professionals.
Green Transition and Circular Economy: The government's focus on sustainable and circular economy practices.

Social and Societal Environmental Factors

Sustainability Crisis, Digitalisation, Globalisation: Shaping societal challenges.
Changing Work and Learning Environments: Emergence of new professions, obsolescence of old ones, continuous learning, general and specialised skills, transdisciplinary skills, metaskills, teamwork, systems thinking.
Foresight, Shared Objectives, Collaboration, and Networks: Anticipatory actions, common goals, cooperation, accessible education, informal-non-formal-formal learning.
Open Recognition of Learning and Competence: Decentralised learning, shared learning, diverse learners
Perception of Work, Lifestyle, and Consumption: Evolving views on work, lifestyle, and consumption patterns.
Uncertainty and Complexity: Navigating through
Values and Interests: Societal values and interests.
New job opportunities due to Circular Economy

Technological Environmental Factors

Digitalisation: A pervasive factor influencing all areas.
Integration into Engineering Education: Incorporation of digitalisation in engineering education.
Significance of Green Transition and Circular Economy Strategies: Critical role in green transition and circular economy strategies, as well as educational transformation.

Ecological Environmental Factors

Climate Change and Adaptation: Minimising and preparing for climate change, biodiversity loss, and overexploitation of natural resources
Shift from Linear Growth to Circular Economy: Emphasis on material and energy efficiency, ecodesign.
EU Green Transition and Circular Economy Programs: Supporting instruments, investments, life cycle thinking and analysis.
EU and Finland's Leadership: Leading positions in sustainable practices.
Business Model Transformation and Preparedness: Adaptation of business models and readiness for changes.
Renewable Energy Sources, Environmentally-Friendly Materials, Technological Advancements: new resource efficient technologies, value chain thinking.

Fig 2. Summary of the most significant environmental factors confirmed in the PESTE analysis.

3.2 Implementation of LAB's and the Technology Unit's Strategic Directions in Circular Economy Education

Comparing LAB's strategy with the PESTE environmental analysis conducted during the study, it can be observed that they align closely in nearly all areas. Tables 1 and 2 provide a summary analysis of how the curricula and competencies of Sustainable Solutions Engineering and Environmental Technology programmes align with the general principles underlying competence in this work. They clearly show that the new programmes are well align with LeAB's and the technology unit's strategic guidelines. While the assessments are subjective, even cross-evaluated and includes various assumptions, the summary gives a good overview of areas that may still require development and further strengthening.

Both programmes aim to better reach students from diverse backgrounds (age, employment, parenthood) and enable multi-location, as well as time and place-independent, studying. Purely online education currently offers limited opportunities for collaboration with the working world, which needs to be developed in the future, as well as cooperation with secondary vocational education.

Table 1. Internal (and implementation) alignment of Sustainable Solutions Engineering and Environmental Technology programmes with LAB's educational strategies (- = does not align; + = partial alignment; ++ = substantial alignment; +++ = complete alignment)

Factors	**Sust. Solutions Eng** (Online)	**Environmental Technology** (blended learning)
Cost effectiveness	++	+++
Decreasing resources	++	++
Decreasing age cohorts	+++	+++
Working students	++	+++
Students with families	+++	+++
Multilocality	+++	+++
Changing student age structure (+25 years)	+++	+++
Increased proportion of vocational degree students	+	+
Increasing virtual studies	+++	+++
Non-degree education volume	+(+)	+(+)
Flexibility in education	++(+)	++(+)
Alternative pedagogical methods	++	++(+)
Integration of lifelong learning and degree programs	++	++(+)
Close collaboration with working life	+	++
Future-oriented competence and RDI	++	++
Teaching based on RDI activities	++	++

Table 2. Alignment of LAB technology unit's strategic guidelines with Sustainable Solutions Engineering and Environmental Technology programmes (- = does not align; + = partial alignment; ++ = substantial alignment; +++ = complete alignment)

Factors	**Sust. Solutions Eng** (Online)	**Environmental Technology** (blended learning)
Industry-oriented and fast-acting education	++	+++
Laboratory environments	+	++
Synergies between programs	++	++

Systematic partnerships	+	++
Work-life-oriented practices and piloting	+	++
International project activities and innovation-enabling professional networks	+	++
Focus on priority areas	+++	+++
Increasing the number of degrees	+++	+++
Diverse implementation methods	+++	+++
Collaboration with other programs and universities	+	++
Technology profiling	+++	+++

4 SUMMARY

Strategic management is the most common way to address challenges faced by higher education institutions due to globalisation, digitalisation, and sustainability. The need to align education and research activities with the demands of the business sector and learners in a complex and dynamic environment should be emphasised. Various factors such as new work and learning trends, revenue models, organisational innovations, and collaboration networks are trends for future of education. The vision, dialogue among stakeholders, and government measures in supporting strategic work is important. Successful strategy implementation is seen as contingent upon leadership culture and the competency of the workforce.

This study showed that organization strategy should be consider in the curriculum development process. The PESTE environmental analysis, as observed in this work, is suitable for future competency-based curriculum planning and supports the gathering of background information. The author strongly believes that it is a useful tool for developing any education alongside with strategic guidance. It will also help to adapt organisations and individuals in the higher education operating environment, emphasising the increasing importance of knowledge, entrepreneurial attitudes, and practices, as well as the influence of globalisation and digitalisation on education. The importance of multidirectional and multilevel cooperation among different actors is emphasised even more.

REFERENCES

Byers, T., Seelig, T., Sheppard, S., and Weilerstein, P. 2013. Entrepreneurship: Its Role in Engineering Education. The Bridge. Linking engineering and society. Volume 43, No. 2, 35 – 40. https://www.nae.edu/File.aspx?id=88638.

Dailey-Hebert, A. and Dennis, K., S. 2015. Introduction: New Opportunities for Development? In a book: Transformative Perspectives and Processes in Higher Education (editors: Dailey-Hebert, A. and Dennis, K., S.) Advances in Business Education and Training 6. Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-09247-8_1.

de Haan, H. H. 2014. Competitive advantage, what does it really mean in the contects of public higher education institutions. International Journal of Educational Management. 29. 1. 44-61.

du Toit, P., H., de Boery, A-L. and Bothma, T. 2010. Multidisciplinary collaboration:

A necessity for curriculum innovation. World library and information congress: 76th ifla general conference and assembly. 10-15 August 2010, Gothenburg, Sweden

http://www.ifla.org/en/ifla76.

Faulkner, D.O. and Campbell, A. 2009. The Oxford Handbook of Strategy: A Strategy Overview and Competitive Strategy. https://doi.org/10.1093/oxfordhb/9780199275212.003.0001.

Frølich, N., Christensen, T. and Stensaker, B. 2019. Strengthening the strategic capacity of public universities: The role of internal governance models. Public Policy and Administration. 34.4. 475–493.

Hassanien, M. A. 2017. Strategic Planning in Higher Education, a Need for

Innovative Model. Journal of Education, Society and Behavioural Science. 23.2.1-11.

Kamensky, M.2014. Strateginen johtaminen – menestyksen timantti. Alma Talent.

Kamp, A. 2020.Navigating the Landscape of Higher Engineering Education Coping with decades of accelerating change ahead. https://pure.tudelft.nl/ws/portalfiles/portal/79990402/Visiedocument_4TU.CEE_WEB_def.pdf.

Kolmos, A., Hadgraft, R.G. and Holgaard, J. E. 2016. Response strategies for curriculum change in engineering. Internal Journal of Technology and Design Education. 26. 391–411. https://doi.org/10.1007/s10798-015-9319-y.

Memon, R. N., Memon, I. and Siyas, F. A 2015. Green Learning Model for Teaching Requirements Engineering Course. Bahria University Journal of Information & Communication Technologies. 8.

Miller, D. 2015. A Downside to the Entrepreneurial Personality? Entrepreneurship Theory and Practice. Volume 39, Issue 1. https://doi.org/10.1111/etap.12130.

Mulá, I., Tilbury, D., Ryan, A.I., Mader, M., Dlouchá, J., Mader, C., Banayas, J., Dlouhý, J. and Alba, D. 2017. Catalysing Change in Higher Education for sustainable Development. A review of professional development initiatives for university educators. International Journal of Sustainability in Higher Education. 18. 5. 798-820.

Ministry of Education and Culture. 2017. Korkeakoulutus ja tutkimus 2030-luvulle. Taustamuistio korkeakoulutuksen ja tutkimuksen 2030 visiotyölle. https://minedu.fi/documents/1410845/4177242/visio2030-taustamuistio.pdf.

Perera, R. 2020. The PESTLE Analysis. Nerdynaut.

Pucciarelli, F. and Kaplan, A. 2016, Competition and strategy in higher education: Managing complexity and uncertainty. Business Horizons. 59, 311—320.

Ranki, S. 2016. Strateginen johtaminen suomalaisissa ammattikorkeakouluissa. https://trepo.tuni.fi/bitstream/handle/10024/99139/strateginen_johtaminen_2016.pdf?sequence=1&isAllowed=y.

Sitra. 2019. Kohti elinikäistä oppimista: Yhteinen tahtotila, rahoituksen perusteet ja muutoshaasteet. Helsinki: Sitra. https://www.sitra.fi/julkaisut/kohti-elinikaista-oppimista.

Tirronen, J. 2014. Suomalaisten yliopistojen strateginen johtaminen. Hallinon Tutkimus 1/2014. https://www.researchgate.net/profile/Jarkko-Tirronen/publication/261472388_Suomalaisten_yliopistojen_strateginen_johtaminen/links/0c96053456b08004c4000000/Suomalaisten-yliopistojen-strateginen-johtaminen.pdf.

UNESCO. 2016. Education for people and planet: creating sustainable futures for all, Global education monitoring report. https://doi.org/10.54676/AXEQ8566.

Williams, D. A. 2021. Strategic planning in higher education: a simplified B-VAR model. International Journal of Educational Management. 35.6.1205-1220. https://www.emerald.com/insight/0951-354X.htm.

Yűksel, I. 2012. Developing a Multi-Criteria Decision-Making Model for PESTEL Analysis International Journal of Business and Management. 7.24. https://doi.org/10.5539/ijbm.v7n24p52.

INTEGRATING VARIATION THEORY AND COGNITIVE THEORY IN ENGINEERING CLASSROOMS: EFFECT ON STUDENT ACHIEVEMENT

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Keywords: *Variation theory, Cognitive theory, engineering education, student achievement*

ABSTRACT

This study aims to test the usefulness of an integrated pedagogical approach (combination of variation theory and cognitive theory) to teach complex engineering problems in face-to-face classroom environments. 36 undergraduate students in their third year of the 4-year electrical and electronic engineering program were purposively selected who participated voluntarily in this study. Also, a course teacher

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of associate professor level from the same discipline participated in this study and conducted classes following traditional and theory-driven methods. Students were divided into a control group (where the traditional method was applied) and an experimental group (where an integrated pedagogical approach was applied). An observation protocol was used during the application of the treatment to the experimental group to ensure that the integrated approach was utilized as intended. A test was conducted with both groups, and their quiz scores were considered as the outcome of the methods applied. It was revealed that, overall, there is no significant difference in student achievement between the control groups and the experimental group. The findings have implications for engineering educators such as inadequate teacher training may obstruct expected outcomes. Priority attention is recommended to be facilitated to female students and those with low academic performance.

1 INTRODUCTION

1.1 Variation theory and student achievement

Variation theory, a pedagogical approach rooted in the principles of variation and contrast (Ference Marton 2014), has shown remarkable efficacy in enhancing students' learning experiences across diverse educational disciplines that deal with building concepts such as mathematics (Kullberg, Runesson Kempe, and Marton 2017), physics (Wang and Wang 2021) and in engineering education (Thuné and Eckerdal 2009; Hasan, Khan, and Ahmed 2024). Variation theory supports deeper understanding and promotes meaningful connections between ideas by systematically presenting concepts in multiple contexts and highlighting their differences. Ference Marton and Pang (2006) argue that “to learn something, the learner must discern what is to be learned (the object of learning)”, and it is the responsibility of the teacher to create the conditions required for learning to facilitate discernment to take place. Recognizing its impact, the European Association for Research on Learning and Instruction (EARLI) subsequently organized its annual conference: one in 2022 with the theme "Phenomenography and variation theory in practice – addressing educational challenges in a changing world" and another this year, 2024 with the theme *"Phenomenography and variation theory – the core, the diversity and the potential,"* where educators highlight the effect of variation theory on students' cognitive growth, problem-solving abilities, and academic success (The European Association for Research on Learning and Instruction 2022). Variation theory has also been used to teach complex engineering concepts, where students are expected to possess an interrelated set of intellectual skills of creative thinking, critical thinking, and innovative problem-solving abilities (Hasan et al. 2022).

1.2 Cognitive theory and student achievement

Cognitive theory-driven instruction has transformed classroom teaching methods and provided a deep understanding of students' learning (Mayer 1998). The cognitive theory of learning is a theoretical framework that focuses on understanding the internal mental processes, including memory, perception, and problem-solving, to improve how humans gain and utilize knowledge. By examining the complexities involved in brain functions like memory, concentration, and problem-solving, cognitive theory provides teachers with useful tools to use in classrooms to improve students' learning outcomes (Moreno 2009). By utilizing concepts such as metacognition and schema theory, educators can create learning activities that foster their students' more profound comprehension and critical thinking abilities. This method is necessary in engineering classrooms to encourage active involvement and long-term retention of the content, going beyond conventional rote memory (Hadie et al. 2018). Therefore, Engineering students are better prepared to understand complex engineering concepts and apply their knowledge in various situations, opening the door to academic success and work-integrated learning (Karim, Campbell, and Hasan 2019).

1.3 Positionality statement

Previous research has mostly reported the advantages of using either variation theory or cognitive theory in single empirical research. Utilizing both theories simultaneously in face-to-face teaching is a unique idea, particularly in engineering, which may have potential opportunities and challenges.

Combining cognitive theory and variation theory provides an integrated approach to education that uses each theory's advantages to improve student learning. While cognitive theory explores the mental processes underpinning learning, variation theory emphasizes the value of providing a wide range of situations and viewpoints to promote a deeper understanding. When combined, they create an engaging educational atmosphere that strengthens critical thinking abilities and profound conceptual knowledge.

However, merging cognitive and variation theories may be challenging from different perspectives. For example, educators may struggle to balance each theory's instructional practices. Adaptable lesson planning and collaboration between educators may be needed to align both theories for use in classroom settings. Thus, integrating variation theory with cognitive theory may improve student learning, but its complicated nature raises concerns regarding the usefulness of such integration. This study particularly investigates to what extent this integrated pedagogical approach provides benefit (or not) to engineering classrooms by seeking answers to the following two research questions:

1. *How does the teaching method (integration of variation theory and cognitive theory) influence students' achievement in engineering education?*
2. *Do students' academic background and gender influence their conceptual development and learning outcomes after applying variation and cognitive theory in engineering classrooms?*

2 METHODOLOGY

2.1 Research Design

As this research aims to investigate the influence of the proposed integrated pedagogical approach on students' achievement, the researchers followed the guidelines of a design study. The steps involved in designing this research are shown in Fig 1. The first step was to train the course teacher who taught a complex engineering topic in a face-to-face classroom.

Fig 1: Steps involved in the research design

Following the training, the course teacher prepared a lesson plan based on the learning study, which was then verified by the other authors of this study (Ling, Chik, and Pang 2006). The third author of this study was the course teacher and taught a topic of electrical engineering named *Properties of Various Optical Fibers* in the course *Optoelectronics* (*Sub Code: EEE 4671*). The intended learning outcome of the class varies from *knowledge to create* of the Cognitive domain of learning. The first and the third author, experienced in variation and cognitive theory, had several meetings to train the course teacher. However, this training session was held after the teacher had already taught one group of students (control group) and before teaching another group (experimental group) of the same cohort. A test was then administered for both groups of students together. The score of the test was considered as their achievement. In order to answer the research questions, the following hypotheses were developed as a guide for this research.

Hypothesis 1:	*Application of an integrated pedagogical approach in engineering classrooms influences students' achievements.*
Hypothesis 2:	*Gender influences student achievement.*
Hypothesis 3:	*Academic background influences student achievement.*

2.2 Ethical Considerations

This study was approved by the Department of Research, Extension, Advisory, Services, and Publications (REASP) of the university (Ethical Clearance number: 24-001). All participants provided informed consent after receiving comprehensive information about the study's purposes, methods, possible risks, and benefits. Participants were informed that their involvement was voluntary and that they had the freedom to withdraw from their participation at any point without facing consequences. To ensure confidentiality, all data collected were anonymized and stored securely, accessible only to the research team. Participants' identities were protected in all reports and publications.

2.3 Participants

36 undergraduate students studying 3rd year from the Electrical and Electronic Engineering department were chosen purposively as the sample for this study. A control group of 19 participants was taught in the traditional method, and an experimental group of 17 was taught following the integrated pedagogical approach. An experienced teacher from the same university, who is the third authors of this study, conducted these classes. A summary of the participants is presented in Table 1.

Table 1. Summary of the participants

		Gender		Academic Background		
Groups	Total	Male	Female	Good CGPA	Average CGPA	Below-average CGPA
Group A (Control Group)	19	18	01	11	04	04
Group B (Experimental Group)	17	11	06	7	06	04
Total	36	29	7	18	10	8

Note: Good CGPA (>3.74), Average CGPA (3.74 to 3.50), Below-average CGPA (<3.5)

2.4 Data Collection

The necessary background information (gender, academic background) of the students for both groups was collected by the course teacher, who is also one of the authors of this article. Students' achievement scores were collected after taking the test. An observation sheet was developed in consultation with the experts to ensure the integrated pedagogical approach was used. One of the authors of the article observed the class and took notes.

2.5 Data Analysis

For data analysis, SPSS software version 26 was used. Students' achievements (quiz marks) were not normally distributed. Due to the nature of the data, only non-parametric tests were used to test the hypotheses, which are discussed below.

1. For hypotheses 1 and 2, the dependent variables are categorical (methods of teaching in hypothesis 1 and gender in hypothesis 2, and the dependent variable was in ratio measurement (students' achievement). The sample size of each group was also less than 30. Considering the nature of the variables and group size, the Mann-Whitney U test was the good fit to test hypotheses 1 and 2.
2. For hypothesis 3, the independent variable "students' academic background" consisted of three categories: Good CGPA, Average CGPA, and Below-average CGPA. The dependent variable was measured at the continuous level. Considering the nature of the variables and small sample size, the Kruskal-Wallis non-parametric test was used.

3 RESULTS

3.1 Testing of Hypothesis 1: Application of an integrated pedagogical approach in engineering classrooms influences students' achievements.

Table 2. Two-tailed Maan-Whitney Test for Student achievement by pedagogical approach

Variable	Mean Rank		*U*	*z*	*p*
	Group A Control Group	Group B Experimental Group			
Student achievement	19.97	16.85	133.500	-.891	0.379

Note: *p>0.05*

A Mann-Whitney U test was performed to evaluate whether students' achievement differed by the pedagogical approaches applied. There were 19 students in the control group where the traditional teaching approach was applied and 17 students in the experimental group where the integrated teaching approach (combination of variation theory and cognitive theory) was applied. The result indicated that there was no significant difference between the achievement of students in both groups, z = -0.891, p = 0.379. It can be concluded that applying an integrated pedagogical approach in the engineering classroom does not influence student achievement.

3.2 Testing of Hypothesis 2: Gender influences student achievement.

Table 3. Two-tailed Maan-Whitney Test for Student Achievement by Gender

Variable	Mean Rank				
	Male	Female	*U*	*z*	*p*
Student Achievement	20.48	10.29	44.00	-2.30	0.020

Note: *p<0.05*

A Mann-Whitney U test was performed to evaluate whether students' achievement differed by gender. There were 29 male and 7 female students. The result indicated a significant difference between the achievement of male students and female students, z = -2.30, p = 0.020. It can be concluded that gender influences student achievement and male students' achievement is significantly higher than female students. If there were fewer female students in Group B (Experimental Group), the positive effect of the integrated teaching method would be realized. In other words, it is not only the teaching method, but also other associated variables, such as gender may influence students' achievement.

3.3 Testing of Hypothesis 3: Academic background influences student achievement.

Table 4. Kruskal-Wallis Rank Sum Test for Student Achievement by Academic Background

Levels	Mean Rank	*λ2*	*df*	*p*
Good CGPA	23.08	7.926	2	0.019
Average CGPA	11.65			
Below-Average CGPA	16.75			

Note: *p<0.05*

A Kruskal-Wallis test was conducted to evaluate the differences among the three categories of students based on their academic background (Good CGPA, Average CGPA, and Below-Average CGPA). The test revealed a statistically significant difference between the students' achievements and their academic background (p<0.5). They indicate that students with good CGPA yield the highest score (23.08). Also, Students with below-average CGPA performed better than those with an average CGPA, suggesting that third-year students in this category are dedicated to improving their academic performance.

3.4 Potential factors influencing the implementation of variation theory on student learning.

3.4.1 Students' Psychological State

The classes were conducted just after the semester-final exam result was published, which could affect student attentiveness to participate in class activities. Eventually, the implementation of cognitive they may not work with such students.

3.4.2 Time Frame between the class conducted and the test taken

The test was taken two weeks after the class was conducted (for the experimental group) and three weeks after the class was conducted (for the control group). It may have caused students to forget information and fail to achieve the desired test result.

3.4.3 Lack of adequate training for teachers

Lack of proper training and understanding could affect a teacher's teaching method, which may result in no change in students' learning; rather, in some cases may obstacle learning. Given the long-standing reliance on traditional methods, changing the classroom environment by implementing a new methodology would have been challenging.

3.4.3 Student's readiness for a new method of learning

Similar to the case of the teachers, students have been experiencing the traditional way of teaching. Teachers need to provide guidance to students regarding the intended conditions of learning in the classroom to ensure that students grasp the concept and derive benefits from integrated theory-oriented teaching.

4 SUMMARY AND ACKNOWLEDGEMENTS

The result shows that the integrated pedagogical approach (combination of cognitive and variation theory) in engineering classrooms does not influence students' achievements. However, this pedagogical approach provides better learning outcomes for male students and high academic background students. We need to acknowledge the limitations of this study having a small sample size that performs non-parametric tests. Moreover, the achievement test with one test is not adequate to generalize the findings. The second phase of this research will explore the qualitative understanding of students on engineering topics as a basis for evaluation. To achieve this, the phenomenographic approach will be adapted (F. Marton and Pong 2005), which will allow us to investigate deeper into students' understanding of specific engineering concepts. Therefore, well-trained teachers will be employed who will conduct classes using the integrated method and take several tests with a much bigger sample balancing male and female students.

REFERENCES

Hadie, Siti Nurma Hanim, Asma' Hassan, Zul Izhar Mohd Ismail, Hairul Nizam Ismail, Saiful Bahri Talip, and Ahmad Fuad Abdul Rahim. 2018. "Empowering students' minds through a cognitive load theory-based lecture model: A metacognitive approach." *Innovations in Education and Teaching International* 55 (4): 398-407.

Hasan, Mahbub, Md Shahadat Hossain Khan, and A. K. M. Foysal Ahmed. 2024. "Application of variation theory in STEM education: A comprehensive guideline for STEM teachers." *MethodsX* 12: 102500. https://doi.org/https://doi.org/10.1016/j.mex.2023.102500.

Hasan, Mahbub, Shahadat Hossain Khan, A. K. M. Foysal Ahmed, Azharul Karim, Akbar Hossain, and A.K.M Parvez Iqbal. 2022. "Variation Theory in Teaching and Phenomenography in Learning: What's their Impact when Applied in Engineering Classrooms?" 50th Annual Conference of The European Society for Engineering Education (SEFI), Barcelona, Spain, 19-22 September 2022.

Karim, Azharul, Matthew Campbell, and Mahbub Hasan. 2019. "A new method of integrating project-based and work-integrated learning in postgraduate engineering study." *The Curriculum Journal*: 1-17.

Kullberg, Angelika, Ulla Runesson Kempe, and Ference Marton. 2017. "What is made possible to learn when using the variation theory of learning in teaching mathematics?" *Zdm* 49: 559-569.

Ling, Lo Mun, Pakey Chik, and Ming Fai Pang. 2006. "Patterns of variation in teaching the colour of light to primary 3 students." *Instructional Science* 34: 1-19.

Marton, F., and W. Y. Pong. 2005. "On the unit of description in phenomenography." *Higher Education Research and Development* 24 (4): 335-348. https://doi.org/10.1080/07294360500284706.

Marton, Ference. 2014. *Necessary conditions of learning*. Routledge.

Marton, Ference, and Ming Fai Pang. 2006. "On some necessary conditions of learning." *The Journal of the Learning sciences* 15 (2): 193-220.

Mayer, Richard E. 1998. "Cognitive theory for education: What teachers need to know."

Moreno, R. 2009. *Educational Psychology*. Wiley.

The European Association for Research on Learning and Instruction. 2022. "Phenomenography and Variation Theory in Practice." 2022 EARLI SIG 9 conference, Stockholm University, Sweden.

Thuné, Michael, and Anna Eckerdal. 2009. "Variation theory applied to students' conceptions of computer programming." *European journal of engineering education* 34 (4): 339-347.

Wang, Kang-Jia, and Guo-Dong Wang. 2021. "Variational theory and new abundant solutions to the (1+ 2)-dimensional chiral nonlinear Schrödinger equation in optics." *Physics Letters A* 412: 127588.

Enhancing International Chemical Engineering Postgraduate Taught Students' Teamwork Skills via the Inclusive Workshop and Team-building Games

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Conference Key Areas*: Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing; Teaching social and human sciences to engineering and science students.*
Keywords*: Engineering Education; Teamwork; International Students; Inclusive Workshop; Learning Game.*

ABSTRACT

The internationalisation of higher education has led to a surge in the number of international students enrolled in UK universities, particularly in one-year postgraduate taught (PGT) engineering courses. Another significant change is the recent shift in engineering education towards a more project-based approach, which means that teamwork is increasingly becoming a key skill that influences the success of student learning. However, many international students show deficiencies in basic teamwork skills due to insufficient attention to developing these skills during their undergraduate studies. In addition, most of these students have limited or no relevant work experience before the PGT course. Hence, emphasising and helping them to improve their teamwork skills during their academic year will not only improve their academic performance but also strengthen their future career prospects. Recognising this necessity, this study introduces an inclusive workshop framework and team-building games designed to provide PGT students with the opportunity to develop teamwork skills by engaging in team role plays where they

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learn how to behave, contribute and interrelate with others in a team within an engineering educational setting.

1 INTRODUCTION

1.1 Teamwork in Engineering Education

With the recent shift towards project-based engineering education, the impact of teamwork on the academic journey and future career development of engineering students has become increasingly important. The integration of teamwork into the higher education curriculum necessitates educators to adopt and implement effective teaching, learning, and assessment methods, ensuring that students acquire indispensable soft skills alongside technical proficiency. Teamwork is indeed a crucial aspect for engineers and engineering students, and it can lead to improved problem-solving abilities, increased innovation, and enhanced project outcomes in engineering practice.

Collaboration among team members allows for the pooling of diverse skills, knowledge, and perspectives, which can result in innovative solutions to complex engineering problems (Campion, Papper, and Medsker 2006). A study by Smith-Jentsch, Salas, and Baker (2006) also underscored the importance of teamwork in enhancing decision-making processes within engineering teams. By working together, team members can leverage their collective expertise to analyse problems from various angles and arrive at well-informed and responsible decisions. Salas et al. (2014) emphasised the significance of teamwork in engineering projects, highlighting that collaboration among team members with diverse skills and expertise can result in more creative solutions and better decision-making processes.

In addition to project outcomes and decision-making, teamwork plays a crucial role in the professional development of engineering students. Johnson, Johnson, and Smith (2014) found that engaging in team-based projects helps students develop essential skills such as communication, leadership, and conflict resolution. Moreover, teamwork in engineering education aligns with the Accreditation Board for Engineering and Technology (ABET) criteria, which has long prioritised teamwork and communication skills as common skills that engineering graduates must possess (ABET 2023). Thus, it is clear that by learning teamwork in classrooms, engineering students can leverage the skills and expertise of their peers to tackle complex problems, drive innovation, and ultimately achieve better project outcomes in their studies and work.

1.2 Efficient Curriculum Design to Promote Teamwork in Engineering Education

An efficient curriculum design in engineering education can significantly promote teamwork among students through strategies such as project-based learning, team-building exercises, peer assessment, and faculty support (Bronson, Ng, and Wong 2007; Korkmaz and Kalayci 2019; Oladiran et al. 2011; Van den Beemt et al. 2020). Knight and Novoselich (2017) suggested that purposefully incorporating professional skills development in the curriculum can effectively nurture leadership skills among undergraduate engineering students. Research conducted by Suckarieh and Krupar (2005) also presented a course design called "Leadership and Teamwork from Within," employing experiential learning, community service, and problem-based learning strategies, which aligned with traditional frameworks of American applied engineering education to impart leadership and teamwork principles to engineering and technology students. Chen et al. (2011) introduced a novel assessment approach combining students' team performance and learning styles for teaching and assessing teamwork among software engineering undergraduates. Furthermore, Jiang et al. (2017) demonstrated a "joint assignment" project wherein biomedical engineering students collaborated with peers from diverse disciplines, enriching their teamwork capabilities. Takai and Esterman (2019) proposed a conceptual design of a team effectiveness model to augment teamwork in engineering education, with a particular emphasis on team member collaboration and the design process. Beddoes (2020) introduced a typology aimed at fostering successful interdisciplinary teamwork and enhancing awareness of teamwork among engineering graduates. In brief, integrating experiential modules, emphasising professional skills development, and providing structured teamwork training are essential strategies to enhance teamwork among students and better prepare them for the demands of collaborative work environments.

1.3 Gamification to Promote Teamwork

Gamification in higher education has also gained significant attention in recent years. It has emerged as a promising strategy to promote teamwork among students (Langendahl, Cook, and Mark-Herbert 2017). Previous research findings into improving students' learning outcomes and performance via incorporating game elements and combining teamwork and collaboration have been reported consistently (Diaz-Ramirez 2020; Forndran and Zacharias 2019; Sailer and Homner 2019; Rakhmanita, Kusumawardhani, and Anggarini 2023). Studies by Su and Cheng (2014) and Alsawaier (2018) also highlighted the positive impact of gamified learning activities on student motivation and engagement, which are essential components for promoting teamwork among students. The development of new digital methods, tools and games to be applied to teaching and learning was also critical to promote in promoting the integration of education into industrial practice (Markopoulos et al. 2015). Paciarotti, Bertozzi, and Sillaots (2021) introduced the Learner-Designer Approach to Serious Games (LDASG) as a new approach to gamification to promote inclusivity among engineering student groups. Furthermore, Maraffi and Sacerdoti (2018) reported the successful implementation of a Computer Classroom Role-Playing Game (CCRPG), emphasising the importance of user-friendly tools that promote teamwork in teaching and learning STEM subjects. Gamification is still in the developmental stage in higher education, but it can play a positive role in facilitating student learning outcomes and developing soft skills by combining it with traditional classroom teaching.

2 METHODOLOGY

2.1 Project Overview and Research Questions

This study applies a mixed-methods research design to investigate the teamwork performance and team dynamics of international chemical engineering postgraduate taught (PGT) students in a workshop setting. In recent years, an increasing number of Chinese students have opted to pursue a master's degree at UK universities. Although there has been a significant amount of previous research on students' teamwork, most of it has originated and been conducted using an existing business teamwork test (Aranzabal, Epelde, and Artetxe 2022; Aritzeta, Swailes, and Senior

2007). This test does not specifically address the learning and practical characteristics of students, and therefore, this leaves a gap to investigate teamwork performance and enhancement strategies in academic settings, particularly for Chinese students studying in UK universities.

This study primarily examines Chinese students' strengths and weaknesses in team-based learning in UK education settings and explores potential approaches to enhance their skills by engaging them in inclusive workshops, in-depth interviews, and focus groups. Based on the findings, we will further design diversified teamwork games and a team role test that are more suitable for application in educational contexts, with the aim of improving students' understanding of teamwork and their teamwork skills in future professional development. The complete research sequence is summarised in Table 1.

Table 1: Research Sequence of Designing the Inclusive Workshop and Team-building Games.

Phase	Activity	Data Type
1	Design the workshop process and team-building board game.	Desk research
2	Conduct the workshop	Practical
3	Investigate students' teamwork behaviours by engaging them in inclusive activities.	Quantitative data
4	Students fill out a post-activity questionnaire.	Quantitative & Quantitative data
5	Students are invited to participate in semi-structured interviews and focus group studies after the workshop.	Qualitative data
6	Improve the design of the team-building game and transfer it into a digital format.	Desk research
7	Develop and test a new team role test for educational settings.	Desk research, qualitative and quantitative data

2.2 The Workshop Study Design

This inclusive workshop study was conducted among PGT students on MSc Environmental and Energy Engineering and MSc Environmental and Energy Engineering with Industrial Management at the University of Sheffield during the autumn semester of the 2023 -2024 academic year (according to the internal admission data, the average annual enrolment rate of Chinese students in these two programmes was 63% from 2021 to 2023). It comprised a board game (Activity 1) adapted from a traditional team-building activity, "Lost at Sea" ("Lost at Sea - a team building game") and a project simulation activity, "Create Your Project" (Activity 2). Before the workshop, students were grouped into groups of 5-6 individuals, with the group formation predetermined by the departmental academic staff. Fig.1 presents the general schematic plan of the workshop study process to be conducted and the learning objectives expected to be achieved. Students will collaborate in groups during the workshop to complete various tasks. By engaging in team-building games, activities, and role tests, the students can learn about teamwork skills and strategies, and further understand their own collaborative abilities. The workshop will be followed by semi-structured interviews and focus groups to gain deeper insights into international students' perceptions of teamwork within the UK educational environment. Therefore, the research aims to support international students in forming better and continuously developing the teamwork skills and strategies essential for their life-long learning growth based on understanding the students' teamwork characteristics and improving the teamwork teaching approach at UK universities.

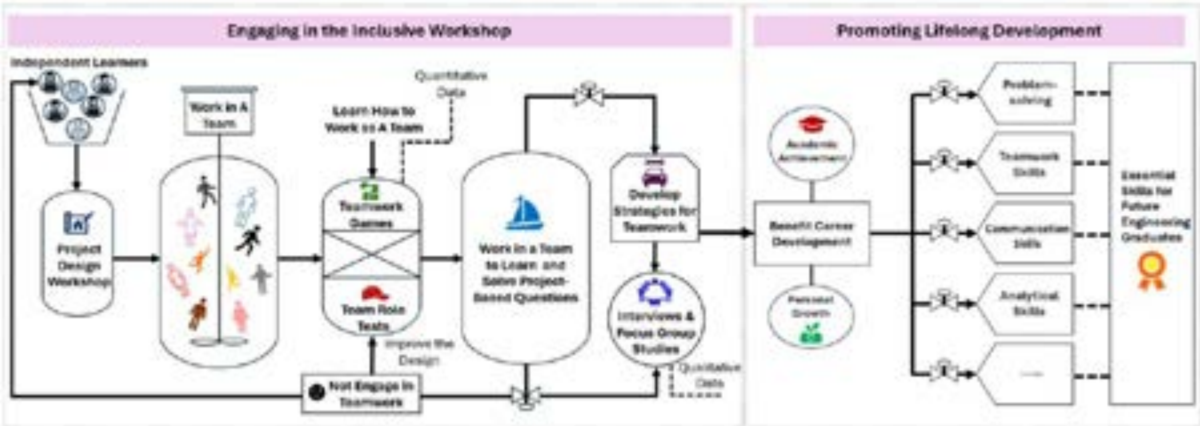


Fig. 1: The schematic diagram of the process of the inclusive teamwork workshop.

2.3 Team-building Game and Project-based Simulation Design

The team-building game used in Activity 1 was modified and redesigned based on the traditional team-building activity "Lost at Sea". The general game objectives and flow still followed the main logic of the original game (the game instructions mentioned in section 2.2 contained a detailed description of the content and process of the game). However, the original game design contained massive textual descriptions of the background and survival items, which required participants to have good English reading, reasoning and communication skills. But this setting may make it challenging for students who lack teamwork experience and English skills to be included and play the game smoothly. International students, especially, may experience language barriers when they first enter a Western educational environment, as they might tend to switch between languages (e.g., Chinese students translate English into Chinese and then into English again) while learning technical expertise. This additional presence of language switching may impact their ability to learn and accept new information or distract them from paying attention to the language rather than the learning content.

Therefore, to maximise the participation of a diverse range of students in the learning activities and to facilitate a smooth transition and adaptation of international students to the English teaching environment, we added simplified text descriptions and corresponding images for each survival item in the design to help students understand the game. Fig.2 illustrates the design template of the clue cards and the playing board for the team-building game applied in Activity 1.

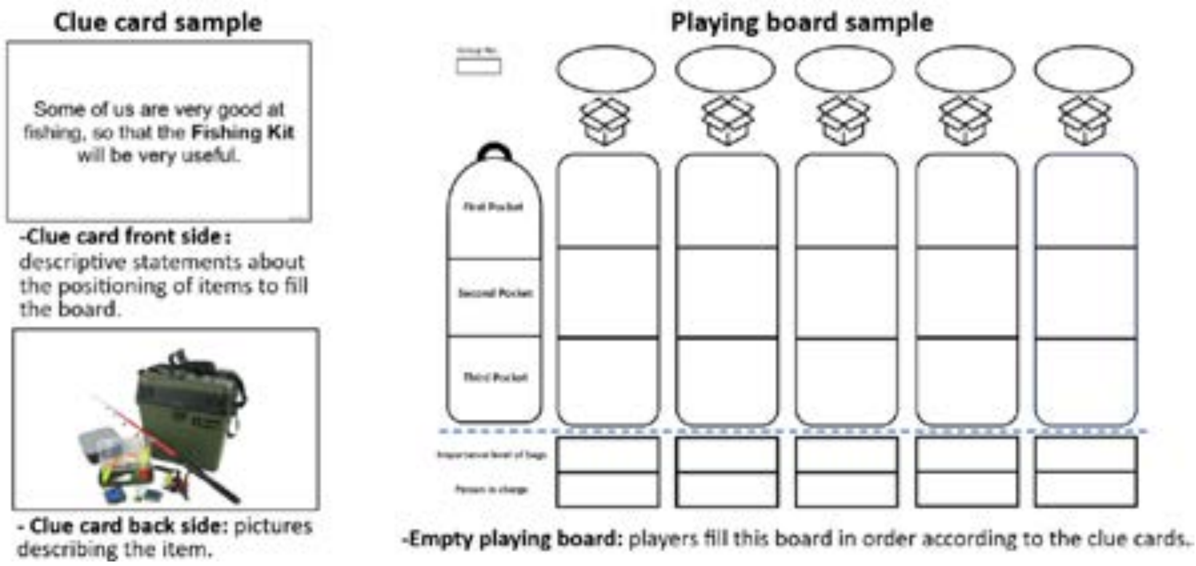


Fig 2: The design template of the clue cards and the playing board for the team-building board game. The left side of the figure shows a sample of a game card; the top left shows the front of the card containing a textual description to help students understand the importance level of the item, while the bottom left shows the back of the game card, which is an image of the item associated with a written description. The right side shows the playing board, divided by a dotted line into two parts: the upper part is filled with items to be put into different backpacks according to the cards' contents, while the lower part is filled with the importance levels and participants in charge of the different backpacks.

In Activity 2, we improved and redesigned a project design-based simulation game derived from the business simulation models (Baruah and Mao 2021; Levant, Coulmont, and Sandu 2016). Table 2 outlines the principle for assigning roles in the project-based learning Activity 2. The theme of the project-based design was the development of sustainable energy applications and devices, enabling students to make connections between the simulation and their professional knowledge. The detailed task responsibilities were described in each role's learning materials to promote collaboration with different roles.

Table 2. The role and task assignment principle for Activity 2.

If the bag you choose to take in Activity 1 is*:	The role you can consider to be in Activity 2 is:	Role description & task:
1st rank survival bag	Leader	Learning material pack 1
2nd rank survival bag	Responsible for calculating work	Learning material pack 2
3rd rank survival bag	Responsible for hands-on activity	Learning material pack 3
4th rank survival bag	Generating ideas	Learning material pack 4
5th rank survival bag	Making slides	Learning material pack 5

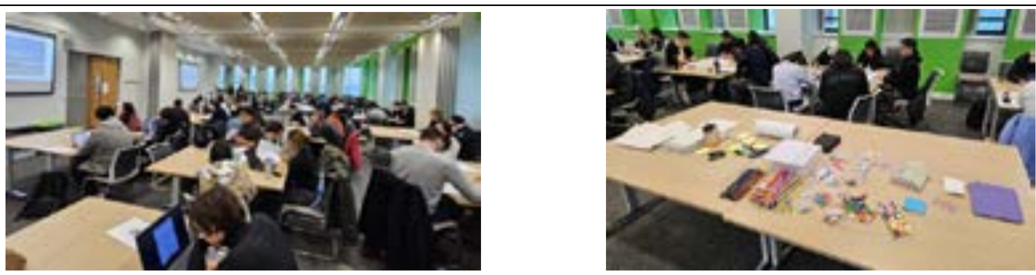
**At the end of Activity 1, the workshop facilitators will inform students about the importance of the backpacks. Students will then have a group discussion about who is responsible for the different backpacks. The backpacks students choose after discussing will be used as a basis for playing different roles in Activity 2.*

3 RESULTS

3.1 PGT students' engagement

A total of 83 students, including both home and international participants, formed 18 groups for the inclusive workshop. Among these, 86% were international students, with 83% of this international cohort originating from mainland China. This highlights the highly international nature of the learning environment within these postgraduate programmes. Notably, the group formations were organised by departmental staff to avoid homogeneity and ensure diverse team compositions (16 groups were mixed with Chinese, other international and home students; only two groups were completely Chinese). The deliberate pre-formation of diverse groups enhanced both the cultural diversity within teams and the potential for rich exchanges of communication and collaboration. This setup allowed for a broader range of perspectives and problem-solving approaches, facilitating a more inclusive and practical teamwork experience.

However, this arrangement also presents certain challenges. For instance, due to English proficiency, international students might face difficulties adjusting to different communication styles and collaborative patterns among their peers from various backgrounds. Most of the groups participating in the workshop consisted of students from different nationalities and cultural backgrounds, but the majority of each group still consisted of Chinese students (e.g., in a group of five students, four were from China, while the other one was a home student or from another country). Due to the limited team diversity, it may impact the efficacy of teamwork and the overall learning experience. Such a composition of the student cohorts is becoming more prevalent in UK master's programmes. Thus, providing adequate support and varied resources is necessary to enrich students' learning process and promote the effective achievement of learning outcomes, which will be an essential strategy to be adopted in teaching practice research. The complete process of the PGT students' participation in the workshop is shown in Fig.3.



Introduction and Learning Materials

Engaging in Activities and Presentation

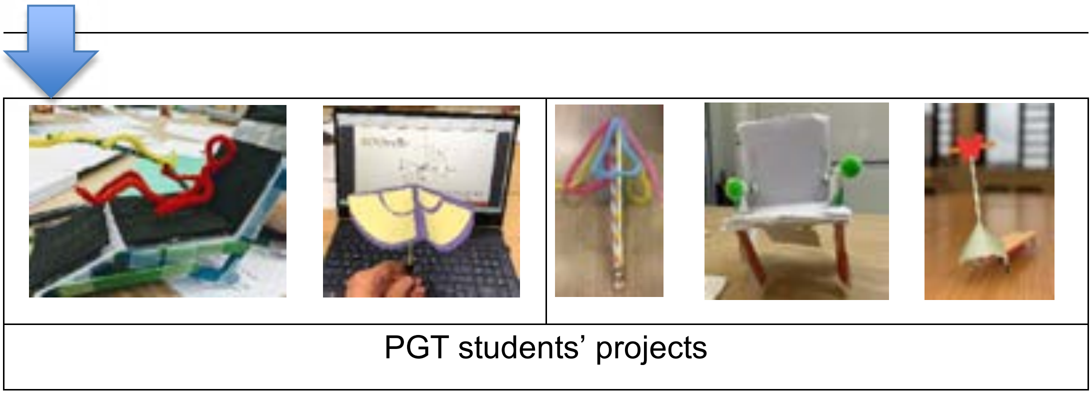


Fig. 3: PGT Students' Participation in the Workshop: The top shows the beginning of the workshop, where the facilitators explained the main content, process, and rules of the workshop; the middle shows the main component of the workshop, where students participated in activities and did hands-on work; and the bottom shows the prototypes of a sustainable energy device/application designed and built by the PGT students themselves.

3.2 PGT students' team performance

At the end of the workshop, we asked the students to give feedback and obtained preliminary insights into students' perceptions of the workshop. The results of the feedback showed that 87% of the PGT students who participated in the workshop felt that they were more of a collaborator in the team, while the other 13% felt that they were mostly in a leadership position (data presented in Fig.4). The students were also asked if they felt that their participation in the workshop had improved their knowledge and understanding of teamwork. For international students, their responses were distributed as follows: the majority of respondents (78%) indicated a certain level of agreement with the statement, with 33% agreeing and 45% strongly agreeing, while 18% expressed neutral. The remaining 4% disagreed, and 1% strongly disagreed (data presented in Fig.5). For home students, the results revealed that most of them also exhibited positive perceptions towards the workshop. 72% of respondents either agreed (54%) or strongly agreed (18%) that they gained insights to enhance their understanding of teamwork. Conversely, 28% of participants expressed disagreement, with 10% strongly disagreeing, 18% disagreeing with the statement, and no respondents were neutral in their stance (data presented in Fig.6).

The above data results show that a high percentage of students perceiving themselves as collaborators suggests that the workshop effectively fostered a sense of teamwork and collective participation. In contrast, the smaller proportion of students identifying as leaders indicates a potential area for further development in leadership skills within team settings. Furthermore, the positive feedback from most international students underscores the effectiveness of the team-building games to promote communication among group members. Yet, the neutral and negative responses also suggest that the workshop design may not holistically meet the learning needs of different students, and we will follow up with interviews to further investigate the perception of international PGT students to learn teamwork skills at UK universities.

It is worth noting that the majority of home students also viewed the workshop positively, but the relatively higher percentage of disagreement compared to international students raises questions about the differing expectations and experiences of home students in mixed-cultural settings, particularly in PGT programmes. This suggests that while the workshop was generally beneficial, better understanding and addressing the distinct perspectives and challenges faced by diverse students in such internationalised environments is needed to ensure students' overall effective learning experience.

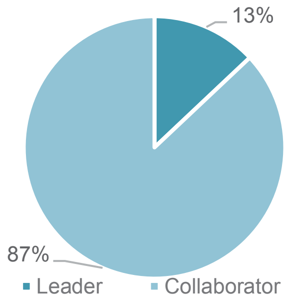


Fig. 4: The role preference of PGT students in group work. (87% preferred to be collaborators, while 13% intended to be leaders).

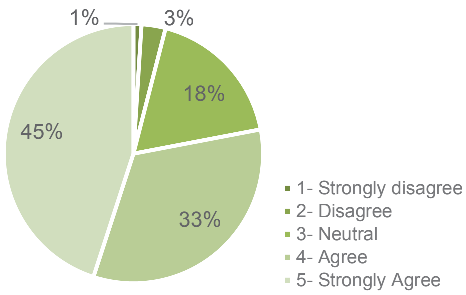


Fig. 5: Self-assessment of international students' improved understanding of teamwork after the workshop. 78% of international students agreed (45% strongly agree and 33% agree), 18% were neutral, and 4% disagreed (1% strongly disagree and 3% disagree).

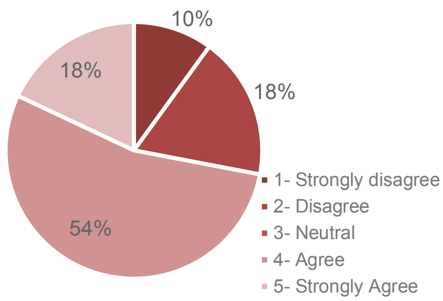


Fig. 6: Self-assessment of home students' improved understanding of teamwork after the workshop. 72% of home students agreed (18% strongly agree and 54% agree), and 28% disagreed (10% strongly disagree and 18% disagree).

4 SUMMARY

This study presented an inclusive workshop framework and team-building games designed to provide international PGT students with the opportunity to develop teamwork skills. This research is driven by the observed inconsistency between international students' team performance during collaborative work and the results of the commercial team role test they completed, such as the Belbin questionnaire. The commercial team role tests are typically designed for experienced professionals in business environments, not for university students with limited work experience. Therefore, this study seeks to develop team games and tests tailored to the academic context, reflecting the team behaviours of university students, particularly international students at UK universities. Currently, the prototype team games have been developed and tested with one PGT cohort. The early results and feedback have been positive and welcoming. In the following research phase, we will refine the inclusive workshop design, develop the team role test further and apply it to digital platforms to accommodate diverse learning needs, with the aim of improving the teamwork skills of international students in UK higher education institutions.

REFERENCES

ABET. 2023. "Criteria for Accrediting Engineering Technology Programs, 2023 – 2024." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/.

Alsawaier, Raed S. 2018. "The effect of gamification on motivation and engagement." *International Journal of Information and Learning Technology* 35 (1): 56-79.

Aranzabal, A, E Epelde, and M Artetxe. 2022. "Team formation on the basis of Belbin's roles to enhance students' performance in project based learning." *Education for Chemical Engineers* 38: 22-37. https://doi.org/10.1016/j.ece.2021.09.001

Aritzeta, Aitor, Stephen Swailes, and Barbara Senior. 2007. "Belbin's Team Role Model: Development, Validity and Applications for Team Building." *Journal of Management Studies* 44 (1): 96-118. https://doi.org/10.1111/j.1467-6486.2007.00666.x

Baruah, Bidyut, and Sixiao Mao. 2021. "An effective game-based business simulation tool for enhancing entrepreneurial skills among engineering students." In *2021 19th International Conference on Information Technology Based Higher Education and Training (ITHET), Sydney, Australia, 2021*, pp. 01-06, doi: 10.1109/ITHET50392.2021.9759800

Beddoes, Kacey. 2020. "Interdisciplinary teamwork artefacts and practices: a typology for promoting successful teamwork in engineering education." *Australasian journal of engineering education.* 25 (2): 133-141. https://doi.org/10.1080/22054952.2020.1836753.

Bronson, Paul, Anne Ng, and Kwong K. Wong. 2007. "Design and Implementation of a peer assessment tool for Problem Based Learning in Engineering." In *Australasian Association for Engineering Education (AAEE) Conference, Melbourne, 2007*.

Campion, Michael A., Ellen M. Papper, and Gina J. Medsker. 2006. "Relations between Work Team Characteristics and Effectiveness: A Replication and Extension." *Personnel Psychology* 49 (2): 429-452. https://doi.org/10.1111/j.1744-6570.1996.tb01806.x.

Chen, Jian, Guoyong Qiu, Liu Yuan, Li Zhang, and Gang Lu. 2011. "Assessing Teamwork Performance in Software Engineering Education: A Case in a Software Engineering Undergraduate Course." In *2011 18th Asia-Pacific Software Engineering Conference, Ho Chi Minh City, Vietnam, 2018,* pp. 17-24. doi: 10.1109/APSEC.2011.50.

Diaz-Ramirez, J. 2020. "Gamification in engineering education - An empirical assessment on learning and game performance." *Heliyon* 6 (9): e04972. https://doi.org/10.1016/j.heliyon.2020.e04972.

Forndran, Freerik, and Carlos Renato Zacharias. 2019. "Gamified experimental physics classes: a promising active learning methodology for higher education." *European Journal of Physics* 40 (4). https://doi.org/10.1088/1361-6404/ab215e.

Jiang, Jiehui , Yuting Zhang, Mi Zhou, Xiaosong Zheng, and Zhuangzhi Yan. 2017. "The role of a creative “joint assignment” project in biomedical engineering bachelor degree education." In *39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Jeju, Korea (South), 2017*, pp. 34-37.. doi: 10.1109/EMBC.2017.8036756.

Johnson, David W. , Roger T. Johnson, and Karl A. Smith. 2014. "Cooperative Learning: Improving University Instruction By Basing Practice On Validated Theory." *Journal on Excellence in University Teaching* 25 (4): 1-26.

Knight, David B., and Brian J. Novoselich. 2017. "Curricular and Co-curricular Influences on Undergraduate Engineering Student Leadership." *Journal of Engineering Education* 106 (1): 44-70. https://doi.org/10.1002/jee.20153.

Korkmaz, Güneş, and Nurdan Kalayci. 2019. "Theoretical Foundations of Project Based Curricula in Higher Education." *Cukurova University Faculty of Education* 48 (1): 236-274. https://doi.org/10.14812/cufej.479322.

Langendahl, Per-Anders, Matthew Cook, and Cecilia Mark-Herbert. 2017. "Exploring Gamification in Management Education for Sustainable Development." *Creative Education* 08 (14): 2243-2257. https://doi.org/10.4236/ce.2017.814154.

Levant, Yves, Michel Coulmont, and Raluca Sandu. 2016. "Business simulation as an active learning activity for developing soft skills." *Accounting Education* 25 (4): 368-395. https://doi.org/10.1080/09639284.2016.1191272.

"Lost at Sea - a team building game." https://insight.typepad.co.uk/insight/2009/02/lost-at-sea-a-team-building-game.html.

Maraffi, Sabina, and Francesco M. Sacerdoti. 2018. "Geoquest Project Implementation and Experimentation of a Computer Classroom Role Playing Game: Final Results." In *2018 Proceedings of the 6th Mediterranean Interdisciplinary Forum on Social Sciences and Humanities (MIFS 2018), Barcellona, Spain, 2018,* pp. 24-25. https://doi.org/10.19044/esj.2018.c5p3.

Markopoulos, Angelos P., Anastasios Fragkou, Petros D. Kasidiaris, and J. Paulo Davim. 2015. "Gamification in engineering education and professional training." *International Journal of Mechanical Engineering Education* 43 (2): 118-131. https://doi.org/10.1177/0306419015591324.

Oladiran, M. T., J. Uziak, M. Eisenberg, and C. Scheffer. 2011. "Global engineering teams – a programme promoting teamwork in engineering design and manufacturing." *European Journal of Engineering Education* 36 (2): 173-186. https://doi.org/10.1080/03043797.2011.573534.

Paciarotti, Claudia, Gabriele Bertozzi, and Martin Sillaots. 2021. "A new approach to Gamification in engineering education: the Learner-Designer Approach to

Serious Games." *European Journal of Engineering Education* 46 (6): 1092-1116. https://doi.org/10.1080/03043797.2021.1997922.

Rakhmanita, Ani , Paramitha Kusumawardhani, and Desy Tri Anggarini. 2023. "Gamification in Teaching Innovation: Perception of Teacher Adaptation with the Organism-response Stimulus Paradigm." *Jurnal Education and Development* 11 (1): 221-224. doi: 10.37081/ed.v11i1.4330.

Sailer, Michael, and Lisa Homner. 2019. "The Gamification of Learning: a Meta-analysis." *Educational Psychology Review* 32 (1): 77-112. https://doi.org/10.1007/s10648-019-09498-w.

Salas, Eduardo, Marissa L. Shuffler, Amanda L. Thayer, Wendy L. Bedwell, and Elizabeth H. Lazzara. 2014. "Understanding and Improving Teamwork in Organizations: A Scientifically Based Practical Guide." *Human Resource Management* 54 (4): 599-622. https://doi.org/10.1002/hrm.21628.

Smith-Jentsch, Kimberly A., Eduardo Salas, and David P. Baker. 2006. "Training Team Performance-Related Assertiveness." *Personnel Psychology* 49 (4): 909-936. https://doi.org/10.1111/j.1744-6570.1996.tb02454.x.

Su, C-H, and C-H Cheng. 2014. "A mobile gamification learning system for improving the learning motivation and achievements." *Journal of Computer Assisted Learning* 31 (3): 268-286. https://doi.org/10.1111/jcal.12088.

Suckarieh, George , and Jason Krupar. 2005. "Leadership and Teamwork Education for Engineering and Technology Students: An Experiential Learning and Community Service Approach." In *2005 American Society for Engineering Education Annual Conference (AESS), 2005*, pp. 10–869.

Takai, Shun, and Marcos Esterman. 2019. "A Conceptual Framework and a Research Roadmap towards Enhancing Team Working in Engineering Education." In *2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, *2019*, vol. 59216, p. V003T04A007. https://doi.org/10.1115/DETC2019-97638

Van den Beemt, Antoine, Miles MacLeod, Jan Van der Veen, Anne Van de Ven, Sophie van Baalen, Renate Klaassen, and Mieke Boon. 2020. "Interdisciplinary engineering education: A review of vision, teaching, and support." *Journal of Engineering Education* 109 (3): 508-555. https://doi.org/10.1002/jee.20347.

Unfold the complexity of engineering learning in a transdisciplinary environment: a Q. study from the University of Twente

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ABSTRACT

Universities are adopting more comprehensive teaching methods in an effort to prepare engineers for complicated problem solving. By engaging in Problem Based Learning (PBL) and Challenge Based Learning (CBL), students not only acquire content knowledge, but also encounter intricate settings where they collaborate with stakeholders, cultivate professional skills, and adapt to transdisciplinary situations. At the University of Twente, students were provided assistance in cultivating transdisciplinary competency through the CBL based semester project. Upon conclusion, participants were instructed to assess their personal learning experience and conduct a Q survey to rank the aspects they deemed most and least significant in this process. The results indicate that transdisciplinary learning is a personal journey, and students will find certain components more difficult and more beneficial based on their prior professional development. However, the trend indicates that

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they highly prioritize contacts with stakeholders and view teamwork as a means to effectively achieve this. They deem individual learning to be of lesser significance, as well as the act of reflecting on interactions with stakeholders and the process itself.

1 INTRODUCTION

To address issues such as climate change, sustainability threats, and inequality, fostering collaboration is necessary not only across different academic fields but also with non-academic stakeholders like industry and broader society (Ramachandran et al., 2022; Roysen and Cruz, 2020; Ward et al., 2019). Meeting market demands (labour or otherwise) requires recognizing the need for a new type of engineer. This enhanced engineer would not only prioritize the knowledge need to excel but also the competencies required to tackle societal challenges effectively (Mulder et al., 2012). Worldwide is consensual the need to educate engineers for unpredictable, volatile professional contexts and equip them with required competences and skills such as complex problem solving, communication, collaboration, interdisciplinarity, critical and creative thinking, etc. This calls for problem oriented, student-centred, collaborative, and contextual learning environments such as Problem Based Learning (PBL), and Challenge Based Learning (CBL).

University of Twente has adopted the CBL approach to develop students' skills beyond basic knowledge during their studies. University College Twente (UCT), part of the University of Twente, offers an Honors Bachelor of Science program that provides students with a comprehensive education in mathematics, natural sciences, and social sciences. Engaged in CBL environment, students in this program work with various stakeholders (e.g., peers, teachers, staff, external partners) to address societal challenges. Through CBL projects, students collaborate with, for example, government and industry partners to develop sustainable technology solutions and devise market introduction strategies. However, learning through transdisciplinary collaboration with external and non-academic partners might trigger student emotions which impacts their learning experiences and achievements. For example, it can trigger apprehension and uncertainty about how to interact and communicate efficiently with stakeholders, balance the hierarchical approach where stakeholders are regarded as experts and students as apprentices. Another example is how to effectively handle, and integrate knowledge learned in the challenge solving process. Students might achieve results expected, albeit in an instinctive manner, but this not necessary secures the needed attaining confidence in how to interact in transdisciplinary settings (see for example, Horn *et al.*, 2024)

In overall, it is fundamental understand in which ways student experience transdisciplinary learning (socially, emotionally, and cognitively) and what do they consider most important to support their transdisciplinary learning (see for example, Horn *et al.*, 2024; Akkerman, & Bakker, 2011). To support student transdisciplinary learning in a CBL environment, UCT in collaboration with Aalborg University (AAU), designed and implemented a tool based with aim to support students transdisciplinary learning. The tool design took the point of departure on Guliker and Oonk (2019) transdisciplinary learning model. It comprises seven stages, named learning mechanisms, and each stage provided prompt questions to guide students on what to consider when engaging and learning from, and with, stakeholders. The evaluation of the tool comprised two phases: (i) pre- and post- focus groups interviews and (ii) a Q study. This paper reports the results of the Q study and explores the following research question:

What do engineering students consider most important to support their collaboration with external stakeholders?

Guliker and Oonk (2019) transdisciplinary learning model revolves around four key stages: Identification, Coordination, Reflection, and Transformation. These stages are recognized as pivotal in facilitating collaborative learning across disciplines and in co-creating sustainable knowledge and practices, including in transdisciplinary environments. They encompass: (1) Identification, gaining insights into diverse current practices at disciplinary boundaries; (2) Coordination, collaborating with others to tackle shared challenges; (3) Reflection, gaining a multifaceted understanding of problems through diverse perspectives; and (4) Transformation, jointly developing novel knowledge or practices.

2 METHODOLOGY

2.1 Q methodology

Q methodology is a research approach used to systematically study subjective viewpoints and perspectives on a particular topic or issue. It combines elements of both quantitative and qualitative methods to capture individual beliefs, perceptions, and viewpoints while considering the subjectivity of study participants. Through a structured process involving steps such as developing a concourse (the range of statements representing viewpoints), constructing a Q set (a set of statements representing the concourse), conducting participant Q sorting (participants rank-order the statements according to their agreement or preference), and performing factor analysis, Q methodology aims to identify underlying patterns or factors in subjective viewpoints. This methodology is particularly useful for exploring complex concepts or issues where multiple perspectives exist, such as learning mechanisms to support student learning in a transdisciplinary environment.

Concourse development and Q-set construction

In this study, the concourse is draw from Guliker and Oonk (2019), two UCT tutors empirical experiences in facilitating students learning in their CBL projects. The initial concourse collaboratively crafted by first and second authors, both seasoned research experts and educators in CBL and PBL. Several rounds of discussion and revision of initial concourse led to first Q set comprising 32 statements. To enhance study validity, two international experts on PBL and CBL reviewed the initial Q-set draft, which consolidated the final 32-item version. Table 1 (available in annex) presents the Q set items, grouped according to learning mechanisms.

P-Set

P-set is composed by 13 students in 2nd semester of ATLAS, the UCT honours Bachelor program, with ages ranging between 18 and 23 years old. Additionally, P-set comprises students from different nationalities, namely Dutch (n=8), German (n=2), US/Dutch (n=1), Spanish (n=1) and Iranian (n=1), whereas six are males, four are females and three refer to other genders, or did not disclose it.

Q. sorting and post-sorting activities

After securing ethical approval from the University of Twente, the Q sorting process commenced, with participants physically conducting the sorting. Each participant received an informed consent form detailing the study's aims, format, procedure, and data management strategies to aid their decision to participate, followed by the Q set and sorting grid. Participants were prompted with the question: “Based on your experience in using the tool for transdisciplinary collaboration, what did you consider most important in supporting your collaboration with external stakeholders?” and tasked with individual ranking the Q set items based on what they consider most important. All 32 statements must be ranked hierarchically from -5 to +5, indicating their importance, where each grid allowed only one. Fig. 1 provides an example of a grid used to collect students’ responses.

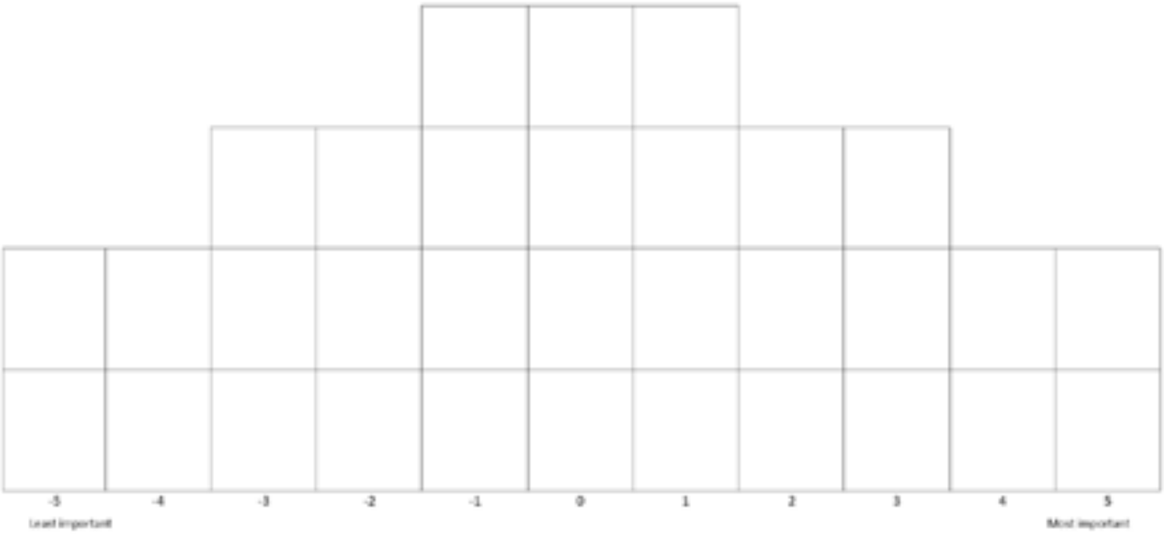

Fig. 1. Example of Q sorting grid.

In the post-sorting activities, each participant is asked to elaborate on reasons why they ranked given statements as most important (+5) and least important (-5).

Q. factor analysis and interpretation

The Q-sort correlations and inverted factor analysis involved inputting and reviewing raw data by the first and fourth authors before importing it into KADE, a Q analysis tool known for condensing data and identifying the most informative factor solution through Principal Components analysis and Varimax Rotation (Banasick, 2019). Four factors were chosen based on statistical criteria (eigenvalues ≥ 1.00 and significant loading participants per factor) (Watts and Stenner, 2012). After discussions and several rounds of KADE analysis, the research team agreed on the factors' theoretical significance and the most informative solution (Lundberg et al., 2020). Twelve participants significantly leaned towards one of the four factors (factor loading< 0.456), and one confounded sort occurred (Du and Lundberg, 2021).

3 RESULTS

In overall, all participants subjective opinions were significantly loaded in four factors. The four factors are described, combining the quantitative attributes, i.e., items ranked highest and lowest, and respective qualitative justifications provided by the participants. Each statement is referred to by its item number, correspondent learning mechanism and rated on a scale from +5 to -5 (e.g., '#5(R)/3' refers to statement 5, learning mechanisms reflection, with a rate value of 3). For distinguishing statements, 'D' ($p < .05$) is used after the value to emphasize statements in which the viewpoints significantly differed, and D* is used to indicate 'significantly distinguishing statements' ($p < 0.01$). Table 2 provides an overview of the results.

Table 2. Overview of results

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
n	6	2	2	2
Gender	M: 3; F: 2; Other: 1	F: 1; Other: 1	M: 2	M: 1; Other: 1
Eigenvalues	4.1974	1.8438	1.6093	1.1625
% Explained variance	32	14	12	9
Highest-ranked items	#4(T): 5 D* #10(T): 5	#17(pre-I): 5 D* #1(C): 5	#1(C): 5 #7(pre-C): 5 D*	#10(T): 5 #12(I): 5 D*
Lowest-ranked items	#20(R): -5 #13(pre-I): -5 D*	#16(R): -5 #22(R): -5 D	#5(R): -5 #6(pre-I): -5	#8(post-C): -5 D* #19(pre-C): -5
Distinguished items	#4(T): 5 D* #32(T): 3 D #11(pre-I): -2 D* #21(pre-I): -4 D* #13(pre-I): -5 D*	#17(pre-I): 5 D* #18(I): 0 D #2(I): -2 D* #26(C): -3 D #10(T): -3 D*	#7(pre-C): 5 D*	#12(I): 5 D*; #5 (R): 2 D* #27(I): 0 D* #24(pre-C): -2 D* #29(C): -3 D #8 (post-C): -5 D*

3.1 Factor 1. Multi-perspectives and co-creation of solutions as true value in collaborating with stakeholders.

Six participants consider as most important to support their transdisciplinary collaboration the ability to "combine of different perspectives to generate new perspectives" (#4(T): 5 D*) and to "assess if the knowledge gathered is relevant to the challenge being addressed" (#10(T): 5). Both statements refer to transformation dimension of transdisciplinary learning, and students associated it by "what real means" to collaborate with stakeholders and the "true value" that brings to the development of solutions. As students F1-8 and F1-11 state respectively:

"*In my eyes, they (the items) define what collaborating with external stakeholders really means. To combine different perspectives on a challenge and obtain a solution through the process*" (student F1-8).

"*Collaborating with a certain stakeholder is only relevant if they can provide value. It is therefore crucial to identify these with important knowledge*" (student F1-11).

For these students, the least important aspects to support their transdisciplinary learning is to evaluate if the "individual learning goals are achieved" (#20(R): -5) and the "Set up individual learning goals" (#13(pre-I): -5 D*). Students perceived collaboration with stakeholders require focus and excel in other competences like communication as student F1-7 individual learning goals become less relevant. For this student, individual learning goals are important when it comes to team dynamic, as following states:

"*I think the individual learning goals are not as relevant as other concepts detailed here. In our group, individual learning goals more pertained to group dynamics and working in the challenge itself*". (Student F1-7)

3.2 Factor 2. Safe and good team work as pre-conditions to promote positive stakeholders' collaboration.

Two participants consider "Create openness to share my individual thoughts about the project (e.g., important tasks, uncertainties, etc.)" (#17(pre-I): 5 D*) and "Set up team plans to prepare oneself before engaging with stakeholders" (#1(C): 5) as most important when learning in transdisciplinarity environments.

For these two students, create a work environment that is safe and open is a pre-condition create positive engagement with stakeholders, and consequently the project, as Student F2-2 states:

"*I choose 1 and 27 specifically since I think a good knowledge base and a good safe/ good working team help a project tremendously*" (Student F2-2).

In opposition, they ranked lowest the ability to "Reflect on collaboration with stakeholders as the driver to create positive impacts on society" (#16(R): -5)

and to "Reflect on collaboration with stakeholders as the driver to develop innovative solutions (#22(R): -5 D). They explain that "*stakeholder contact is the driver behind innovation and positive impact on society*" (F2-2), or that even though it is important to reflect in overall, it is not "*specifically the driver to creative and positive impacts*" (F2-4).

3.3 Factor 3. Plan and strategize to gain the most from stakeholders' engagement.

Defining "strategies to engage with stakeholders" (#1(C): 5) and setting "up team plans to prepare oneself before engaging with stakeholders" (#7(pre-C): 5 D*) are consider most important by two students. Students have referred that being ready "*to meet the stakeholder in short time they have available*" (student F3-1) is most important so you can take most of the meeting and engagement. Therefore, strategies like "*proposing and discussing question for stakeholder meeting beforehand in the team made a difference*" (student F3 -1), so then the time came the team knew what is needed to address the challenge and how. This position is shared by student F3-5, who refer preparedness as important strategy to "*gain the correct knowledge*" from experts.

On the other hand, they consider "set up plans for future development of professional skills" (#5(R): -5) and "develop a sense of belonging to the team" (#6(pre-I): -5) as least important. They justify their positions by stating that "*the background of experts was similar to their own, so I don't understand what the professional differences*" could be (student F3-1), and that "*sense of belonging did not influence the context with experts, since I feel that the tools have contributed to developed the sense of belonging*" (student F3-5).

3.4 Factor 4. Identify and assess the “right” knowledge.

“Assess if the knowledge gathered is relevant to the challenge being addressed” (#10(T): 5) and “Identify sources (e.g., books, scientific articles, etc.) necessary for the required knowledge” (#12(I): 5 D*) significantly loaded in factor 4, grouping two students’ opinions which highlight the knowledge and sources as most important to support their transdisciplinarity learning. Both students emphasise the role of knowledge from an individual perspective, like student F4-6 who states that by identifying their weaknesses they can improve and address them throughout the learning process. Student F4-13 also emphasise on knowledge by stress the importance of being able to critically reflect on its “nature” and suitability to apply in building arguments on decisions made.

On the other hand, “evaluate on team experience when engaging with stakeholders” and “develop coping mechanisms to deal with negative emotions such as anxiety and nervousness, when engaging with stakeholders” are the two items considered as least important by these two students. Main reasons relate with lack of experience in performing the tasks as part of the project (student F4-6) or in meetings with stakeholders (student F4-13).

4 DISCUSSION

Based on the results that have been provided, certain patterns stand out. It is evident that the individual learning is given less weight in the transdisciplinary process. Instead, students value more to work in teams and engage with stakeholders together. Involving stakeholders and obtaining, selecting, and integrating knowledge to produce new knowledge are the most crucial aspects of transdisciplinary learning that they identify. They consider that to succeed, strong teamwork is a prerequisite, and that working in teams is the most effective way to complete tasks involving stakeholders since it enables them to organize and discuss their own ideas prior to meeting with stakeholders. It is believed that this preparation is essential for productive stakeholder participation since it enables students to identify their knowledge gaps and be ready for discussions on subjects. It is also emphasized that a key element influencing effective transdisciplinary learning is their own disciplinary learning and preparedness.

They argued that thinking back on stakeholder interactions had less of an impact on society. Based on their feedback, the general reflection is favourable; nonetheless, the influence comes from the engagement with stakeholders, not reflection on it. Given that debates and information exchange are considered as advances to already existing knowledge, this can be understood as a result of those events. Furthermore, they believe that thinking back on "sense of belonging" and "further development of professional skills" is less significant. They discovered that's the process's natural course for development.

5 CONCLUSION AND FINAL RECOMMENDATIONS

This explorative study examined what do engineer students consider most important in supporting their learning for transdisciplinary. Here, transdisciplinarity is defined as collaboration with external, non-academic stakeholders from whom student collect, select, transfer, and integrate knowledge with aim to solve a real and authentic societal challenge (Gulikers & Oonk, 2019). The theoretical framework underlying the Q set is based on four learning mechanisms for transdisciplinary learning referred by Gulikers & Oonk, 2019, adjusted to UCT context by its practitioners and researchers. First, the Q analysis provided four factors, where the subjective opinions from 12 students are grouped. This indicates an emergent pattern that students where potentially students have different needs and prioritize different aspects of transdisciplinary learning mechanisms. Additionally, such knowledge can enable educators to better scaffold students in their transdisciplinary learning. Second, the student sample is small, only 13 participants, with 12 loading significantly in four factors. For this reason, no inferences can be made but nonetheless it is indicative of diversity of subjective opinions students have concerning the meaning and value of transdisciplinary learning in engineering formal education. The study comprises other limitations besides the small sample of students. For example, the construction of Q set could be revised and improved through a pilot by involving student; comprise a more systematic literature review on transdisciplinary learning which complete the work of Gulikers & Oonk (2019). That said, several recommendations can be made, from a research perspective (e.g., enlarge sample, compare several semesters), and from an educational perspective (e.g., organize workshops and tailor-made activities which address students' needs and apprehensions).

REFERENCES

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. Review of educational research, 81(2), 132-169.

Banasick, S., (2019). KADE: A desktop application for Q methodology. *J. Open Source Softw*. 4, 1–4.

Du, X., Lundberg, A., (2021). Examining emic viewpoints on a pedagogical development program's long-term effects using Q methodology. *Stud. Educ. Eval*. 71, 101088.

Horn, A., Visser, M.W., Pittens, C.A.C.M. et al. Transdisciplinary learning trajectories: developing action and attitude in interplay. *Humanit Soc Sci Commun* 11, 149 (2024). https://doi.org/10.1057/s41599-023-02541-w

Klemenčič, Manja. 2015. 'What Is Student Agency? An Ontological Exploration in the Context of Research on Student Engagement'. *Student engagement in Europe: Society, higher education and student governance* 20: 11–29.

Lundberg, A., de Leeuw, R., Aliani, R. (2020). Using Q methodology: sorting out subjectivity in educational research. *Educ. Res. Rev*. 31, Article 100361. https://doi.org/10.1016/j.edurev.2020.100361

Mulder, K.F., Segalàs, J., & Ferrer-Balas, D. 2012. How to educate engineers for/in sustainable development: ten years of discussion, remaining challenges. International Journal of Sustainability in Higher Education, 13, 3, 211-218.

Gulikers J & Oonk C. (2019) Towards a Rubric for Stimulating and Evaluating Sustainable Learning. *Sustainability,* 11(4):969. https://doi.org/10.3390/su11040969

Ramachandran, Aishwarya, Klara Abdi, Amanda Giang, Derek Gladwin, and Naoko Ellis. 2022. ‘Transdisciplinary and Interdisciplinary Programmes for Collaborative Graduate Research Training’. *Educational Review* 0(0): 1–18. doi:10.1080/00131911.2022.2134312.

Roysen, Rebeca, and Tânia Cristina Cruz. 2020. ‘Educating for Transitions: Ecovillages as Transdisciplinary Sustainability “Classrooms”’. *International Journal of Sustainability in Higher Education* 21(5): 977–92. doi:10.1108/IJSHE-01-2020-0009.

Ward, Chene E., Nomzamo Dube, Siphamandla Nyambo, and Christopher T. Chawatama. 2019. ‘A Reflection on the Role, Potential and Challenges of Transdisciplinarity at the University of Fort Hare’. *The Journal for Transdisciplinary Research in Southern Africa* 15(1): 9. doi:10.4102/td.v15i1.648.

Watts, S., Stenner, P. (2012). *Doing Q Methodological Research: Theory, Method, and Interpretation*. Los Angeles; London: SAGE Publications.

Annex 1

Table 1. Learning mechanisms and corresponding statements, which compose the items of the Q set.

Learning mechanism	Statements	Q item
Pre-identification (**pre-I**)	1. Develop a sense of belonging to the team	6
	2. Set up individual learning goals	13
	3. Create openness to share my individual thoughts about the project (e.g., important tasks, uncertainties, etc.)	17
	4. Identify my individual strengths (e.g., knowledge, skills and/ or competences)	21
	5. Identify my individual weaknesses (e.g., knowledge, skills and/ or competences)	11
Identification (**I**)	6. Identify the knowledge the members of the team have in connection with challenge.	23
	7. Identify what knowledge is lacking to solve the challenge	27
	8. Identify sources (e.g., books, scientific articles, etc.) necessary for the required knowledge	12
	9. Identify which stakeholders hold the knowledge needed to solve the challenge	18
	10. Identify ways to acquire the needed knowledge	28
	11. Develop criteria to assess the appropriateness of the knowledge obtained from stakeholders in relation to the challenge being solved	2
Preparation for cooperation (**pre-C**)	12. Set up team plans to prepare oneself before engaging with stakeholders	7
	13. Prepare to act professionally when engaging with stakeholders	24
	14. Develop coping mechanisms to deal with negative emotions such as anxiety and nervousness, when engaging with stakeholders	19
Cooperation (**C**)	15. Define strategies to engage with stakeholders	1
	16. Accept cultural, social, and/or professional differences of stakeholders when engaging with them	25
	17. Be able to establish agreements with stakeholders for continuous collaboration	29
	18. Be able to communicate effectively with different groups of stakeholders	3

	19. Be open to different perspectives on addressing the challenge when collaborating with stakeholders	26
Post-cooperation (**post-C**)	20. Evaluate on team experience when engaging with stakeholders	8
	21. Be able to improve the strategies used to engage with stakeholders based on previous experiences	15
Transformation (**T**)	22. Assess if the knowledge gathered is relevant to the challenge being addressed	10
	23. Assess the implications of the obtained knowledge for developing solutions	32
	24. Select the knowledge to be integrated in developing new solutions	30
	25. Be able to combine different perspectives to generate new perspectives	4
	26. Be able to integrate new knowledge in the existing collective one (i.e., the knowledge that already exist among the team members)	31
	27. Be capable of influencing one's preconceived view	14
Reflection (**R**)	28. Evaluate if the individual learning goals are achieved	20
	29. Set up plans for future development of professional skills	5
	30. Reflect on collaboration with stakeholders as the driver to develop innovative solutions	22
	31. Reflect on collaboration with stakeholders as the driver to create positive impacts on society	16
	32. Reflect on the shortcomings of the solutions given the strategies used to collaborate with stakeholders	9

USING DELIBERATE DISCUSSIONS TO DEVELOP A RESPONSIBLE ENGINEERING MINDSET AMONG STUDENTS

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Keywords: *Responsible engineering; ethics education; case studies; qualitative study; discussion-based learning*

ABSTRACT

In this research paper, we present a study of how deliberate discussions among students can guide the development of a responsible engineering mindset. We used a role-play case study intervention to teach students about the responsible and ethical dimensions involved in the use of facial recognition technology (FRT) on a college campus. Role-play discussions are a productive mechanism for teaching responsibility given the central role of deliberation in this process. From the literature we synthesized a framework (PAIR) that has four dimensions corresponding to the responsible use of technology: ***P***ractice, ***A***nticipation, ***I***nclusion, and ***R***eflexivity. We used this framework to analyze student responses at the group-level. The data was collected from 38 students enrolled in an undergraduate course on 'Technology and Society' at a US university. Two researchers conducted a thematic analysis of student responses to a range of prompts following the discussion. We found evidence of all elements from the PAIR framework in student discussions. We discuss the implications of our findings.

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1 INTRODUCTION

Engineered products and services directly or indirectly shape many aspects of how people live and work. Being cognizant of the sociotechnical aspects of engineering is therefore important for students and professionals alike (Martin et al., 2019), and inculcating values of responsibility towards society is a common goal within engineering education (Lathem et al., 2011; Zandvoort, 2008). Often through standalone courses on technology and society, or through an embedded approach, where responsible engineering is introduced through design or technical courses, engineering educators strive to provide students with a holistic mindset to guide their work (Rea et al., 2021). In this paper, we present a study on the use of deliberative discussions to inculcate a mindset of responsible use among students. We designed a role-play case study on the use of facial recognition technology (FRT) and students read the case and subsequently engaged in a dialogue on the merits of using the technology to make a college campus more secure. In the rest of the paper, we first briefly review prior work, followed by a description of our implementation and methodology. We then present the findings and discuss the implications.

2 PRIOR WORK

2.1 Deliberation

Much of the work in the literature on responsibility within engineering and technology comes from the field of responsible innovation. Within that literature, deliberation has been recognized as a central component of designing technology that takes societal considerations into account (Parkhill et al., 2013). Primarily, by engaging different stakeholders and having a comprehensive dialogue, diverse issues, concerns, and opinions about the potential use of technology are brought to the table. The important elements are representation of different voices, the opportunity to state a case, and openness to other ideas and perspectives (Shen et al., 2021). Within emerging technologies such as AI (Weerts et al., 2022), scholars argue that deliberation is important in “finding optimal solutions” and “this process should satisfy conditions of inclusiveness to various stakeholders, ensure the reciprocity of actors, and facilitate diverse and well-informed arguments and viewpoints (Buhmann and Fieseler, 2021, pg. 1).” Using role-play case studies, as we discuss later, we replicate these conditions of deliberate discussion for students.

2.2 PAIR Framework

In addition to the process of deliberation, prior work on responsible innovation and engineering points to several factors that are essential for evaluating a new technology. These include the following four dimensions that form the framework we use for analyzing the data (Frigo et al., 2021; Stilgoe et al., 2020; Stone et al., 2020; van Grunsven et al., 2023): a. *Practice* - This dimension refers to practical concerns associated with the use of an engineered product or service that preclude or support its use more broadly and in the specific context of implementation. For the context of our analysis, we use this dimension to assess the practical viewpoints of stakeholders and specific concerns they focus on if the technology is in use, e.g., cost of implementation. b. *Anticipation* - This dimension refers to a forward-looking stance that considers different contingencies and what is plausible and possible. Within responsible innovation literature, this dimension can often refer to hypothetical future use as well, a more sci-fi approach, so to say, but in our analysis, we use it to evaluate future aspects of technology in use that students anticipate, e.g., data security needs once personal data is collected. c. *Inclusion* - This dimension refers to the representation of different stakeholder voices, including those not in power, and the nature of overall participation within the deliberation. In our study, the inclusion of different viewpoints is already designed using role-play and a discussion script that requires each stakeholder to voice their opinion. Given the focus on responsibility, for our analysis, we have used inclusion also to explore specific concerns such as racial bias in algorithms. d. *Reflexivity* - This dimension refers to trade-offs in decision-making based on different relevant factors and self-reflexivity in terms of understanding that one's perspective might differ from others and might not be universally held. In our analysis, reflexivity is present both in terms of changes in personal viewpoints and evaluation of pros and cons related to FRT.

Although we have analytically separated these dimensions, in conversation and discussion, they are often intricately linked with each other, and more than one dimension is often present in a single stakeholder statement or viewpoint.

3 DELIBERATION AND ROLE-PLAY CASE STUDIES

Role-playing case studies promote an active learning environment beyond what is possible in a traditional classroom and encourage students to contextualize the case or scenario they are working on in a situated manner and engage in sensemaking and perspectival thinking (Brummel et al., 2010; Loui, 2009; Herzog et al., 2024). Role-plays are commonly used in teaching engineering and technology ethics Martin et al., 2019; Shapiro et al., 2021). Role-plays serve as an instrument to guide students to engage with, debate, and evaluate decisions from the perspective of different roles. By making students aware of other perspectives, they better understand pressures and influences that would otherwise have been hidden. Furthermore, role-plays provide a collaborative learning pedagogical approach that is effective for deliberation because 1) collaboration triggers cognitive processes associated with learning, including perspectival thinking; 2) collaborative activity allows learners to strengthen understanding of material they have already learned and repair mental models that maybe fragmented or incomplete; and, 3) a cognitive-elaboration approach within collaborative learning requires actively processing information, and aims to elaborate basic information-processing activities such as encoding, activation of schemas, rehearsal, metacognition, perspective, and retrieval. In addition to the discussion aspect of role-plays, the other effective element is the “relatability” that can be designed in them in the sense that the narrative can focus on both a technology and context that students find interesting and relatable (Mehta et al., 2023). This makes recognizing ethical issues convenient and facilitates decision-making. Therefore, due to its situated learning element, case studies, particularly role-plays, allow students to explore many sides to a problem and develop multiple perspectives facilitating decision-making through collaboration and consensus with peers.

4 FACIAL RECOGNITION TECHNOLOGY (FRT) ROLE-PLAY CASE STUDY

The role-play scenario we designed follows a fictional situation involving the stakeholder's decision to use FRT to help monitor university campus security (Andrejevic et al., 2020). In this scenario, facial recognition is a method of identifying or verifying an individual's identity using the features of their face. Facial recognition systems can identify people in photos, video, or real-time. Prior work has shown that face recognition data can be prone to error, which can, for instance, implicate people for crimes they have not committed (Brey, 2004). Recent research has also shown that facial recognition software is particularly erroneous at recognizing African Americans and other ethnic minorities, women, and young people, often misidentifying or failing to identify them, disparately impacting certain groups' outcomes (Raji & Buolamwini, 2019; Williams, 2020).

In the case, Trisha Brown, Chief of Safety and Emergency Management (SEM) at the University, has put together a cross-functional committee (played by participants of the role-play activity) to provide a recommendation on the use of the technology along with the pros and cons of adopting facial recognition technology or a different solution. The committee is charged with identifying barriers to adopting the technology that the campus would face. The committee's composition is such that different stakeholders from the campus community can have a voice in a decision that will likely affect everyone. Table 1 depicts the roles. Details are available online (Hingle & Johri, 2024; Johri, 2024).

Table 1: Roles for FRT Role-Play Case Study

Role	Role Title	Role Description
A	Vice President of Information Technology Software and Services	A is has recently moved to AHU after a successful career in the industry. He is an unabashed technology optimist who believes that IT can solve almost any organizational problem, and once a solution has been implemented problems can be addressed.
B	Undergrad psychology; VP student senate	B represents students' welfare on this taskforce. B is a frequent user of social media and has used it to drum up support for causes such as the safety of women on campus.
C	Professor of History and a member of the faculty senate	C represents the faculty on this taskforce. As a historian, he often takes a long-term perspective and is cicumspect of technology-based solutions.
D	Associate vice-president in the provost office at AHU	D looks at student admissions and retention and is worried that a perception that the university is not doing enough for student safety might impact admissions. D thinks FRT would put AHU at the forefront of technology use and safety.
E	Senior Director, Equity and Inclusiveness (OEI) at AHU	E manages a range of efforts that can assist with advancing AHU's mission to admit and support a broad range of students. E is skeptical of any effort that might undermine inclusiveness on campus and this includes technology-driven projects.
F	Director, FaceAware, a non-profit consultancy in the field of FR	F is providing consulting for the taskforce pro bono. F is a renowned expert on FR and was responsible for creating one of the first deployable applications of facial recognition. F has been a proponent of facial recognition but is cognizant of problems with FR technology.

5 IMPLEMENTATION

The findings in this paper come from a study conducted at a large public university in the United States with undergraduate students majoring in computing technology-related fields. The study was conducted in a technology and society course with 39 predominantly junior and senior-level (3rd and 4th year) undergraduate students majoring in computer networking, information technology, and cybersecurity. Students participated in the role-play in groups of 6-7 students. Students were given the readings based on the case study to prepare for the role-play. Pre- and post-class assignments helped students prepare for the exercise and helped articulate their learnings, respectively. Participants were provided the role-play outline a few weeks before the role-play activity and given specific roles ahead of time to allow for preparation. In addition, participants were also provided reading materials and articles (both peer-reviewed and news-focused) related to the use of FRT to supplement their understanding of the scenarios. The role descriptions outlined the stance each role could take, but also left space for improvisation. The role-play activity was conducted in class, where participants were asked to take the perspective of their assigned role and engage with the other role-play participants. The role-play discussion was facilitated by a moderator, who provided some initial questions to focus the conversation. Participants were then asked to explain their role-based recommendation before leading into debating and negotiating with the other participants.

6 METHODOLOGY

6.1 Data

Data was collected in Spring 2024 and consisted of textual responses to open-ended questions. The study was approved by the Institutional Review Board (IRB), and only data from participants who consented (38 out of 44) was included. All participants completed a pre-discussion assignment focused on understanding students' perspectives on the case material presented. The pre-discussion assignment tasked students with outlining an individual recommendation to the committee lead based on their understanding of their role and the context of the scenario. Participants were also asked to identify any ethical issues and barriers that their role may be presented with while establishing their chosen recommendation. Finally, a post-discussion assignment captured the final consensus of the group and collected feedback on the participant's experience in the role-play scenario. Prior to this course, the students had one class period on ethics in an introductory course.

6.2 Analysis

Students understanding of responsible use and their decisions for the case study were analyzed qualitatively by the two authors using thematic analysis of responses to pre/post-class assessments (Braun and Clarke, 2012). Themes were drawn inductively and deductively in consultation with the literature review. Students' responses were coded to identify ethical themes, identify dilemmas in the case study, and demonstrate a multidimensional approach to making decisions about responsible use. A decision was made, after examining individual students' data, to undertake a group-based analysis to reach an understanding that reflected the deliberation process more accurately.

7 FINDINGS

After reading individual responses, we analyzed the data at the group level to better understand the outcomes of the deliberation process. Overall, of the seven groups that participated in the discussion, one group recommended that FRT be used, three groups recommended that FRT use be phased in slowly so that its usefulness and harms can be tested in a smaller setting, and three groups rejected the use of FRT completely and described alternative routes forward. Although each group fixated on some concerns over others, each group discussed many factors, and almost all relevant issues related to responsible use were brought up. Privacy and security were the most discussed issues, which is not surprising given the case topic and the fact that many students were majoring in cybersecurity.

Table 2: PAIR Framework applied to student responses.

		PAIR Dimensions			
Group	**Group Decision**	*Practice*	*Anticipation*	*Inclusion*	*Reflexivity*
1	FRT can be used but slowly phased in.	“**Collecting and storing biometric data**, raises privacy concerns.” “The privacy of students is an issue…**cameras** will have biometrics of all the students on the campus.”	“Users may not be fully **aware of the extent of data** being collected or how it will be used, leading to **potential breaches of privacy**.”	“**I partially agree** with the group decision that the school could implement the FRT **slowly but not everywhere**…I will only agree with this idea **if the school provides a clear consent form** of how they will use the students' data before they do the work.”	“The case study discussion **deepened my understanding of the complex interplay between privacy, cybersecurity, and ethics** in technology deployment…**I have a better understanding** that before doing any technology implementation **we have to always consider the privacy of the users… ensure responsibility** in case anything happens.”
2	FRT should not be used.	“**Data collected** must be checked regularly to verify it's **accuracy by utilizing automated auditing system** to detect any updated features change from the images data/info.” “**Updating the databases**, maintaining the system, and so on **will cost the university**	“We should **stick to what already works** such as biometric scans and physical ID cards. This **gives us time to improve facial recognition technology**, especially its security”. “The **public opinion** towards FRT will matter **if**	“The **issue of consent** was always an issue of FRT due to **people worried about personal privacy**.” “Needs transparency with students to have their consent of what is being collected that they would **feel like their activities are being watched for other purposes**.”	“**This discussion helped me see how rapidly technology is developing**…**I also realized how important it is to teach people about the importance of their privacy,** even if they have nothing to hide.” “FRT is a prime example of how cons of improving technology may

		additional money.”	**people do not have a positive** experience with it.”		sometimes outweigh the pros. **I believe that at this moment, we should stick to alternative or already existing ways of identification**.”
3	FRT should not be used.	“It isn't **cost effective**; people can easily **bypass it by wearing a mask**.” “**Too costly** and comes with too many risks to be considered practical.” “**Amount of data…could lead to ransomware** or DDOSing or stuff of that sort.”	“**Even if the technology was used properly** and only alerted campus police when someone not registered comes on campus, then eventually the **security would stop paying attention to the FRT because it would be pinging them all day long**.”	“It **disproportionately affects people of color, and this disparity needs to be addressed**. I have also learned this technology is not ready for mass market adoption, and that **assurances are needed of a bias-free and secure** system.”	“**I went from staunchly opposed to mildly in favor, with some caveats**... When someone mentioned that this technology was not correctly recognizing people of color, **I suggested that implementing it on campus would give it a larger data set with which to become more accurate**.” “If I were to use our discussion today as the example, yes we talked about how it invades people's privacy but it would also make campus more secure (ideally) **we also talked about how much money would go into this technology and actually affect security**.”
4	FRT can be used but slowly phased in.	“We all agreed that it was **not an effective use of money** and just created more problems than it solved.” “I had many concerns…**a third party would be handling the system and database**.”	“FRT would make the university **vulnerable to even more cyber-attacks**…The group offered solutions such as **very heavily guarded and encrypted storage rooms** where physical local data of students and faculties information would be kept it.”	“I feel that **implied consent due to being affiliated is not good enough**.” “**As long as people know** that this technology is in use… that should be okay… **they have the option to go into these areas or not**.”	“After the discussion **I became aware of the legal issues that would come with the deploying of the technology**. There should be disclosure in certain areas and having more people overlook the storage and detection of people within this campus” “FRT and AI is only the beginning of this new age of surveillance and privacy. **I believe it is crucial for regulations and policies** to be implemented nationwide.”

5	FRT should be used.	“**How is stored data handled… with such a growing campus requires a lot of storage** and should be localized to secure the data won't be used by companies or be outsourced through some ulterior motives besides the school safety.”	“Because I believe that FRT is a **good technology to use but is it still not good enough**…still not the best tool to use… privacy concerns.”	“**It may flag people of color or even someone who is just wearing hats, or anything**, and that could create a problem, and get the innocent in trouble. Also, **if the system gets hacked into, the hacker can use other people's faces to commit other crimes**.”	“I **learned some smart and innovative ways to see just how accurate and efficient the FRT could be**. We discussed the use of the FRT in just a small section but still a good amount of traffic area on the campus to test and see how well the FRT works on its own. **If there is bias or inaccuracies, then either improve it or disregard the implementation** all together.” “**My perspective towards the system changed especially towards the safety of such a system and how stored data is handled**.”
6	FRT should not be used.	“**Sensitive information such as biometrics should not be lightly dealt with**…FRT will bring along a lot of violation to privacy laws and mistrust within the community.” “**Cost of implementation exceeds the benefit of the system**.”	“Though there are problems I believe that with the proper approach they can be fixed and properly applied. I see that **in the near future applications like this will be heavily utilized** on college campuses because of the potential and upside of this form of technology.”	“Even if FRT was more secure, that doesn't change the fact that **students will still be uncomfortable getting their faces scanned** every day. Our group and I agreed that **extensive surveillance** can make students feel like they are always being watched and would feel like they are not enjoying a full sense of **freedom**. FRT also brings forward privacy issues and **risk of discrimination**.”	“**I realized that…If FRT was implemented, then it would take large amounts of AI power, surveillance measures, and personnel to keep the FRT system secure**. This is costly. And the more AI that is incorporated into places, the more difficult privacy becomes, because going so far as to track someone's face can make people uncomfortable.” “**My personal viewpoint changed because my classmates proposed a new view to me about the detrimental effects of this type of technology**. I now hold the view that it is not wise to implement it, and also not fair to students that would not like to be

					recorded everywhere.”
7	FRT can be used but slowly phased in.	“It would also be good for us to begin with **physical security first**...do more to prevent issues such as robbery more than using AI and facial recognition.” “There are **potential data breach concerns** as well, since biometric data can be copied or stolen.” “**The cost of [FRT] would be better in the long run** compared to more police force.”	“**Technical issues regarding FRT that have not been solved** yet, such as spoofing and just the overall lack of accuracy in the algorithm.” “**Problems could be fixed in the long run as the technology getting better** since AI is constantly adapting and changing.”	“**There are many cases of bias and false positives in FRT that can lead to discriminatory situations** and legal troubles.” “It is prone to errors and bias. As someone who supports equality, **the implementation of racially biased technology…I cannot condone** the use of it on campus.”	“**After this case study, I see that there is a trade-off between privacy and cybersecurity and you can't have both**... this topic is a gray area in our field because even though we have good intention with the use of FRT, it also prone to bias and people using it with bad intention,.” “**My perspective did change a little because at first I was heavily against the use of AI or facial recognition in general on campus however, I was convinced that using it little by little and testing** it for any false positives, or perhaps creating our own AI that we can supply information to that is not racially biased, could be a better alternative.”

Overall, students were exposed to and able to develop a holistic understanding and mindset for responsible use taking into consideration the practical, plausible, and impact concerns related to FRT as depicted in the quotes (Table 2). In relation to *practice*, the following concerns were raised. First, the cost-effectiveness of using FRT was questioned by several groups. The technology is not cheap, and it requires constant updates. Students questioned if the trade-off between using FRT as opposed to increasing physical security on campus was worth the investment. Students also expressed practical concerns about data collection, maintenance, and handling. They were particularly worried about a third-party company handling personal and private data for university members. At least one team argued, though, that in the long run, investment in FRT will pay off.

In relation to *anticipation*, students focused on the potential security issues that will be created as increasing amounts of data are collected and stored. Ransomware and other cyber-attacks on the data were foreseeable problems. They also worried that in terms of the algorithms, FRT still had issues and was not a fully developed technology, especially given its use on a college campus with many students, faculty, and staff, and a possibly large number of guests. Some groups also argued that they anticipate the technology to get better and the availability of data from the campus might help improve the facial recognition algorithm.

Inclusion concerns were evident in students' discussion of the inherent bias of FRT, especially in relation to people of color and its ineffectiveness in case anyone was wearing a mask or a hat. They also brought up concerns about the lack of freedom for students and the extensive surveillance. False positive in recognition was another issue that was brought up. Overall, most groups concurred that using FRT did not create an inclusive environment.

Finally, *reflexivity* was reflected in student comments about changes in their perspective and in their thinking about the use of FRT. Students reported improved awareness of societal and ethical issues, the need for regulations, and the downsides of using FRT. Some students reported understanding that there is a trade-off involved and it is hard to balance security and privacy. They also reported that they think there is a need to educate everyone about privacy issues.

8 DISCUSSION AND IMPLICATIONS

In this paper, we present a study of how responsible use of technology can be taught to students using a role-play case study approach, as this method provided affordances for deliberate discussion of a topic. The PAIR Framework provided a lens to track student recognition and learning through the different phases of their engagement with subject matter.

The assignment of roles to students was critical in including different perspectives and leading to deliberate discussion focused on the pros and cons of using the technology and the foreseeable problems and improvements that can be achieved in the future. The discussion and subsequent assignments also provided students the affordance to reflexively analyze their own learnings. Overall, the study also points to the advantage of a loosely guided discussion that allows students to engage with a topic and express diverse viewpoints.

Interestingly, we found that although the groups discussed the same case and students played similar roles across the groups, the discussion varied, and the groups reached different final recommendations. The groups were rightfully cautious with employing a system that would likely change how different participants on the campus grounds interact, especially when the details of the change could not be easily anticipated. Ultimately, implementing a novel system in a new setting requires time and students highlighted their uncertainty through their discussion and decision.

This work has certain limitations. The data is from just one course. The role-play was not designed specifically to look at 'responsible use', although the case by default prompted that discussion given the need to analyze technology and make recommendations balancing societal issues. In the future, the PAIR framework can be used to design cases specifically for facilitating a responsible mindset.

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REFERENCES

Andrejevic, Mark, and Neil Selwyn. "Facial recognition technology in schools: Critical questions and concerns." Learning, Media and Technology 45, no. 2 (2020): 115-128.

Braun, Virginia and Clarke, Victoria. "Thematic analysis". In APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological, edited by H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher, 57–71. APA. (2012)

Brey, Philip. "Ethical aspects of facial recognition systems in public places." Journal of information, communication and ethics in society 2, no. 2 (2004): 97-109.

Brummel, Bradley J., C. K. Gunsalus, Kerri L. Anderson, and Michael C. Loui. "Development of role-play scenarios for teaching responsible conduct of research." Science and engineering ethics 16 (2010): 573-589.

Buhmann, Alexander, and Christian Fieseler. "Towards a deliberative framework for responsible innovation in artificial intelligence." Technology in Society 64 (2021): 101475.

Frigo, Giovanni, Florian Marthaler, Albert Albers, Sascha Ott, and Rafaela Hillerbrand. "Training responsible engineers. Phronesis and the role of virtues in teaching engineering ethics." Australasian Journal of Engineering Education 26, no. 1 (2021): 25-37.

Herzog, Christian, Aditya Johri & Roland Tormey. Teaching ethics using case studies. In Chance, S., Børsen, T., Martin, D., Tormey, R., Lennerfors, T. T., & Bombaerts, G., (Eds.). International Handbook of Engineering Ethics Education. Routledge. (2024) https://doi.org/10.4324/9781003464259

Hingle, Ashish, and Aditya Johri. "Role-Play Case Studies to Teach Computing Ethics: Theoretical Foundations and Practical Guidelines." Proceedings of HICSS (2024).

Johri, Aditya (2024). Facial Recognition Case Description and Details. Available: https://onlineethics.org/cases/george-mason-tech-ethics/utilizing-facial-recognition-university-campus

Lathem, Sandra A., Maureen D. Neumann, and Nancy Hayden. "The socially responsible engineer: Assessing student attitudes of roles and responsibilities." Journal of Engineering Education 100, no. 3 (2011): 444-474.

Loui, Michael C. "What can students learn in an extended role-play simulation on technology and society?." Bulletin of Science, Technology & Society 29, no. 1 (2009): 37-47.

Martin, Diana Adela, Eddie Conlon, and Brian Bowe. "The role of role-play in student awareness of the social dimension of the engineering profession." European Journal of Engineering Education 44, no. 6 (2019): 882-905.

Mehta, Shruti, Ashish Hingle & Aditya Johri. Teaching Sustainability Through A Role-Play Case Study Of E-Scooter Use On College Campuses. European Society for Engineering Education (SEFI). (2023) DOI: 10.21427/EZXC-6M65

Orchard, Alexi, and Marcel O'Gorman. "Fostering responsible innovation with critical design methods." Journal of Responsible Innovation 11, no. 1 (2024): 2318823.

Owen, Richard, Jack Stilgoe, Phil Macnaghten, Mike Gorman, Erik Fisher, and Dave Guston. "A framework for responsible innovation." Responsible innovation: managing the responsible emergence of science and innovation in society (2013): 27-50.

Parkhill, Karen, Nick Pidgeon, Adam Corner, and Naomi Vaughan. "Deliberation and responsible innovation: a geoengineering case study." Responsible innovation: managing the responsible emergence of science and innovation in society (2013): 219-239.

Raji, I. D. and J. Buolamwini, "Actionable Auditing: Investigating the Impact of Publicly Naming Biased Performance Results of Commercial AI Products," Proceedings of the 2019 AAAI/ACM Conference on AI, Ethics, and Society, 2019.

Rea, Stephen Campbell, Kylee Shiekh, Qin Zhu, and Dean Nieusma. "The hidden curriculum and the professional formation of responsible engineers: A review of relevant literature in ASEE conference proceedings." In 2021 ASEE Virtual Annual Conference Content Access. 2021.

Shapiro, Ben Rydal, Emma Lovegall, Amanda Meng, Jason Borenstein, and Ellen Zegura. "Using role-play to scale the integration of ethics across the Computer Science curriculum." In Proceedings of the 52nd ACM Technical Symposium on Computer Science Education, pp. 1034-1040. 2021.

Shen, Hong, Wesley H. Deng, Aditi Chattopadhyay, Zhiwei Steven Wu, Xu Wang, and Haiyi Zhu. "Value cards: An educational toolkit for teaching social impacts of machine learning through deliberation." In *2021 ACM conference on fairness, accountability, and transparency Published Proceedings: Online,* pp. 850-861. 2021.

Stilgoe, Jack, Richard Owen, and Phil Macnaghten. "Developing a framework for responsible innovation." In The Ethics of Nanotechnology, Geoengineering, and Clean Energy, pp. 347-359. Routledge, 2020.

Stone, T. W., Marin, L., & Van Grunsven, J. B. (2020). "Before responsible innovation: Teaching anticipation as a competency for engineers". In Engaging engineering education: Proceedings of the 48th annual SEFI conference (pp. 1371-1377). SEFI.

van Grunsven, Janna, Taylor Stone, and Lavinia Marin. "Fostering responsible anticipation in engineering ethics education: how a multi-disciplinary enrichment of the responsible innovation framework can help." European Journal of Engineering Education (2023): 1-16.

Weerts, Hilde Jacoba Petronella, and Mykola Pechenizkiy. "Teaching responsible machine learning to engineers." In Proceedings of the Second Teaching Machine Learning and Artificial Intelligence Workshop, pp. 40-45. PMLR, 2022.

Williams, Damien Patrick. "Fitting the description: historical and sociotechnical elements of facial recognition and anti-black surveillance." Journal of Responsible Innovation 7, no. sup1 (2020): 74-83.

Zandvoort, H. "Preparing engineers for social responsibility." European Journal of Engineering Education 33, no. 2 (2008): 133-140.

FIRST-YEAR ENGINEERING STUDENTS' MATHEMATICAL SKILLS AND PERCEPTIONS OF STUDYING MATHEMATICS

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Conference Key Areas*: Teaching foundational disciplines of Mathematics and Physics in engineering education; Diversity, equity and inclusion in our universities and in our teaching*
Keywords*: Mathematics education, mathematical competence, student attitudes*

ABSTRACT

The objective of this paper is to describe and analyse the backgrounds and attitudes of students participating in their first year of Bachelor's degree studies in engineering in the Finnish education system regarding the study of mathematics, as well as the students' basic mathematical skills in 2023. The data used in the study has been collected from two Finnish universities.

The data consists of Finnish and international students' answers to a mathematics basic skills test and their reactions to some statements about studying mathematics. International students' test scores were higher than Finnish students', especially in tasks related to differentiation and trigonometry. No significant difference was found between the answers of men and women.

Both Finnish and international students felt that mathematics will be important to them in their working life, but this feeling was much stronger among the international students. Women are more likely than men to agree on a statement of having worked hard in their previous studies to learn mathematics.

1 INTRODUCTION

1.1 Engineering students' mathematical skills

Students' mathematical skills and abilities have weakened in many European countries during the last couple of decades (European Commission 2024). The SEFI Mathematics Working Group has also noticed this trend in engineering education, which has led to them publishing a competence-based curriculum (SEFI Mathematics Working Group 2013). Understanding the level of students' mathematical knowledge and skills is essential for planning teaching methods and learning content. It cannot be assumed that students' skill level at the beginning of their studies remains independent of their starting year. Students are becoming a more heterogeneous group with different backgrounds, and there have also been changes in topics studied at previous education levels. In addition, the COVID-19 pandemic could have caused interruptions in mathematics studies.

One reason for the increase in heterogeneity is the internationalization of students, which leads to significant differences among students in the types of studies they have completed before university, particularly in natural sciences and mathematics. In Finland, the number of international students in engineering degree programmes has grown drastically. For example, at Lappeenranta-Lahti University of Technology LUT, there were only about 30 international students starting their studies in 2016, whereas in 2022 the corresponding number was more than 230 (Vipunen n.d.). Today, LUT University has a total of 7 international bachelor's programmes in technology.

Tampere University of Technology started analysing incoming engineering students' mathematical skills by the Mathematics Basic Skills Test (BST) in 2002 (Joutsenlahti, Ali-Löytty and Pohjolainen 2016). A modernized version of the test is still in use at Tampere University, the successor of Tampere University of Technology. All students on first year mathematics courses take BST at the beginning of their first semester. The test consists of 16 basic mathematical tasks that are considered essential to master at the start of the studies. Time limit for taking the test is 50 minutes. Students are instructed to take the test independently and not using a calculator, mathematical software, or other material. In recent years, students have taken BST in an unsupervised environment, so it cannot be verified if the students have followed this instruction.

BTS is implemented using STACK (System for Teaching and Assessment using a Computer Algebra Kernel) (Sangwin 2013) that provides automatic assessment of students' answers. If deficiencies are found in students' skills, they are guided to review material. The STACK version of BST was taken into use in 2018, but the mathematical tasks were quite similar already during the years 2002-2017. Results of BST have been analysed for the years 2006-2017 by Myllykoski et al. (2018), showing that students' results in BST deteriorated between 2013-2015. This was seen in, for example, weak skills in manipulating expressions and managing simple calculation rules. In 2006-2017, the weakest competence was found in test questions on trigonometry, differentiation, and logarithms.

1.2 Gender differences in mathematics

Finnish secondary schooling comes with several gender differences regarding mathematics. In grade nine, at the end of lower secondary school, girls' average performance in mathematics is better than boys', but girls are underrepresented among the top performers. Girls also have a lower mathematics self-efficacy and higher mathematics anxiety than boys. (Hiltunen at el. 2023.) At the end of the upper secondary school girls still have more negative feelings towards mathematics than boys at all performance levels. However, among the high achievers, girls seem to like mathematics more than boys. In this performance level there are also no gender differences in mathematics self-efficacy although in the lower performance levels it remains lower for girls than boys. (Metsämuuronen 2017.) In 2023 more girls took the upper secondary school matriculation exam in the advanced mathematics syllabus than boys, but boys performed better in the examination (Vipunen n.d.).

In upper secondary school, boys are more likely to choose advanced mathematics than basic mathematics, and vice versa for girls (Vipunen n.d.). There are no gender differences in the motives for choosing the advanced level mathematics, and the top motives for both girls and boys are the perceived usefulness of the curriculum, enjoyment and interest in mathematics, and self-efficacy, ability, and confidence in mathematics. However, the reasons for not choosing advanced level mathematics differ with girls justifying their decision with lack of enjoyment and interest, or self-efficacy, ability, and confidence statistically more often than boys. (Kaleva et al. 2019.).

According to Tossavainen et al. (2021), in the first year of engineering studies, women seem to have better performance in mathematics than men. No gender differences in mathematics self-efficacy were detected, but women appear to be more interested in mathematical thinking whereas men emphasise the utility value of mathematics more (Tossavainen et al. 2021). Yet, women show a stronger surface approach to learning mathematics than men (Rämö et al. 2023).

1.3 Research questions

The objective of this research was to better understand the mathematical starting level competence of the diverging engineering student body and explore the possible explanations behind the differences in skills. Studies on students' preliminary mathematical skills and perceptions on mathematics have been conducted earlier (e.g. Joutsenlahti, Ali-Löytty and Pohjolainen 2016, Charalambides et al. 2023, Francis and Jacobson 2022). Charalambides et al. (2023) studied students' prior beliefs and self-efficacy beliefs in relation to their initial mathematical skills, finding interrelations of the students' previous achievements and experiences with their beliefs and self-efficacy beliefs in mathematics. Francis and Jacobson (2022) observed that students' performance on a prerequisite test designed for Calculus I course was associated with their retention in the engineering programme. However, these studies did not specifically address genders or international and domestic degree programmes separately. Thus, the objective of this research was operationalised into the following two research questions:

RQ1: Are there differences in mathematics performance level or pre-university interests and attitudes towards mathematics between the i) women and men and ii) students in Finnish and international engineering degree programmes before the first engineering mathematics courses?

RQ2: Is the performance level or the differences in it connected to pre-university interests and attitudes towards mathematics?

2 METHODOLOGY

2.1 Participants

The participants of this study were first year engineering higher education students in two research-oriented universities in Finland, Tampere University (N=579) and Lappeenranta-Lahti University of Technology LUT (N=265). The total number of participants was N=844, of which 578 were men and 252 women. The average age was 21.63 (SD 2.63) years. 685 students studied in Finnish engineering programmes in one of the two participating universities, 159 in an international engineering programme, where the teaching language was English. The participants gave their consent to participate in this research and were informed that they could withdraw from the study at any point. Research permission was granted by both universities involved in this study. At LUT University, the data has been collected from students of the LUT School of Energy Systems faculty's departments of Energy Technology, Mechanical Engineering, Electrical Engineering and Sustainability Science. At Tampere University, the participating students came from all Bachelor of Science programmes in engineering. The data on international study programmes used in this article has been collected from three programmes of the LUT University: Energy Engineering, Electrical Engineering and Mechanical Engineering. These three Bachelor of Engineering degree programmes have been implemented in cooperation with Hebei University of Technology (HEBUT), China.

2.2 Procedure

In the beginning of their first mathematics course at the university level, the participants filled in a background questionnaire and completed the test in basic mathematics skills. Both the questionnaire and the test were online, and the students filled them outside of learning events. Their answers were collected, pseudonymized and combined for analysis. All statistical analyses were performed with Matlab. The original basic skills test had 16 tasks, but since there was a technical problem with one of the tasks in the online system, and one task had a translation difficulty, scores of 14 tasks were used in the analyses.

3 RESULTS

3.1 Basic mathematical skills

The basic mathematics skills test had 14 tasks, all worth one point. The students scored on average 10.42 points with standard deviation of 2.69 points. According to the two-sample t-test, $t(828)= .34$, $p= .73$, there was no significant difference in the basic skills test scores between men ($M=10.43$, $SD=2.71$) and women ($M=10.36$, $SD=2.69$). But, in the international programme the points ($M=11.54$, $SD=2.64$) were significantly higher than in the Finnish study programmes ($M=10.16$, $SD=2.64$), with $t(842)=5.92$ and $p< .001$. Histograms of the score distributions for the international study programme and the Finnish study programmes can be seen in Figure 1.

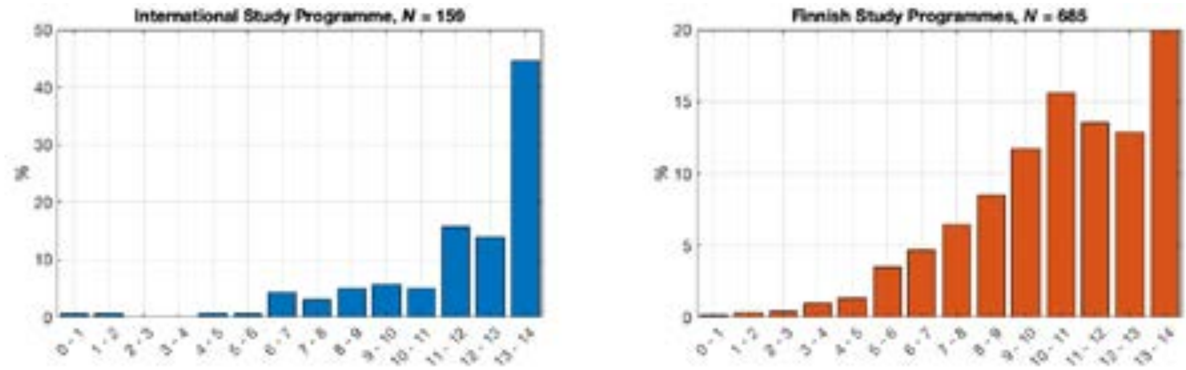

Fig. 1. Basic skills test score distributions for the international study programme (N=159) and the Finnish study programmes (N=685)

Figure 2 presents the differences for the international programme and the Finnish programmes in the means for each task with error bars. Positive difference means that the international programmes performed better. It can be observed that the biggest differences occur in tasks 10, 11 and 12. These tasks considered trigonometry (10 and 11) and the derivative of a fourth order polynomial (12).

Fig. 2. Differences between the means in BST tasks between the international study programme and the Finnish study programmes

3.2 The students' perceptions of mathematics studies

Students were asked to give their opinion on three statements about mathematics studies on a five-point Likert scale (1 = completely disagree, 5 = completely agree). The statements were

- L1. In my previous studies, mathematics was a pleasant subject for me.
- L2. In my previous studies I had to work hard to learn math.
- L3. I feel that mathematical skills will be important to me in the future in working life.

Students in general agreed with the first statement (M=4.04, SD=0.95), with no significant difference between men and women or between the international programme and the Finnish programmes, but for the second statement (M=3.60, SD=1.12) women reported having had to work harder (M=3.74, SD=1.08) than men (M=3.55, SD=1.12) by the two-sample t-test, t(828)=2.31, p=.02. No difference was observed between the international and the Finnish programmes. In L3, the students considered in general mathematics to be important for them in the future (M=4.23, SD=0.81), but by the two-sample t-test (t(842)=4.30, p<.001), the students in the international programme (M=4.41, SD=0.82) considered mathematics to be even more important than the students in the Finnish programmes (M=4.05, SD=0.83), with no difference between the genders.

We studied the correlation between the statements L1-L3 and the basic skills test result. Figure 3, produced with corrplot in Matlab, presents a grid of scatter plots between pairs of variables with a least-squares reference line with slope equal to a displayed correlation coefficient. Histograms of individual variables appear along the diagonal. The correlation coefficients are presented in red when p<.05.

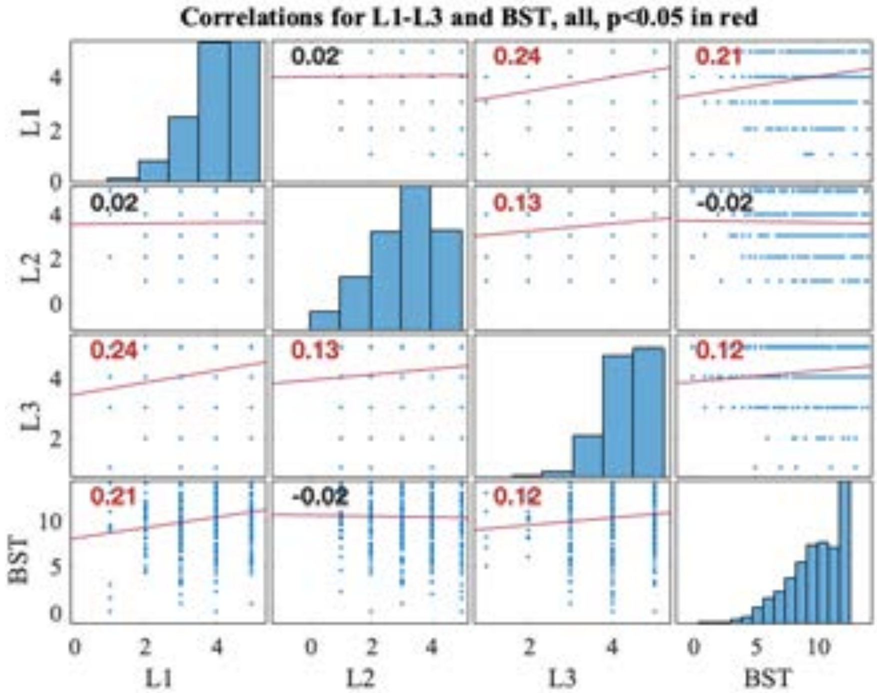

Fig. 3. Correlations between the statements L1-L3 and BST result

4 Discussion

In this study, more differences were observed between the students in the international study programme and the Finnish study programmes than between the genders. We observed that international students performed better on average in BST, and they valued mathematics utility higher. In many countries, students are accustomed to completing more homework and covering the entire textbook compared to Finnish students. Additionally, they might enrol in entry-test centres before securing a study place at Finnish universities. Due to certain scholarship requirements, international students might also be more motivated to study and get good grades. These aspects may explain their better performance in BST.

The biggest differences between the international programme students and Finnish programme students were found in two trigonometry tasks and a differentiation task. According to previous experiences, trigonometry is challenging for Finnish students (Myllykoski et al. 2018). Also, according to research, trigonometry is one area of mathematics that students find difficult and abstract compared to other mathematics subjects (Gur 2009). Previous research has also shown that first-year university students have challenges understanding angles in radians and using the unit circle

(Orhun 2010). The trigonometry tasks of BST are related to exactly these things. Perhaps the pre-university teaching approach (Ngu 2023) differs between the international programme students and Finnish programme students, which could explain the difference in trigonometry tasks.

BST did not show differences in mathematical skills between women and men. This was somewhat expected, because even though boys are overrepresented among the top performers in mathematics prior to university (Metsämuuronen 2017, Vipunen n.d.), the self-selection of girls to study engineering is much stronger than for boys, which is likely to make women a more homogeneous group in terms of mathematical abilities and even up the difference in performance level.

When it comes to pre-university experiences in mathematics, women reported having to study hard more often than men. By the end of upper secondary school, girls tend to harbour more negative feelings towards mathematics on all performance levels than the boys (Metsämuuronen 2017), and the experience of a heavy workload could contribute to more study stress associated with mathematics to women than men.

In general, the students' perceptions of having had to study hard in mathematics did not correlate with BST results. This might be due to students having varying interpretations of the respective statement. Some students find mathematics interesting and motivating, they aim high, and are prepared to work hard to learn. Some might struggle with mathematics and face difficulty in learning, and therefore feel that they have to work hard. Hence, in order to really understand the significance of working hard for mathematics performance, more detailed information is needed.

It should be noted that this study had certain limitations. One clear limitation of this study is the use of a non-supervised test, which may result in participants utilizing materials, calculators, software, or group work even though they were instructed not to do so. In the future, we aim to get back to pre-COVID-19 arrangements, where the test is taken under supervision. Additionally, two BST tasks had to be removed from analysis due to technical and/or language problems. Another limitation is the slightly different study programme profiles, as all Finnish programmes were grouped together, as well as all international programmes, potentially introducing variability in the results.

All in all, the student population has become significantly more international in recent years, and there are observable differences in skills and perspectives between students from different cultural backgrounds even more than between genders. Therefore, it is essential to know the students' skills in the beginning of engineering studies to be able to best facilitate learning. A test such as BST performed yearly can provide up-to-date information in the changing environment and thus assist teachers in planning learning materials and tutoring according to students' levels of knowledge in different areas of mathematics.

REFERENCES

Charalambides, M., Panaoura, R., Tsolaki, E., and S. Pericleous. "First Year Engineering Students' Difficulties with Math Courses - What Is the Starting Point for Academic Teachers?" *Education Sciences* 13, no. 8 (2023): 835. https://doi.org/10.3390/educsci13080835

European Commission. “Directorate-General for Education, Youth, Sport and Culture, The twin challenge of equity and excellence in basic skills in the EU – An EU comparative analysis of the PISA 2022 results” Publications Office of the European Union (2024), https://data.europa.eu/doi/10.2766/881521

Francis, C., and M. Jacobson. “Math Assessment as an Indicator of Program Retention”. Paper presented at *2022 ASEE Annual Conference & Exposition*, *Minneapolis, MN*. 10.18260/1-2--41495.

Gur, H. “Trigonometry Learning”. *New Horizons in Education 57 no.1* (2009): 67-80

Hiltunen, J., Ahonen, A., Hienonen, N., Kauppinen, H., Kotila, J., Lehtola, P., Leino, K., Lintuvuori, M., Nissinen, K., Puhakka, E., Sirén, M., Vainikainen, M-P., and J. Vettenranta. “PISA 2022 ensituloksia [PISA 2022 first results]”. *Publications of the Ministry of Education and Culture* (2023): 49.

Joutsenlahti, J., Ali-Löytty S., and S. Pohjolainen. “Developing Learning and Teaching in Engineering Mathematics with and without Technology”. *SEFI 2016 Annual Conference Proceedings*, European Society for Engineering Education SEFI, 2016.

Kaleva, S., Pursiainen, J., Hakola, M., Rusanen, J. and H. Muukkonen. “Students’ reasons for STEM choices and the relationship of mathematics choice to university admission”. *International Journal of STEM Education* 43, no. 6 (2019): 1-12. https://doi.org/10.1186/s40594-019-0196-x

Metsämuuronen, J. “Oppia ikä kaikki – Matemaattinen osaaminen toisen asteen koulutuksen lopussa 2015 [Mathematical competence at the end of secondary education 2015]”. Finnish Education Evaluation Centre (FINEEC), publications 1:(2017).

Myllykoski, T. J., Mattila, P., Ali-Löytty, S., Kaarakka, T., and E. Viro. “Yliopistomatematiikan sähköisten tehtävien ja matemaattisen ajattelun kehittäminen [Electronic problems in university mathematics and development of mathematical thinking]”. *FMSERA Journal* 2, no. 1 (2018): 46-55.

Ngu, B.H. and H.P. Phan. “Differential instructional effectiveness: overcoming the challenge of learning to solve trigonometry problems that involved algebraic transformation skills”. *European Journal of Psychology Education* 38 (2023): 1505–1525. https://doi.org/10.1007/s10212-022-00670-5

Orhun, N. “The gap between Real numbers and trigonometric relations”. *Quaderni di Ricerca in Didattica, no. 20,* (2010): 175-184.

Sangwin, C. *Computer Aided Assessment of Mathematics*. Oxford University Press, 2013. ISBN 978-0-19-966035-3.

SEFI Mathematics Working Group. “A Framework for Mathematics Curricula in Engineering Education”. SEFI, (2013). ISBN 9782873520076. Available at https://www.sefi.be/publication/a-framework-for-mathematics-curricula-in-engineering-education/

Tossavainen T., Rensaa, R.J., Haukkanen, P., Mattila, M. and M. Johansson. “First-year engineering students’ mathematics task performance and its relation to their motivational values and views about mathematics”. *European Journal of Engineering*

Education 46, no. 4 (2021): 604-617.
https://doi.org/10.1080/03043797.2020.1849032

Rämö, J., Nokelainen, P., Kangaslampi, R., Viro, E., Kaarakka, T., Nieminen, M., Hirvonen, J. and S. Ali-Löytty. “Engineering students’ approaches to learning in two student-centred instructional models before and during the COVID-19 pandemic”. *European Journal of Engineering Education* 48, no. 6 (2023): 1186-1212.
https://doi.org/10.1080/03043797.2023.2206794

Vipunen, Vipunen – Education statistics Finland, n.d. Available at
https://vipunen.fi/en-gb/. Visited March 14th 2024.

Students' Perspective on Innovation, Entrepreneurship and New Technologies for a Responsible STEM Education

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Keywords: *Curriculum, Innovation, Entrepreneurship, New technologies, Skills*

ABSTRACT

In order to achieve net-zero carbon emissions in the world by 2050, it is necessary to shape responsible and skilled individuals through Higher STEM Education. This paper focuses on assessing the perspective of STEM students regarding the incorporation of new curriculum activities and topics aligned with the evolving needs of today's society. Specifically, the study evaluates the inclusion of innovation, new technologies, and entrepreneurship in the curriculum, through a series of sessions, workshops, and discussions conducted in summer 2023. The paper highlights the significance of an innovative curriculum in STEM education and identifies the way essential skills and competencies of future engineers can be developed to face today's constantly changing world. This paper proposes applicable actions for institutions and associations involved in European Higher Education. By emphasising the importance of an adaptive curriculum, this research contributes to the ongoing dialogue on shaping STEM education to align with the demands of the

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future, therefore fostering the development of individuals equipped to address the challenges posed by the rapidly evolving global landscape.

1 INTRODUCTION

1.1 General overview

This paper represents the perspectives of STEM students regarding the inclusion of a new and innovative study curriculum in STEM education. It is essential that engineers understand the challenges of the future of this planet and society, and realise the impact their solutions have (Bronstein and Lampe 2023). The challenges that engineers are expected to tackle in the future (Zhang and Morris 2020), can only be solved if the skills and knowledge related to them are integrated into Higher Education Institutions (HEI) policies and strategies (Hobusch and Froehlich 2021). Several technological sectors are increasingly in need of graduates who are aware, creative, able to keep up with constant innovation, and who do not hesitate to delve into challenges. In order to bridge the gap between science and engineering education and the skills needed for industries and communities of the 21st century, there has been a growing need from industry bodies to educate STEM students not just in innovation and new technologies, but also in entrepreneurship (Amalua and Shorta 2023, Lynch and Kamovich 2021, Hermann and Bossle 2020). Interestingly enough, the current integration of entrepreneurship, innovation, and new technologies in formal engineering education appears to be far from accomplished, although various studies agree on the importance of doing so (Bronstein and Lampe 2023, Marjoram 2015, Kaminsky 2017, Höller and Vorbach 2017). Hence, through an exploratory project, this paper aims to address the following research question: How should STEM studies be shaped according to the STEM students in order to provide them with the necessary tools to act responsibly?

1.2 Objectives of the research

<u>Objective 1:</u> Identify which skills are perceived as more crucial in the educational path of STEM students, by delving into the students' and young graduates' experiences within their educational path.

<u>Objective 2:</u> Define which parts of the mentioned topics should be most integrated into the curriculum.

<u>Objective 3:</u> Determine the activities through which the following topics can be integrated into the curriculum and ways in which they can influence students to achieve the necessary skills for the future.

2 METHODOLOGY

Data from November 2022 to August 2023 were analysed in two phases: primary research at the BEST Symposium on Education (BSE) and a secondary literature review. The BSE gathered opinions on STEM education from students at 16 universities across 10 European countries, with a focus on entrepreneurship, innovation, and technologies for sustainable development. This was complemented by a survey of 226 students from 63 universities, which examined the inclusion of sustainability in current studies, critical skills for the future to address global challenges, and activities to develop those skills. The survey data helped understand the usefulness of certain activities, the timing of student experiences with them during their studies, and the overall student engagement, ascertained through multiple-choice questions in a matrix format. Secondary research involved reviewing existing literature on the inclusion of innovation, new technologies, and entrepreneurship in STEM education curricula, as well as analysing data obtained from the primary research. Analysis methods included statistical quantification, pattern identification, idea generation, theoretical testing, and comparative evaluation. The Net Usefulness Score (NUS) and time variance were calculated to assess the impact of activities and the timing of student engagement.

$$NUS = \frac{(Number\ of\ students\ grading\ the\ activity\ with\ 4\ or\ 5) - (Number\ of\ students\ grading\ the\ activity\ with\ 1, 2\ or\ 3)}{Total\ number\ of\ people}$$

For assessing time variance, a normalised formula was applied by assigning numerical values to for each phase point of the studies (0 for Early studies, 1 for Middle of studies and 2 for End of studies). The number of students for each period was multiplied with the given value, and the resulting products were summed. The final sum was then divided by the total number of students who participated in the activity, with the result expressed as a percentage.

3 RESULTS

3.1. Skills development towards responsible engineering

3.1.1. Results

This section outlines proposed curriculum changes to foster responsible engineering. Key recommendations include integrating state-of-the-art technology lessons and practical work, with over 50% of respondents favouring hands-on experience over theoretical learning. Industry-academia partnerships and entrepreneurship skills are also highlighted as vital for adapting to rapid technological advancements. Figure 1 illustrates the proposed activities and their sequential introduction, alongside their role in enhancing soft skills like problem-solving, creativity, and leadership, ultimately shaping responsible engineers. Entrepreneurship skills are considered irreplaceable in the curriculum of engineering students to allow engineers to adapt to increasingly fast-changing scenarios and technologies (European Commission, 2018).

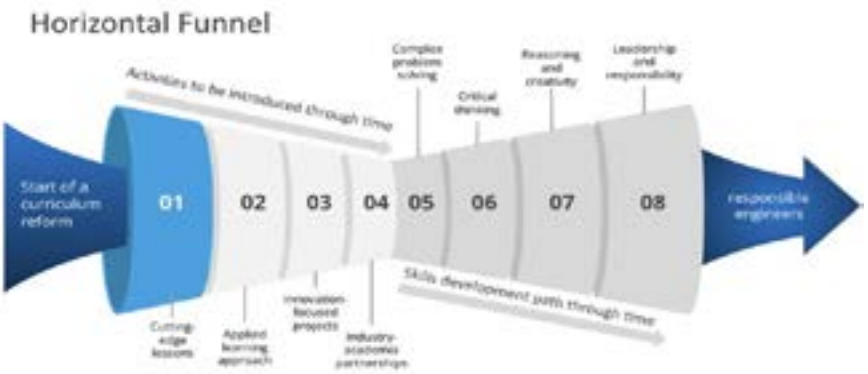

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Figure 1. Horizontal funnel showing activities to be introduced in the curriculum (on the left, the order of activities is narrowing down towards right proportionally to introduction timing) and their impact on soft skills for responsible engineers (on the right, the order of activities is expanding towards right proportionally to development timing).

Through these activities, students recognise that first they would have the opportunity to develop complex problem solving skills. All students agreed that experiential learning will help them perceive the larger picture of the current sustainability challenges that the world is facing today, which in turn will have a positive influence on their creativity and promote critical ways of reasoning. Leadership and responsibility would be developed over time, resulting in responsible engineers post graduation.

3.1.2. Recommendations

To prepare engineers for the future, educational institutions must update curricula to reflect industry needs and societal expectations. This involves enriching programs with case studies, entrepreneurship courses, internships, and projects focused on innovation. Strengthening ties with industry is crucial for exposing students to real-world challenges and integrating innovation, entrepreneurship, and emerging teaching methods through collaboration. Incorporating state-of-the-art technologies and addressing global challenges within the curriculum are essential steps in shaping responsible engineers equipped for the 21st century.

3.2 Learning activities for enhancing skills of responsible engineer

3.2.1. Results

Five student focus groups evaluated activities for fostering sustainable development and responsible engineering education. Figure 2 illustrates these activities and their preferred implementation scales: individual, class-specific, cross-functional, and cross-organisational. The consensus was that sustainability, innovation, and problem-solving courses are most beneficial, suitable for various implementation levels. Activities like podcasts and industry partnerships were favoured for enhancing practical skills and soft skills development. The significance of leadership, communication, and creativity in achieving an entrepreneurial mindset is supported by Škare and Tejero (2022). Workshops, lectures, and internships with diverse stakeholders were also recommended for practical learning experiences.

Figure 2. Heat map showing correlation between specific activities to be introduced in the curriculum and frequency how often they were mentioned among the focus groups, categories by the scale of the implementation (from I - Individual approach to IV - cross-organisational approach).

3.2.2. Recommendations

To advance engineering education, students recommend a curriculum that emphasises practical application through hands-on projects and entrepreneurial activities. Collaboration across different majors should be encouraged to foster a diverse skill set, while soft skills development must be integrated via workshops and conferences. Additionally, innovative assessment methods need to be adopted to accurately track students' progress and ensure they are equipped for the challenges of responsible engineering.

3.3 Learning activities aimed at enhancing creativity and innovation

3.3.1. Results

Survey results, as illustrated in Figure 3, analyse student perspectives on the relevance and timing of activities that promote creativity and innovation within the curriculum. The Net Usefulness Score (NUS) ranges from -100% to +100%, reflecting when activities are experienced during studies: early (-100%), middle (0%), or late (+100%). The bubble size indicates the number of students who participated in each activity. Most activities are encountered mid-studies, with "Community or volunteer hands-on projects" and "Competitions, hackathons, innovation and entrepreneurship programs/challenges" often introduced earlier. Projects with real-life applications received the highest NUS of 67%, experienced by over 50% of students, mainly towards the end of their education (time variance of 27%). Community projects, engaged in early by more than 60% of students, also scored a high NUS of 56%. In contrast, "Simulation and future building scenarios" and "Projects linked to the UN SDGs" are highly valued (NUS of 39% and 52%, respectively) but less accessible, with fewer than half of the students having the opportunity to engage with them, typically in the latter half of their studies. Notably, activities with negative NUS, specifically "Experience working with digital twins" and "Project experience in the metaverse," had the least engagement and were introduced late in the curriculum, indicating a need for earlier exposure to these emerging technologies.

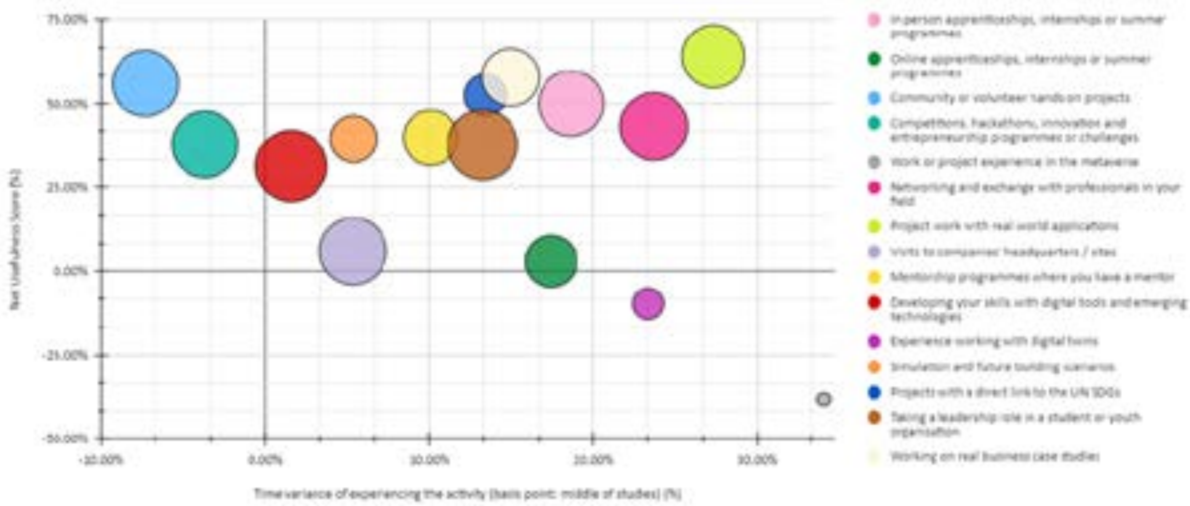

Figure 3. Bubble chart representing Student Activity Impact: Time variance vs. Net usefulness score vs. Student Engagement of specific activities

3.3.2. Recommendations

It is evident that the most useful and impactful opportunities for students are available to them only later in the studies. We suggest following the industry trends and making sure that the curriculum is up to date with all of the innovation and new skills that will be desirable for new engineers to have. Implementing “Simulation and future building scenarios” and “Projects with direct link to the UN SDGs” early in the engineering studies, would be the most impactful educational activity to be introduced in the curriculum of STEM students because they have a really high usefulness score compared to the number of students who had a chance to experience them (the smallest bubble). The second most impactful improvement would be reached by developing a system that allows any student to participate in those kinds of activities since not many students had a chance to experience them during their studies. Another important course of action is to implement additional courses on Project work with real world applications. In person apprenticeships, internships or summer programmes and Networking and exchange with professionals in your field both have a very high usefulness score, but face the barrier of having late time experience, thus earning a place in education only in very specific use cases and not as activities carried out across the board. We appeal to the inclusion of the mentioned activities earlier during stem studies.

4 EVOLUTION OF STUDENTS OPINIONS OVER THE YEARS

The paper submitted by BEST for the SEFI 2018 conference, titled "A Student's Perspective on Entrepreneurship and Innovation in European STEM Education," underscored the importance of entrepreneurial skills in engineering education. The paper analysed data from previous BEST Symposia on Education over the 13 years preceding the conference submission and related to four Events on Education (EoEs) (Porto 2017, Ankara 2015, Ljubljana 2010, and Zagreb 2009) organised by BEST, whose topics are directly or indirectly related to innovation and entrepreneurship. It advocated for competencies that enable students to be proactive and confident. The paper recommended practical, hands-on entrepreneurship education, facilitated through EoEs, to capture student opinions. It also highlighted students' desire for more practical projects and stronger university support for entrepreneurship, alongside a call for enhanced academia-industry collaboration to ensure curricula reflect real-world challenges.

In our current research paper, students advocate for a curriculum that embraces new technologies to keep pace with rapid technological advancements. The paper emphasises the importance of practical and experiential learning, urging educators to provide students with real-world examples and opportunities to tackle sustainability challenges directly. It stresses the need for skills like problem-solving, critical thinking, and active learning, while maintaining that entrepreneurship is essential for navigating fast-evolving scenarios. Additionally, it calls for the early introduction of topics such as sustainability, innovation, and problem-solving in educational programs to better prepare students for their future responsibilities. The evolution of student opinions from 2005 to the present shows a significant shift from a focus on entrepreneurship to a broader inclusion of innovation and new technologies, reflecting an expanded vision for STEM education. The latest paper emphasises the critical role of technology, advocating for its integration early in the curriculum to meet the changing demands of the job market and societal needs. While both papers underscore the importance of practical application, the current paper places substantial emphasis on sustainability, aligning with the global movement towards responsible engineering practices. In summary, over the years, students have maintained the importance of entrepreneurship but have expanded their focus to include innovation and new technologies. There is a clear trend towards integrating these topics earlier in the curriculum and aligning them with real-world challenges, particularly those related to sustainability. The evolution reflects a maturing perspective that recognises the multifaceted role of engineers in society.

5 SUMMARY AND ACKNOWLEDGEMENTS

To ensure constant adaptation and innovation in the curriculum of HEI in Europe, it is necessary to follow and understand the needs of today's students. This research pinpoints direction of those changes, placing the largest emphasis on the following:

1. Universities should focus more on practical and project work for students, throughout their whole studies;
2. Universities should strengthen the relationships with industry and other partners, in order to provide opportunities to students to learn on real-world problems;
3. Universities should expand existing curriculum with new teaching activities, such as soft skills training and workshops organised together with industry and other institutions. The topic of sustainability and entrepreneurship should also be included in formal course modules.
4. These activities have a high usefulness score but a small number of students had a chance to experience them during their studies. Therefore, HEI and other stakeholders (including industry) should focus on introducing them earlier in engineering curricula:
    - Simulation and future building scenarios;
    - Projects with direct links to UN SDGs;
    - Working on real business case studies.
5. Meanwhile we recommend to also keep the activities that already have a high usefulness score and a high participation such as:
    - Community and volunteer hands on projects
    - Project work with real world applications
    - In person apprenticeships, internships or summer programmes

To achieve future sustainability goals, we must educate engineers today. Effective education requires curriculum reforms, with investment from all stakeholders, to equip engineers with the necessary knowledge and skills to address forthcoming challenges. This paper invited professors and Universities to be the catalyst of this change.

REFERENCES

Bronstein A.A., S.Lampe, “Fostering future engineers as transformational agents: Integrating sustainability and entrepreneurship in engineering education”, *Procedia Computer Science*, 958, (2023), https://doi.org/10.1016/j.procs.2023.01.372

Zhang G., E. Morris, “Research Opportunities and Challenges in Engineering System Evolution”, *Journal of Mechanical Design*, Volume 142, Issue 8, (2020), https://doi.org/10.1115/1.4045908

Hobusch U., D.E. Froehlich, “Education for Sustainable Development: Impact and Blind Spots within Different Routes in Austrian Teacher Education”, (2021), https://doi.org/10.3390/su132111585

Amalua E.H., M. Shorta, “Critical skills needs and challenges for STEM/STEAM graduates increased employability and entrepreneurship in the solar energy sector”, *Renewable and sustainable energy reviews*, Volume 187, (2023): page 7, Fig. 10. and page 8 paragraph 1 and Fig. 11. https://doi.org/10.1016/j.rser.2023.113776

Lynch M. and U. Kamovich, “Combining technology and entrepreneurial education through design thinking: Students reflection on the learning process”, *Technological Forecasting and Social Change*, Volume 164, (2021), https://doi.org/10.1016/j.techfore.2019.06.015

Hermann R. R. and Bossle M. B., “Bringing an entrepreneurial focus to sustainability education: A teaching framework based on content analysis”, *Journal of cleaner production*, Volume 246, (2020), https://doi.org/10.1016/j.jclepro.2019.119038

Marjoram T., Transforming Engineering Education: For Technological Innovation and Social Development (2015). In: Christensen, S., Didier, C., Jamison, A., Meganck, M., Mitcham, C., Newberry, B. (eds) International Perspectives on Engineering Education, pp 321–341.Philosophy of Engineering and Technology, vol 20. Springer, Cham. https://doi.org/10.1007/978-3-319-16169-3_16

Kaminsky P., The future of engineering education, (2017), https://engineering.berkeley.edu/news/2017/11/the-future-of-engineering-education/

Höller H., Vorbach S., “Entrepreneurship in engineering education”, (2017), Paper presented at the *International Conference on Interactive Collaborative Learning, Belfast, United Kingdom, 21-23.09.2016.* https://doi.org/10.1007/978-3-319-50340-0_43

European Commission. Entrepreneurship and SMEs-Female Entrepreneurs. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. Accessed: Jul. 18, 2018. https://single-market-economy.ec.europa.eu/smes/supporting-entrepreneurship/women-entrepreneurs_en?prefLang=pt

M. Škare, C. Blanko-Gonzalez-Tejero, “Scientometric analysis on entrepreneurial skills: creativity, communication, leadership: How strong is the association?”, *Technological Forecasting and Social Change*, Volume 182, (2022), https://doi.org/10.1016/j.techfore.2022.121851

C. Bombaca, F. Draxler, “A students’ perspective on entrepreneurship and innovation in European STEM Education”, (2018), paper presented at *SEFI Annual conference, Copenhagen, Denmark, 17-21.09.2018.*

The Role of Reflection-Informed Learning and Instruction in an Introductory Physics Course for Engineering and Science Students

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ABSTRACT

This research explores the role of reflection-informed learning and instruction on students' learning in an introductory physics course. Participants of this quasi-experimental study were 199 engineering and science students (n=105 in the control group and n=94 in the intervention group). Students in the intervention group were instructed to reflect on their learning experiences after each lecture using the CourseMIRROR mobile application, while students in the control group did not. To answer our first research question (i.e., Did the students in the intervention group perform better than ones in the control condition?), we conducted Kruskal-Wallis tests, and results showed that the intervention group showed significantly better academic performance than the control group. To answer our second research question (i.e., Are the quantity and the quality of student reflection a significant predictor of academic performance?), multiple linear regressions were conducted, We found that the number of reflections was a significant factor in predicting a learner's academic performance, while specificity of reflections was not. Our study extends the existing literature on the impact of prompting student reflection in learning to a relatively underexplored context of large-size, lecture-oriented classrooms. Also, our study found that intervention in the form of encouraging students to reflect more often on their learning experiences can lead to improved academic performance. By evaluating reflection quantity and quality, our research contributes new insights into how these aspects influence academic performance. Lastly, our study adds to previous findings on utilizing mobile applications to support reflection activities in large classrooms by investigating their application in a traditional, lecture-based physics course.

1 INTRODUCTION

Reflection is a generic term for "human activities in which people recapture their experience, think about it, mull it over, and evaluate it" (Boud, Keogh, and Walker 1985, 19). Reflection can be classified into reflection-in-action and reflection-on-action (Schon 1983). Reflection-in-action is metacognitively reflecting on one's learning or behavior during learning, while reflection-on-action happens after learning or learning activities are completed (Schon 1983). In the context of undergraduate education, many science and engineering courses are taught in lecture-based format, especially in introductory courses where hundreds of students enroll (Owens et al. 2017). Reflection-in-action tends to be difficult to implement in this course as it may require significant changes in existing instructional methods. Reflection-on-action can be implemented individually outside the classroom after taking a lecture, so they seem easier to implement than reflection-in-action. Still, just with traditional instruction tools, promoting reflection-on-action in a large classroom can be challenging due to the logistics involved in collecting a large number of student reflections and assessing the relevance and quality of each reflection in a timely manner. By using digital technology accessible to individual students and instructors, such as a mobile application, individual reflection activities can be incorporated into a course more easily.

Reflection-informed learning and instruction (RILI) is a pedagogical model that encourages students to reflect on their learning in courses using technology and uses their reflection-on-action data to improve instructional strategies (Menekse 2020). The RILI model can be useful in undergraduate education from two perspectives: students and educators. Firstly, undergraduate students are given more autonomy in their learning, but such autonomy can lead to a lack of self-regulation of learning. Prompting students to reflect on their learning regularly can foster self-regulated learning (Zimmerman and Kitsantas 2005), thus preventing such situations. For example, students can review class materials that are particularly confusing or search for additional information regarding interesting concepts. Secondly, educators can leverage students' reflections as diagnostic tools to assess their understanding of new concepts and identify areas requiring further explanation (Menekse 2020). This facilitates the adaptation of instructional strategies and the modification of teaching materials to address students' needs or areas of interest. For example, after reviewing student reflection data, instructors may choose to post external online resources on a learning management system aimed at clarifying concepts that students found confusing. The advantages of the RILI model are particularly notable within the realm of engineering college education. This is attributed to the prevalent challenge faced in many college-level engineering courses, where instruction occurs within large class sizes, making it hard for instructors to monitor individual students' learning progress. Several previous works in engineering education employed the RILI model in various contexts. They investigated its impacts on problem-solving processes in a physics course (De Laet, Sijmkens, and De Cock 2021), improvement in the quality of reflection in an interdisciplinary engineering program (Wilhelm 2021), engineering teachers' instructional strategies (Eshuis, Mittendorff, and Daggenvoorde-Baarslag 2023), and academic performance in an industrial engineering course (Menekse 2020).

2 RELATED WORKS & RESEARCH QUESTIONS

The impact of reflection after learning on academic performance has been extensively studied, with research consistently highlighting its positive effects on students' academic performance. For example, a meta-analysis of 45 selected studies (Guo 2022) showed that the positive effect of metacognitive prompts on learning outcomes was consistent across undergraduate and K-12 students. Such studies were all experimental or quasi-experimental research but were limited to computer-based learning environments, excluding using digital tools in traditional classroom environments. Metacognitive prompts in this meta-analysis study include pre-learning (task perception, planning), during-learning (monitoring, control), and post-learning (evaluation, reflection). For example, Kauffman et al. (2008) showed that reflection prompts (i.e., questions designed to encourage students to reflect on how well they have solved problems and to evaluate and revise solutions when necessary) positively impacted problem-solving efficiency and writing quality. Another study by Wong et al. (2021) explored the impact of self-regulated learning (SRL) prompts, including reflection prompts, on students' engagement in SRL behavior and learning outcomes in Massive Open Online Courses. Results showed no significant impact on learning outcomes but a positive impact on SRL engagement.

Meanwhile, Menekse et al. (2022) compared the impact of generic and specific reflection prompts on engineering students' academic achievement in a course. Results showed that students who received the specific prompts performed significantly better on exams and projects than those who received the generic prompts. While numerous studies have explored the use of reflective prompts and digital tools in various educational settings, applying such methodologies to physics courses remains relatively novel. Regarding the impact of the number and quality of reflections, few studies have systematically tested these factors using robust models and indicators. Previous research (e.g., Menekse et al. (2022)) has examined the quality of reflections in general engineering contexts, but few studies applied multiple linear regression models to evaluate the predictive power of reflection quantity and quality, specifically in physics courses.

In higher education settings, technology-supported reflection on learning has gained significant attention as a means to enhance educational experiences. Various digital tools and platforms have been developed to facilitate reflection processes, enabling students to engage in metacognitive activities that deepen their understanding of course material and foster critical thinking skills. For instance, one design-based research by Leinonen et al. (2016) suggested two mobile apps for reflection (i.e., ReFlex and TeamUp). It showed their positive impacts on fostering K-12 students' classroom learning through reflective practices. They used the framework suggested by Fleck and Fitzpatrick (2010) to include various levels of reflection, from descriptive reflection (i.e., a mere description of events without further elaboration) to critical reflection (i.e., reflections with consideration of social/ethical issues). Another study by Knoth et al. (2020) explored how a mobile app named Reflect.UP promotes reflection at irregular intervals and its impact on students' learning experiences. This app was designed particularly to support student engagement during the introductory phase of a course by pushing reflective questions that refer to organizational knowledge (e.g., Where do I get a library card?), academic knowledge (e.g., How do I read a table?) and skills knowledge (e.g., Can I do what is required of me, and does what is required fulfill my expectations?). The empirical results showed what skills students wanted to improve eventually and how they were satisfied with the app usage. Still, the use of mobile applications to support reflection in traditional classroom environments, particularly in physics courses, is underexplored. Our study is among the first to investigate the impact of reflection prompts delivered via a mobile app in an introductory physics course.

This research aims to explore the role of reflection-informed learning and instruction in students' academic performance in an introductory physics course. We narrowly define student reflection as reflections on interesting and confusing concepts that students learned in each lecture. We set our first research question as follows: RQ1) Did the students in the intervention group perform better than ones in the control condition? The intervention for promoting reflection is using a mobile application that prompts students to leave reflections after each lecture. Also, to further explore why promoting reflection can be helpful for academic performance, we set our second research question as follows: RQ2) Are the quantity and the quality of student reflection a significant predictor of academic performance? The two research questions are answered by employing a quasi-experimental research method where we collected and analyzed student reflection data from an actual physics course.

3 METHOD

3.1 Participant

Participants of this study were 199 engineering and science students at a public university in the Northeastern region of the United States. They were enrolled in the introductory physics course for science and engineering. The Institutional Review Board (IRB) approved the recruitment of participants. Only students who consented to have their grade information were included in the data analysis. There were two sections of the same class. Students in one section were assigned as the control group (n = 105) as they were not asked to reflect on their learning. In contrast, the students in the other section were assigned as the intervention group (n = 94) as they were asked to reflect on their learning after each lecture during an academic semester. The same instructor taught both sections using the same learning materials and assessment items (e.g., homework, exams, etc.)

3.2 CourseMIRROR App

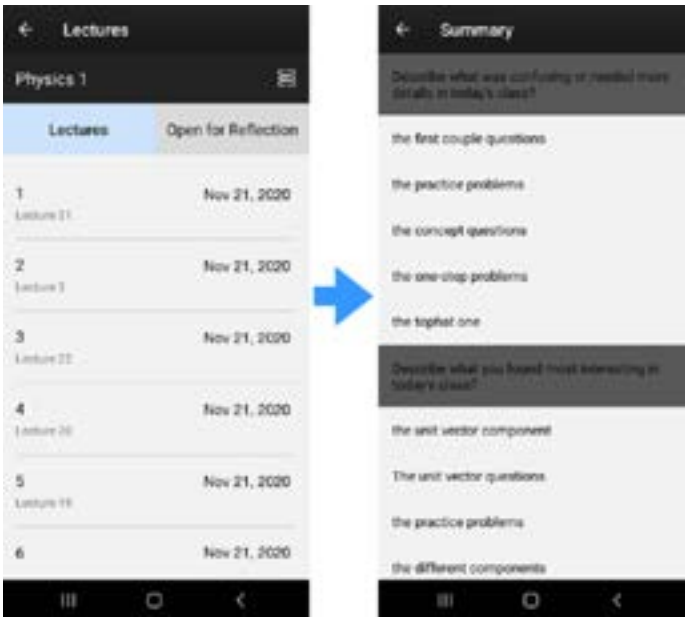

Figure 1. An example screenshot of the CourseMIRROR app.

CourseMIRROR (Mobile In-situ Reflections and Review with Optimized Rubrics) is a mobile application developed to prompt and collect students' self-reflection and in-situ feedback (Fan et al. 2015). This app collects data from student reflections to help instructors identify students' difficulties and provide additional feedback and support for student learning throughout the semester. Figure 1 shows an example of the app's user interface. On the left of this figure, students could choose one of the lectures of a course they are taking. After selecting one lecture, they were asked to answer two reflection questions, namely, 'Describe what was confusing or needed more details in today's class?' and 'Describe what you found most interesting in today's class?' Students were given a specified timeframe to submit their reflections on each lecture. Students and instructors could see the summarized list of responses for both questions, as seen on the right of Figure 1. Data collection through the app started after IRB approved the study. Students were encouraged to use the app, but it was not mandatory. Reflection data collected via this app was tracked only by the researchers, and we used anonymized IDs for each student who agreed to participate in the study. The instructor had access only to the summary of reflections that is automatically generated from the reflections.

3.3 Data Collection and Analysis

To answer RQ1, we compared the academic performances of the control and the experimental groups. The assumption tests (i.e., Shapiro test and Levene's test) revealed that both the normal distribution and the Homogeneity of variance assumptions were violated. Thus, we used the Kruskal-Wallis Rank-Sum test. The dependent variables were set as four measures of academic performance: the average of quiz scores, the average of homework scores, the average of exam scores, and the final score. The final score was calculated as a weighted average of the other variables based on the instructor's decision. The effect size and magnitude for each test were measured using eta-squared based on the H-statistic (Cohen 2013).To answer RQ2, we set predictors of academic performances as the number and the quality of student reflections. To calculate such predictors, we collected student reflection data from the CourseMIRROR server. The number of reflections for each student was calculated as the average of the total reflections written in the entire semester. The quality of the reflections was measured through two variables: the specificity score of reflections on interesting concepts and confusing concepts. The calculation of the specificity score was based on the coding schema developed by the authors' previous works (Butt 2023, Menekse 2020), where NLP (Natural Language Processing) algorithm was used to rate reflection specificity on a 4-point scale from 1 to 4. Scores 1, 2, 3, and 4 indicated shallow reflection without a statement of confusion or interest, vague reflection, general reflection, and specific reflection, respectively.

For both groups, only students who agreed to share their academic performance were included in the data analysis. The reflection data was collected from students in the intervention group who agreed to participate in this study. Nine students did not leave reflections, so we imputed their reflection count and specificity scores using a missing data imputation method called MICE (Multiple Imputation by Chained Equations) following the recommendation by Peugh and Craig (2004) and Cheema (2014).

4 RESULTS AND DISCUSSION

4.1 RQ1

Table 1. Kruskal-Wallis Rank-Sum test results to answer RQ1

DV	Condition	Mean	SD	χ^2	p-value	Effect size	Magnitude
Quizzes	Control	87.95	11.10	16.77	< 0.001***	0.08	Moderate
	Intervention	92.98	3.94				
Home-work	Control	92.81	13.36	6.45	< 0.05*	0.03	Small
	Intervention	95.22	10.63				
Exams	Control	62.67	20.69	57.89	< 0.001***	0.29	Large
	Intervention	83.11	8.79				
Final Score	Control	77.81	13.43	33.29	< 0.001***	0.16	Large
	Intervention	87.28	6.14				

**p*<0.05, ****p*<0.001

Table 1 shows the Kruskal-Wallis test results to compare the academic performances between the control group (n = 105) and the intervention group (n = 94). Reflections were collected from 27 lectures for the intervention group. The average set of reflections was 7.43 (SD = 5.80). As one set of reflections means two written reflections, one on confusing and the other one on interesting concepts, respectively, the average total number of reflections is 14.86 written by 94 students. The intervention group showed significantly better academic performance for all four dependent variables than the control group, with the significance level being 0.05.

These results align with the literature reviewed in Section 2 that proved the positive impacts of reflection intervention on academic achievement. Our results provide experimental evidence on the impacts of mobile-assisted learning, specifically within the relatively underexplored context of traditional STEM lecture-based courses, with even fewer focusing on physics education. Also, our results show that such impacts are effective not only in exam scores but also in ongoing academic performances, such as quiz and homework scores, despite the variation in the effect size.

In addition, the magnitude of effect size was large, particularly in exams, showing that reflecting on interesting and confusing concepts after each lecture positively impacted exam scores more than homework and quiz scores. Since homework and quizzes were conducted more frequently than mid-term and final exams, the positive impact of prompting student reflections might accumulate as students repetitively reflect, eventually becoming evident in exam scores. Future research may explore different measures of learning experiences other than academic performance.

4.2 RQ2

Table 2. Multiple linear regression results to answer RQ2

(a) Regression Statistics

$Multiple\ R^2$	0.06
$Adjusted\ R^2$	0.02
SE	6.07
F	1.75
$p\ value$	0.16

*(b) ANOVA statistics (*p<0.05)*

	df	SS	MS	F	$p\ value$
Number of reflections	1	180.6	180.65	4.91	0.03*
Specificity of reflections on interesting concepts	1	5.8	5.85	0.16	0.69
Specificity of reflections on confusing concepts	1	6.9	6.88	0.19	0.67
Residual	90	3314.6	36.83		

*(c) Coefficient of each predictor (*p<0.05, ***p<0.001)*

Predictors	Coefficient	SE	Standardized coefficient	SE	t	$p\ value$
Number of reflections	0.25	0.11	1.46	0.64	2.28	0.02*
Specificity of reflections on interesting concepts	-0.35	1.33	-0.17	0.66	-0.27	0.79
Specificity of reflections on confusing concepts	-0.45	1.04	-0.29	0.66	-0.43	0.67
(Intercept)	88.24	5.13	87.28	0.63	17.19	0.00***

Table 2 shows the result of multiple linear regression to explore which aspects of student reflections are significant predictors of academic performance. The estimated regression equation to predict one student's total score for the semester is as follows: (Total score) = 88.24 + 0.25 (Number of reflections) - 0.35 (Specificity of reflections on interesting concepts) - 0.45 (Specificity of reflections on confusing concepts). It turns out that the number of reflections was a meaningful variable to predict a learner's academic performance (F(1,180.6) = 4.91, p = 0.03*), despite the R^2 values being small. In contrast, the specificity of reflections was not. Such results were consistent for the other three dependent variables, i.e., quiz, homework, and exam scores.

Our analysis found that the more often students engaged in reflection after lectures, the more likely their academic performance would be high. This could indicate that even though students did not necessarily write high-quality reflections, the fact that they had time to reflect on their learning was sufficient for better academic performance. However, our result does not necessarily mean that the quality of reflections is less important than the number of reflections. Further research might investigate whether the specificity of reflections or another measure of the quality of reflections significantly impacts academic performances or may impact other parts of learning experiences.

5 SUMMARY

This quasi-experimental research explored the role of reflection-informed learning and instruction in students' academic performance in an introductory physics course. Regarding RQ1, results proved the positive impact of prompting reflections on all the measures of academic performance. Regarding RQ2, we conducted multiple linear regressions to examine whether the number and quality of student reflections are significant predictors of academic performance. It turns out that only the number of student reflections was a meaningful predictor. Despite our important findings, our study has a few limitations. First, as we decided to focus on academic performance only, we might have missed the positive impact of prompting student reflections on other aspects of learning experiences, such as motivation and engagement. Second, since we do not have any classroom observation data, there could be some factors that could have influenced students' reflection behaviors across two different sections. Third, as using the CourseMIRROR app was not mandatory, the average number of reflections was not high compared to the number of lectures.

Nevertheless, our study has a three-fold contribution to the engineering education community. First, our study extends the existing literature on the positive impact of prompting student reflection in learning to a relatively underexplored context of large-size, lecture-oriented classrooms commonly found in introductory engineering courses. Also, our study found that intervention in the form of encouraging students to reflect more often on their learning experiences can lead to improved academic performance. By evaluating both the quantity and quality of reflections, our research contributes new insights into how these aspects influence academic performance. Lastly, our study adds to previous findings on how a mobile application can be used to support reflection-on-action activities in a large-enrolment STEM course. While several studies explored the use of apps for reflection in various educational settings, we uniquely investigated their application within a traditional, lecture-based physics course.

REFERENCES

Allison, P. D. (2009). Missing data. *The SAGE handbook of quantitative methods in psychology*, 72-89.

Boud, David, Rosemary Keogh, and David Walker. 1985. “Reflection: Turning Learning into Experience.” *Kogan Page, London*.

Butt, A., S. Anwar, and M. Menekse. 2023. “How Do NLP-Supported Scaffolding Techniques Support Students’ Written Reflections?” In *INTED2023 Proceedings*, 7450–7450. IATED. https://doi.org/10.21125/inted.2023.2036.

Cheema, J. R. (2014). “A review of missing data handling methods in education research”. *Review of Educational Research 84*(4): 487-508. https://doi.org/10.3102/0034654314532697

Cohen, Jacob. 2013. *Statistical Power Analysis for the Behavioral Sciences*. Routledge. https://play.google.com/store/books/details?id=cIJH0lR33bgC.

De Laet, Tinne, Elien Sijmkens, and Mieke De Cock. 2021. “Triggering Reflection and Meta-Cognition in Physics Problem Solving.” In *Proceedings of the 49th Annual Conference of European Society for Engineering Education,* 180–88. Research Papers. https://lirias.kuleuven.be/retrieve/642420.

Eshuis, Elise, Kariene Mittendorff, and Heleen Daggenvoorde-Baarslag. 2023. “Professionalising Science And Engineering Teachers In Guiding And Assessing Reflection.” In *Proceedings of the 51st Annual Conference of European Society for Engineering Education*, 415–24. Research Papers. https://doi.org/10.21427/5EV2-MP91.

Fan, Xiangmin, Wencan Luo, Muhsin Menekse, Diane Litman, and Jingtao Wang. 2015. “CourseMIRROR: Enhancing Large Classroom Instructor-Student Interactions via Mobile Interfaces and Natural Language Processing.” In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 1473–78. CHI EA ’15. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/2702613.2732853.

Fleck, Rowanne, and Geraldine Fitzpatrick. 2010. “Reflecting on Reflection: Framing a Design Landscape.” In *Proceedings of the 22nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*, 216–23. OZCHI ’10. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/1952222.1952269.

Guo, Lin. 2022. “Using Metacognitive Prompts to Enhance Self-regulated Learning and Learning Outcomes: A Meta-analysis of Experimental Studies in Computer-based Learning Environments.” *Journal of Computer Assisted Learning* 38 (3): 811–32. https://doi.org/10.1111/jcal.12650.

Kauffman, Douglas F., Xun Ge, Kui Xie, and Ching-Huei Chen. 2008. “Prompting in Web-Based Environments: Supporting Self-Monitoring and Problem Solving

Skills in College Students." *Journal of Educational Computing Research* 38 (2): 115–37. https://doi.org/10.2190/EC.38.2.a.

Knoth, Alexander, Alexander Kiy, Ina Müller, and Mathias Klein. 2020. "Competences in Context: Students' Expectations and Reflections as Guided by the Mobile Application Reflect.UP." *Technology, Knowledge and Learning* 25 (4): 707–31. https://doi.org/10.1007/s10758-019-09407-8.

Leinonen, Teemu, Anna Keune, Marjaana Veermans, and Tarmo Toikkanen. 2016. "Mobile Apps for Reflection in Learning: A Design Research in K-12 Education." *British Journal of Educational Technology: Journal of the Council for Educational Technology* 47 (1): 184–202. https://doi.org/10.1111/bjet.12224.

Menekse, Muhsin. 2020. "The Reflection-Informed Learning and Instruction to Improve Students' Academic Success in Undergraduate Classrooms." *Journal of Experimental Education* 88 (2): 183–99. https://doi.org/10.1080/00220973.2019.1620159

Menekse, Muhsin, Saira Anwar, and Zeynep Gonca Akdemir. 2022. "How Do Different Reflection Prompts Affect Engineering Students' Academic Performance and Engagement?" *Journal of Experimental Education* 90 (2): 261–79. https://doi.org/10.1080/00220973.2020.1786346.

Owens, Melinda T., Shannon B. Seidel, Mike Wong, Travis E. Bejines, Susanne Lietz, Joseph R. Perez, Shangheng Sit, et al. 2017. "Classroom Sound Can Be Used to Classify Teaching Practices in College Science Courses." *Proceedings of the National Academy of Sciences of the United States of America* 114 (12): 3085–90. https://doi.org/10.1073/pnas.1618693114.

Schon, D. A. 1983. "The Reflective Practicioner: How Professionals Think in Action." academia.edu. 1983. https://www.academia.edu/download/55425701/The_Reflective_Practitioner__How_Professionals_Th.pdf.

Wilhelm, Pascal. 2021. "Fostering Quality of Reflection in First-Year Honours Students in a Bachelor Engineering Program Technology, Liberal Arts & Science (ATLAS)." *Journal of Higher Education Theory and Practice* 21 (16). https://articlearchives.co/index.php/JHETP/article/view/5184.

Wong, Jacqueline, Martine Baars, Björn B. de Koning, and Fred Paas. 2021. "Examining the Use of Prompts to Facilitate Self-Regulated Learning in Massive Open Online Courses." *Computers in Human Behavior* 115 (February): 106596. https://doi.org/10.1016/j.chb.2020.106596.

Zimmerman, Barry J., and Anastasia Kitsantas. 2005. "Homework Practices and Academic Achievement: The Mediating Role of Self-Efficacy and Perceived Responsibility Beliefs." *Contemporary Educational Psychology* 30 (4): 397–417. https://doi.org/10.1016/j.cedpsych.2005.05.003.

ENGAGING ENGINEERING STUDENTS IN STS TOPICS UTILIZING STUDENTS' PERCEIVED RELEVANCE

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ABSTRACT

Teaching Science-Technology-Society (STS) courses to engineering students can be challenging. Several studies have shown that engineering students fail to see the relevance of social and humanist science in engineering education, despite the importance of STS subjects in later professional life.

In this study, we have asked 1515 first-year engineering students about what non-scientific and non-technical topics they believe are important for engineers to be knowledgeable about. These data are analyzed, and the results are used to suggest a way of teaching these subjects in line with students' perceived relevance.

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1 INTRODUCTION

Current discussions in engineering education highlight the need for educating engineers who take a broad perspective on their role in society (CDIO 2020). This is not a completely new development: For example, the American Society for Engineering Education has promoted education in ethics, sustainable development, diversity, and inclusiveness in engineering education for over two decades (ASEE 1999). It can however be argued that the pace of technological change and increased awareness of the complexity of technological challenges have amplified this need.

Engaging engineering students in non-STEM (science, technology, engineering, and mathematics) topics can however be challenging (Bombaerts et al. 2018; Skinner, MacGill, and Outhred 2007; Thorvaldsen and Henne 2017; Fjelland 2022). Students (and faculty members) seem skeptical towards the relevance of ethics, philosophy, and politics in a technological context, topics which at least in Norway have been termed somewhat derogatory as ‘soft subjects’.

This paper seeks to answer the questions of what topics outside science and technology 1st year engineering students perceive as relevant for engineers, and how this motivation can be employed to create engineers prepared to engage in society.

2 THEORY

Gaining knowledge into the pre-existing motivations of engineering students toward non-technical topics, may help in constructing an engineering education that points towards expanding the scope and system perspective of engineering education, while also being perceived as relevant by the majority of students.

To understand engineering student’s motivation for subjects outside of STEM, we will employ the concepts of intrinsic and extrinsic motivation. These concepts make out the basis for self-determination theory (SDT) developed by Ryan and Deci (Ryan and Deci 2017).

The distinction between intrinsic and extrinsic motivation is important for understanding the basis of SDT. Externally motivated learning activities, perceived as controlled by others, are often driven by punishment or external rewards. Intrinsically motivated learning activities driven by the student's own will, are found to be interesting, enjoyable, and appealing. There is a positive relationship between intrinsic motivation and persistence, effort, and engagement. Hence, SDT predicts that students will engage in learning activities they consider meaningful for later endeavors and in line with their interests. Achievements and effort will increase as students move from extrinsic regulation to intrinsic motivation of the learning activity (Ryan and Connell 1989).

The courses and subjects that make out an engineering program are only occasionally a matter of students’ choice. Hence, it would not be appropriate to interpret intrinsic/extrinsic motivation exclusively as a question of student control or choice. For this paper, it is more fruitful to interpret intrinsic/extrinsic motivation as a matter of students’ perceptions of relevance. Courses, subjects, or activities that align well with students’ perceptions of relevance are interpreted as being associated with high intrinsic motivation, and vice versa with extrinsic motivation (Johansen, Eliassen, and Jeno 2023). As mentioned above, ethics, politics, and philosophy seem to induce skepticism among students and faculty, at least partly due to a perceived lack of relevance in its educational context (e.g.Fjelland 2022). In this perspective, how can we motivate engineering students to engage with these topics, when they often seem removed from the primary technical-scientific interests of the students? Different approaches have been made to introduce STS-topics into engineering, with various results (see e.g. Axelsson 2009).

3 METHOD

In this paper, 1515 1st year bachelor engineering students from NTNU in Norway have been asked the question "Apart from learning what you need from science and technology to go into working life - what do you think is the most important thing for an engineer to know something about?" The students were all orally informed about the purpose of the survey, and that their participation would be anonymous. No personal data were gathered from the respondents.

The survey was conducted on students from a full range of engineering study programs, the four largest being mechanical, computer, electrical, construction, and renewable energy during the years 2019-2022, with 333 respondents in 2019 and 469,384 and 329 in 2020-2022, respectively. The survey was conducted during the first few weeks of the first term, as part of a compulsory first-year course called "Introduction to the Engineering Profession". It was conducted in a mix of physical and online lectures in 2019, and online lectures in 2020-22. The data were collected through online student response systems, using the system One2act from 2019-2021 and Mentimeter in 2022, with students responding with open-ended text responses. The responses vary from a single word to a few short sentences, with the majority being short lists of 1-4 topics.

These results were then put through a thematic analysis (Braun and Clarke 2006). Given the relatively clear and brief responses, subsequent clearly defined themes, and a large number of total respondents, the frequency of the different themes was then compared, and this is used to attempt to identify what the best starting points may be in engaging engineering students in non-technical and non-scientific topics.

4 RESULTS

To structure the presentation, we group the themes into four groups. These groups disclose the direction of the different themes' focus.

Group 1 has a *world perspective* focusing on the external consequences of the use of technology, and consists of the following themes:

- *Society:* references to society, but also history, politics, and consequences for the world (from the use of technology). In general, it is STS-oriented.

- *Ethics:* References to ethics, morality, knowing right from wrong, etc. General comments on consequences where it is not specified consequences for what (society/nature) is also coded here.

- *Environment:* References to the environment, climate change, sustainability, etc.

Group 2: has an *interpersonal perspective* focused on human interaction consisting of the following themes:

- *Collaboration*: References to collaboration, cooperation, and teamwork, but also to having ‘people skills’.

- *Communications*: References to communication, writing, and language skills

Group 3 has a *workplace perspective* consisting of the following themes:

- *Work:* General references to work life, but also safety, ESE, and other rules and regulations

- *Practical*: References to practical skills, the necessity of engineers to know the practical work workers do, connecting practice to theory, but also problem-solving of different kinds

- *Economy/management*: References to economy, money, management, and leadership of different kinds, including project management.

Group 4 has an *individual perspective*, looking at individual epistemic/cognitive skills, and consists of the following themes:
- *Method:* References to methodology on a more principled level, but also skills that hint at method, like critical thinking, creativity, logic, and variants of learning to learn.

- *Personal:* Personal qualities that do not fit into the method theme like openness, future orientation, order, grit, and some social skills.

In Table 1, we have sorted the different themes and groups of themes, including the frequency of the different themes.

Table 1: Frequencies of groups, and N and frequencies for individual themes.

Group total frequency	Group 1, *world* Total f =.40			Group 2, *interpersonal* Total f =.33		Group 3, *workplace* Total f =.30			Group 4, *individual* Total f =.20	
Theme	Society	Ethics	Environment	Collaboration	Communication	Work	Practical	Economy/ Management	Method	Personal
N	332	320	101	432	128	150	205	138	151	171
Frequency	.22	.21	.067	.29	.084	.099	.14	.091	.10	.11

In addition to the themes in Table 1, 5.1% of students responded with a technical or scientific subject despite this falling outside the scope of the question, 4.1 % answered with some sort of joke, and 3.6 % with an answer that did not fit any of the mentioned themes, often on a very general level of “seeing the big picture” or “having good general knowledge”.

The groups and themes are, however, not without connections. Group 1's focus is on the world outside engineering, society, and nature, and has connections to Group 3 as the focus is the effect engineers have on the external world through their job. Group 2 has a focus on relations to other humans: colleagues, clients, etc. It also touches on Group 3 as most examples of interaction are in a work-life setting. Group 3 is however focused on the work-life in a less human- and society-oriented sense but touches on Group 2 on some issues on management, and Group 4 where some descriptions of problem-solving are akin to the method theme. Group 4 has an inward focus, on individual skills, but also touches on group 2 in some personal qualities that speak toward social interaction.

Table 2: Relative frequencies of the total amount of students that are in both groups (columns vs rows), e.g. 40% have responses in Group 1, 7,4% have responses in both Group 1 and 2. N in parenthesis.

	Group 1, *world*	Group 2, *interpersonal*	Group 3, *workplace*	Group 4, *individual*
Group 1, *world*	.40 (608)			
Group 2, *interpersonal*	.074 (113)	.33 (501)		
Group 3, *workplace*	.067 (101)	.076 (115)	.30 (451)	
Group 4, *individual*	.047 (71)	.059 (89)	.050 (76)	.20 (302)

This thematic connection is partially reflected in the statistical connections in Table 2, where we can see the frequencies of interconnection between two different groups in students' replies. However, we also see other connections, e.g., students who have a world perspective, a workplace perspective, and an individual perspective tend to have the interpersonal perspective as the most common other group, even though the world perspective is the most common overall. For the interpersonal group, the world and workplace perspectives are positioned similarly.

5 DISCUSSION

The students' preexisting views on necessary knowledge for an engineer have different focus areas or clusters of motivation. They focus on the consequences (of engineering) on the outside world (Group 1), interaction with other individuals or groups of individuals (Group 2), the work as an engineer (Group 3), and individual skills (Group 4).

What we have listed are topics that students see as important in their future role as engineers. Topics that are perceived as relevant will generate a more autonomous form of motivation (Johansen, Eliassen, and Jeno 2023). Hence if a topic is perceived as relevant it will be associated with a more intrinsic motivation (Ryan et al. 2021).

To engage as many students as possible in engineering education creating responsible engineers, we should create cases and present problems that dip into as many as possible of these perspectives.

For example, real-world problems (Group 1) that engineers need to handle through their job (Group 3), involve the need to collaborate and communicate with people of different backgrounds (Group 2) which requires a set of personal skills (Group 4).

It is not hard to see how current problems can fit into such a discourse.

Climate change is an obvious example. It is a real-world problem. There are an increasing number of engineering jobs connected to the issue e.g. in renewable energy, but also still many in fossil fuels. Few, if any, sectors engineers work in are uncoupled from climate issues. Solving the problem requires not only skills in engineering and the natural sciences, but also an understanding of i.e. political processes and global power relations, and thus intimate cooperation between people from different fields.

A world in which war and conflict disrupt traditional flows of energy distribution and transportation of goods creates complex challenges. Designing projects where resources, infrastructure, and logistics are considered vulnerable would motivate the necessity of non-technical considerations. It also necessitates collaboration between engineers in different fields of energy and logistics together with representatives from the social sciences. This connects the world, interpersonal, and work perspectives, with personal skills entering through the openness needed to engage with peers and ideas from multiple fields.

As these surveys were conducted during the students' first term, we can to some extent infer that the students' responses are based on pre-existing perceptions of what is considered relevant for an engineer. If we are to appeal to these motivations, it would be wise to engage with them from the start of the students' education and not postpone engaging with STS-oriented topics until later in the study programs.

Student responses categorized as "world perspective" make out the largest cluster. A system-thinking approach (Axelsson 2009) to non-technical issues would be a fruitful way of combining this with the "work" perspective in framing STS topics for engineering students.

As the collaborative theme is the most common individual theme, the need for collaborating with people with different professional backgrounds to solve complex problems could be a particularly fruitful starting point. To have a basic understanding of other professions and their relationship to engineering is paramount for such a collaboration, and a strong incentive to integrate societal knowledge in engineering. Based on the statistical connections between the groups, the interpersonal perspective (Group 2) also seems to be well-positioned to bring the other perspectives together. This is the perspective that correlates the strongest with all the other groups.

Our suggestion when teaching non-technical topics to engineering students is to frame these topics in exactly the kinds of discourses described above, making them relevant to engineering and in line with students' preexisting perceptions of relevance. This is also in line with ideas in modern engineering education, like the CDIO standard on Integrated Curriculum (CDIO 2020).

5.1 Limitations

This survey has been taken from engineering students at one university in one country on questions that are probably not culturally independent. Furthermore, in

2019, the data were collected both during physical lectures and online lectures, creating a less homogenous data collection that year. In addition, the survey was taken within a course where the students had just had ethics and were moving on to the history of technology. Although no data collection is context-independent, the students' recent connection to some topics may thus skew the results compared to other contexts.

6 CONCLUSION

Despite suggestions from previous research, that bachelor engineering students have limited motivation to learn non-technical/non-scientific topics, we find several clusters of self-reported perceptions of relevance, which again might motivate learning these topics.

These motivations are however mainly dependent on the students' perceived use of these skills, knowledge, and competencies in their future role as engineers. We therefore suggest building educational tools for STS- and similar topics around these existing clusters of motivation. Notably, connecting a combined interpersonal, world- and work-perspective in STS learning contexts.

REFERENCES

ASEE. 1999. "Statements." American Society for Engineering Education. https://www.asee.org/about-us/who-we-are/leadership/our-board-of-directors/statements.

Axelsson, Ann-Sofie. 2009. "Bildning i den tekniska högskolan." In *På spaning efter teknisk bildning*, edited by Karin Wagner Åke Ingermann, Ann-Sofie Axelsson, 222-241. Stockholm: Liber.

Bombaerts, G. J. T., K. I. Doulougeri, A. Spahn, N. M. Nieveen, and B. E. U. Pepin. 2018. "The course structure dilemma: Striving for Engineering students' motivation and deep learning in an ethics and history course." In *Proceedings of the 46th SEFI Annual Conference 2018 - Creativity, Innovation and Entrepreneurship for Engineering Education Excellence*, edited by Robin Clark, Peter Munkebo Hussmann, Hannu-Matti Järvinen, Mike Murphy and Martin Etchells Vigild, 9. Brussels: European Society for Engineering Education (SEFI).

Braun, Virginia, and Victoria Clarke. 2006. "Using thematic analysis in psychology." *Qualitative Research in Psychology* 3 (2): 77-101. https://doi.org/10.1191/1478088706qp063oa. https://www.tandfonline.com/doi/abs/10.1191/1478088706qp063oa.

CDIO. 10.06.2020 2020. *CDIO Standards 3.0.* Gothenburg: CDIO.

Fjelland, Ragnar. 2022. "Teaching Philosophy of Science to Science Students: An Alternative Approach." *Studies in Philosophy and Education* 41 (2): 243-258. https://doi.org/10.1007/s11217-021-09802-8. https://doi.org/10.1007/s11217-021-09802-8.

Johansen, Marius Ole, Sigrunn Eliassen, and Lucas Matias Jeno. 2023. "“Why is this relevant for me?”: increasing content relevance enhances student motivation and vitality." *Frontiers in Psychology* 14. https://doi.org/10.3389/fpsyg.2023.1184804. https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2023.1184804.

Ryan, Richard M, and James P Connell. 1989. "Perceived locus of causality and internalization: Examining reasons for acting in two domains." *Journal of Personality and Social Psychology* 57 (5): 749-761. https://doi.org/10.1037/0022-3514.57.5.749.

Ryan, Richard M, and Edward L Deci. 2017. *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford publications.

Ryan, Richard M, Edward L Deci, Maarten Vansteenkiste, and Bart Soenens. 2021. "Building a science of motivated persons: Self-determination theory's empirical approach to human experience and the regulation of behavior." *Motivation Science* 7 (2): 97-110. https://doi.org/10.1037/mot0000194.

Skinner, Iain, Iain MacGill, and Hugh Outhred. 2007. "Some lessons from a decade of teaching ethics to undergraduate engineering students." *Australian Journal of Professional and Applied Ethics* 9 (2): 133-144.

Thorvaldsen, Per, and Ingvar Henne. 2017. "Irrelevant! Møte mellom to kulturer." MNT-konferansen 2017, Oslo.

MAKING CONFIDENT DESIGNERS: EFFECT OF A DESIGN AND PROTOTYPING COURSE AND GENDER DIFFERENCES IN STUDENTS' ENGINEERING DESIGN SELF-EFFICACY

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ABSTRACT

Prototypes serve multiple purposes in design such as communication, learning and decision-making. In fact, designers often perform multiple cycles of prototyping, testing and design refinement. Yet, design and prototyping processes are often taught in separate courses in the engineering curriculum, as a result of which students may not learn how to leverage the power of prototypes in thinking, learning and refining the design. This may limit their experience of design and negatively impact their self-efficacy for design. In this paper, we report on a field quasi-

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experiment comparing an integrated design and prototyping course with a separate design and prototyping course sequence in terms of students' engineering design and innovation self-efficacy at the end of the course/sequence, and gender differences in self-efficacy. We found that participants in the integrated course showed higher self-efficacy for design, and also that there were differences in self-efficacy between the genders with males reporting higher self-efficacy than females. We conclude by discussing implications of these findings for the engineering curriculum and the way design is taught.

1 INTRODUCTION AND RELATED WORK

Recognizing that engineering students are creators of the future world, engineering accreditation bodies include the ability *to design, implement and test innovative solutions* in the core outcomes required from engineering education (ABET 2023; CTI 2023). Responding to this call, engineering design has become an important focus area for engineering education practitioners and researchers (Froyd et al, 2012; Dym et al, 2005). Prototyping plays a vital role in design, because creating and interacting with prototypes supports thinking, learning and communicating during design (Bohmer et al, 2017; Lauff, 2018; Camburn et al, 2017; Aurigemma et al, 2013). Having prototyping skills allows students to transform their ideas into tangible artefacts that they can use to test, refine and iterate the features, and explore the design space (Newman et al, 2015; Yu et al, 2018). Traditionally, engineering curricula focused on manufacturing practices for prototyping, but the rise of accessible prototyping tools like 3D printers has shifted the emphasis towards rapid prototyping from an early stage (Blikstein, 2013). Design thinking, on the other hand, is a general approach which makes humans a focal point of design, ie, understanding the problem and the people that one is designing solutions for (Dam and Siang, 2021), and identifying users' needs. This methodology encourages designers to think critically, creatively, and deeply, and has therefore become of interest in engineering education (Coleman et al, 2019; Spee and Basaiawmoit, 2016; Acebo et al, 2018), and incorporated into engineering design education to make engineers more innovative (for instance, Zancul et al, 2017; Parmar, 2014). Design thinking also includes a phase of prototyping, as making and testing prototypes helps spark ideas and build a better understanding of the user and problem (Dam and Siang, 2021).

In our institution, the shifting landscape of engineering education led to a rethink of the approach to design and prototyping education. First, the emphasis on manufacturing practices was decreased and that on rapid prototyping was increased, giving students the skill to make things right from their first year. Secondly, a design thinking course was added to help develop students' skill in human-centered design and innovation. However, having students learn prototyping in isolation can result in tinkering, which can be unproductive for developing robust design solutions (Quan & Gupta, 2020). On the other hand, having students make 3d printed prototypes supports their learning of design thinking (Pearson & Dube, 2022). To address this challenge, we revamped our curriculum to integrate design thinking and prototyping skills into a single course. This integrated project-based course required students to work in teams on real-world problems, applying a systematic approach combining design thinking with prototyping skills. In this paper, we report on a field study comparing this integrated course with the previous sequence of separate courses in terms of students' self-efficacy for engineering design and innovation at the end of the course. We also if there are gender differences in self-efficacy after participation in each of the courses.

2 THEORETICAL FRAMEWORK

Self-efficacy is the "belief in one's own competences to perform an intended behavior in spite of barriers" (Lippke, 2020), and is a key construct that affects motivation and behaviour in engineering education, influencing the course of action students pursue, their effort, persistence and resilience, thought patterns, emotional reactions to situations and accomplishments (Ponton et al, 2001). In this work, we adopt Albert Bandura's theory of self-efficacy (Bandura, 1977) according to which self-efficacy is influenced by four primary sources: mastery experiences, vicarious experiences, social persuasion, and physiological and affective states. Scholars argue that it is important to create mastery experiences for engineering skills in the curriculum, as that will enhance students' self-efficacy for these skills (Ponton et al, 2001). By regularly and repeatedly engaging in design thinking and prototyping activities through courses, students practice these skills, confront challenges, and ultimately experience success, and this mastery could be a source of self-efficacy. Through working in teams and exposure to role models (teaching assistants and instructors), participants may enhance their self-efficacy through vicarious experiences. Social persuasion, in the form of constructive feedback, encouragement, and recognition from the teaching team and peers, may also affect self-efficacy beliefs. Together the emphasis on mastery experiences, vicarious experiences and social persuasion may contribute to students' self-efficacy in engineering design and innovation. In addition, we conjecture that the integrated experience of design and prototyping will provide more mastery experiences, along with the emotional arousal stemming from the failure-first, iterative design and prototyping process, together leading to a greater improvement in students self-efficacy than in the sequence of separate courses.

Literature documents the differences between males and females in their self-efficacy for engineering knowledge and skills (Milto et al, 2002; Litzler, 2014; Chachra & Kilgore, 2009; Whitcomb et al, 2020). Research further reports that while females sometimes make positive progress on self-efficacy during their engineering studies (Marra et al, 2009), they can sometimes also exhibit a decline in their confidence relative to males (Felder et al, 1995), suggesting that curricular experiences can impact the self-efficacy of males and females differentially. Therefore, we also investigate if the two courses have a differential impact on males and females.

3 BACKGROUND AND CONTEXT

The study was conducted in the Spring 2023 semester in the Indian Institute of Technology Gandhinagar where students are admitted based on their ranks on a national engineering entrance examination. All students across engineering disciplines take common courses during the first two years. In the first year, students used to take a course on prototyping trades, whose goal was to make students proficient enough in a range of traditional and newer prototyping trades to make artefacts in their course projects later in the curriculum, and second year students took a course on design thinking. During the COVID-19 period of online learning, students could not take the prototyping trades course in their first year because it is an entirely practical course, and so the course was split in two to manage the course load and offered during their second year across two semesters, Fall 2022 and Spring 2023. They formulated a project the first semester, in which they had to add value to an existing product and prototyped it in the second semester. In the Winter 2022 semester between these two semesters, students took the design thinking course to balance their load, in which they learned the design thinking process, making and testing low-fidelity prototypes. Thus, even though they learned design thinking and prototyping trades, these students experienced design and prototyping as distinct thinking and doing processes across one year (course DIS, Figure 1). With the importance of design thinking for innovation growing and change in industry prototyping practices, course planners decided to lower the emphasis on prototyping trades, and add practice in iterative design thinking and prototyping to develop innovative products.

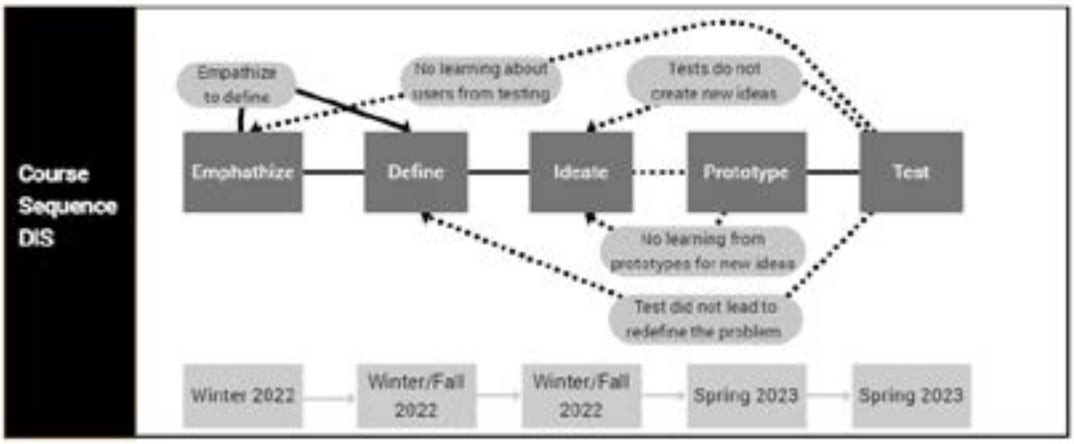

Fig. 1. Course structures of course sequence DIS

This revised emphasis manifested in a new design and prototyping course in Spring 2023 (course INT, Figure 2) for first-year students, wherein students apply the iterative design thinking process shown in Figure 2 to develop a product that solves a problem of their choice. The course includes lectures and activities on design thinking, and simultaneous practical training on a reduced set of prototyping trades. The students work on the project in teams from the start, gradually building up to prototyping, testing and revising once they acquire prototyping skills. They learn how to identify problems from the perspective of multiple stakeholders, and think creatively about the purpose of a product, materials and creating value, signalling a cultural shift towards design thinking, innovation and rapid prototyping practices. Design thinking was taught by the same instructor in both DIS and INT courses, while the prototyping trades were taught by different instructors. The revision, planning and implementation of both courses was done by prototyping instructor for the INT course.

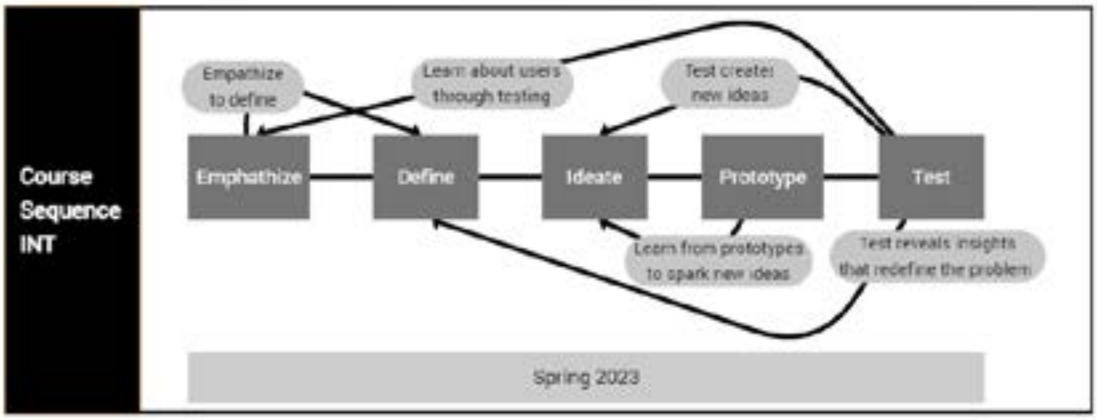

Fig. 2. Course structure of course INT

4 METHODOLOGY

4.1 Research Questions

We hypothesize that students who go through course INT will have higher engineering

design and innovation self-efficacy at the end of the course than students who go through the course sequence DIS. We also hypothesized that males would report higher self-efficacy levels than females in both groups. Our research questions are:

Primary RQ: Are there any differences in the engineering design and innovation self-efficacy between students who experienced the course sequence DIS and those who experienced the course INT?

Secondary RQ: Are there any gender differences in the self-efficacy after experiencing each of the courses?

4.2 Instruments used

We used reliable and validated surveys for assessing self-efficacy in engineering design and innovation, employing the Engineering Design Self-Efficacy Scale (EDSE) (Carberry et al, 2010) to measure engineering design self-efficacy and the innovation self-efficacy items from the Engineering Majors Survey (EMS) (Grau et al, 2016). The EDSE includes items to measure confidence, motivation, success expectancy and anxiety related to the engineering design and prototyping process. The EMS has items to measure confidence and interest in innovative thinking behaviors such as asking questions and generating ideas. In addition, our survey also had questions pertaining to participant demographics and the extent of their prototyping practices.

4.3 Research Design, Participants and Data Collection

We conducted a two-group field quasi-experiment, comparing the self-efficacy of two groups of students after they experienced either course sequence DIS (1 year) or course INT (1 semester). Since this is a field study, we could not randomize participant assignment to each group, nor ensure group equivalence. However, we argue that given that this was the first experience of design thinking and prototyping for both groups of students, and they were both drawn from the same larger population using the same common entrance test, the two groups were equivalent in terms of their engineering design and innovation self-efficacy at the start of the study. We measured their self-efficacy post course sequence DIS and course INT as the scores on the relevant items of the EDSE and EMS scales. We obtained ethical approval for our study from our Institute Ethics Committee and invited all students from both courses to participate. However only 125 students from the DIS course and 69 from the INT course and accepted our invitation, provided informed consent, and completed the self-efficacy survey administered using an online form.

4.4 Analysis Methods

To answer the primary RQ, we examined statistical differences in the self-efficacy scores between the groups using the Mann-Whitney U test. This non-parametric test was chosen because the data was not normally distributed. To answer the secondary RQ and examine statistical differences in the self-efficacy scores between the genders and groups we used the Kruskal-Wallis H test, followed by pairwise comparisons using the Dunn test and the Bonferroni correction.

5 RESULTS

To answer the primary RQ, the statistical analyses (Table 1) showed that participants in the INT group reported statistically significantly higher levels of confidence, motivation and success expectancy for engineering design ($p<0.05$). Interestingly, both groups reported similar levels of anxiety associated with engineering design. For innovation self-efficacy, again participants from the INT group reported statistically significantly higher levels of confidence for and interest in innovation ($p < 0.05$).

Table 1.Differences in self-efficacy between the INT and DIS Interventions

Indicator	Group DIS Mean (SD) (N = 125)	Group INT Mean (SD) (N = 69)	Mann-Whitney (Z)	Mann-Whitney (p)
EDSE Confidence	66.45 (20.8)	**71.79 (20.7)**	-2.342	**0.019**
EDSE Motivation	55.91 (27.9)	**74.52 (22.3)**	-4.727	**0.000**
EDSE Success Expectancy	60.60 (22.9)	**71.14 (20.1)**	-3.494	**0.000**
EDSE Anxiety	**53.40 (26.2)**	46.28 (29.3)	-1.856	0.064
EMS Innovation Confidence	3.24 (0.84)	**3.61 (0.81)**	-2.772	**0.006**
EMS Innovation Interest	3.41 (0.85)	**3.76 (0.85)**	-2.909	**0.004**

Table 2.Differences in self-efficacy between interventions and genders

Indicator	Group DIS Mean (SD) Male (N = 90)	Group DIS Mean (SD) Female (N = 35)	Group INT Mean (SD) Male (N =55)	Group INT Mean (SD) Female (N = 14)	Kruskal-Wallis (H)	Kruskal-Wallis (p)
EDSE Confidence	67.53 (25.9)	63.68 (21.2)	**74.26 (18.6)**	62.06 (26.1)	9.510	**0.023**
EDSE Motivation	55.28 (29.8)	57.52 (25)	**75.15 (20.2)**	72.06 (29.9)	22.383	**0.000**
EDSE Success Expectancy	61.23 (26.3)	58.98 (22.3)	**72.36 (18.4)**	66.35 (26.1)	13.219	**0.004**
EDSE Anxiety	**53.48 (18.4)**	53.21 (26.8)	51.07 (29.6)	27.46 (19.7)	11.689	**0.009**
EMS Innovation Confidence	3.31(1.1)	3.08 (0.99)	**3.62 (0.78)**	3.57 (0.95)	8.940	**0.030**
EMS Innovation Interest	3.42(1)	3.40 (0.79)	3.75 (0.89)	**3.80 (0.69)**	8.496	**0.037**

To answer the secondary RQ (Table 2), we found that male students, in general, rated their confidence higher than female students, and there is a statistically significant difference in confidence levels between interventions and genders. Pairwise comparisons suggest that the differences between the confidence of male students in the INT group is significantly higher than the confidence of female students in the DIS group. Next, male students in the INT group rated their motivation higher than female students, but the levels were almost similar for students from the DIS group and pairwise comparisons revealed that males from the INT group rated their confidence significantly higher than both males and females from the DIS group. Male students in both groups rated their success expectancy higher than female students and pairwise comparisons again show that males from the INT group rated their confidence higher than both males and females from the DIS group. Male and female students in the DIS group had similar anxiety levels, however interestingly, female students in the INT group reported lower anxiety compared to male students, with pairwise comparison tests suggesting that the reported anxiety of females in the INT group was significantly lower than the males in the INT group, and both males and females in the DIS group. In terms of innovation self-efficacy, while both male and female students in the INT groups reported similar levels of innovation self-efficacy, male students in the DIS group reported higher self-efficacy than females. Pairwise comparisons showed that males in the INT group reported significantly higher confidence than females in the DIS group. Regarding interest in innovation, males and females in both groups reported similar levels of interest and follow-up pairwise comparisons showed that there were no significant differences between any of the groups and genders.

6. DISCUSSION

Rapid prototyping tools have accelerated the iterations between ideation and implementation in design. The prototype is tested to refine the features and explore the design space (Yu et al, 2018) and this iterative process offers multiple opportunities to experience success through a gradually deepening engagement with the prototypes (Aurigemma et al, 2013; Newman et al, 2015). We conjectured that these successes offered by the INT course would serve as mastery experiences leading to higher self-efficacy at the end of the course, compared to students who go through the DIS course sequence, and in this work, we report on a field experiment studying this conjecture. We found that students who went through the INT course reported higher levels of confidence, motivation and success expectancy for engineering design, while reporting marginally lower levels of engineering design anxiety than participants who went through the DIS sequence. They also reported higher levels of confidence for and interest in innovation. These results suggest that though students practice the same set of skills, the experience of going through the design thinking and prototyping in an iterative manner in course INT better supported the development of self-efficacy than the DIS sequence. We argue that breaking the loop between prototyping and testing, and empathizing, defining and ideating (Figure 1) led to a situation where students were unable to use concepts of design thinking that they had learned in the previous semester, during prototyping, resulting in lower success and fewer mastery experiences. These findings agree with literature about the positive effects of rapid prototyping on students' design performance (for instance, Greenhalgh, 2016; Lantada et al, 2007) and relate to findings about students' perceptions regarding the usefulness of prototyping for design (Carfagni et al, 2020; Bohmer et al 2017; Fernandez & Jacobson, 2022). These results also agree with findings regarding the effect of design experiences on students' engineering design self-efficacy (Hulls & Rennick, 2020; Michael et al, 2012). Given that students had to develop a solution to a problem they identified, course INT is similar to students working in a makerspace, and so these findings also resonate with findings related to increases in self-efficacy with increased participation in makerspaces (Hilton et al, 2020; Morocz et al 2016; Andrews et al 2021; Carbonnell, 2019).

While it is interesting that the levels of anxiety were not significantly different between the two groups, participants from both groups in our study reported higher levels of anxiety compared to literature (Carberry et al, 2010). This suggests that, while there is an inverse correlation between confidence and anxiety, the strength of the relationship is different for our participants than previously researched populations. This phenomenon requires further exploration. We also found differences in self-efficacy based on gender, with males reporting higher levels of confidence, motivation and success expectancy than females, a finding which agrees with previous research (Milto et al, 2002; Litzler, 2014; Chachra & Kilgore, 2009; Whitcomb et al, 2020). However, given the small number of female participants in the INT group and high variance, we could not make conclusions regarding the statistical significance of these differences. Interestingly, females in the INT group reported statistically significantly lower levels of anxiety than all other groups, and in future work, we propose to explain this finding through qualitative data.

Through this work we contribute to engineering education the structure of a course which can enhance the engineering design and innovation self-efficacy of engineering undergraduates. We recommend that such a course be conducted in a project-based learning (de Los Rios et al, 2010) mode, where students start working on identifying problems and designing solutions right from the start of the course. Students are supported through lectures and activities about design thinking, and practical training in prototyping trades such as 3d printing, laser cutting, PCB milling, use of power tools, and joining and finishing. The goal is for them to be proficient in prototyping by the time they finish making their low-fidelity prototypes, so that they can do their high-fidelity prototyping and iteration phase during the last few weeks of the semester.

While our findings are promising, our study has limitations because it is a field quasi-experiment. Specifically, we could not randomize participant assignment and establish group equivalence because we chose participants and groups according to convenience: group INT consisting of first year students, and group DIS of second year students took the respective courses during the same academic year, with the DIS group following the old course structure and the INT group doing the revised course, and this experiment tested our conjecture regarding the effectiveness of the revised course. Students in the DIS course had not yet been exposed to engineering design or prototyping, and so for the purposes of our study of engineering design self-efficacy the two groups were equivalent. However, to eliminate possible confounds, generalize and better explain our findings, we propose to conduct further studies.

7. CONCLUSIONS

The role of prototyping in design has recently gained prominence because of the “democratization of invention” (Blikstein, 2013) brought on by economical and easy to use prototyping tools. In this work, we report on a study comparing an integrated design and prototyping course (INT) with a separate design and prototyping course sequence (DIS) with respect to students’ self-efficacy, and found that students in the INT course had higher self-efficacy after the course compared to students in the DIS course sequence. Additionally, we found differences between the self-efficacy of males and females, with males in the INT course reporting the highest self-efficacy. Notably, however, females in the integrated course reported lowest anxiety, a finding worthy of further exploration. These findings have implications for engineering education, suggesting that design and prototyping be taught in an integrated manner in a project-based course which offers numerous opportunities for mastery and vicarious experiences, social persuasion and emotional arousal which support the development of self-efficacy.

8 ACKNOWLEDGEMENTS

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REFERENCES

Acebo Moral, Enrique, José Ángel Miguel Dávila, and Liliana Herrera. "Design Thinking (DT) in Engineering Education (EE): A Systematic Literature Review (SLR)." .), Organizational Engineering in Industry 4.0. ICIEOM 2018.: 185-191.

Andrews, M. E., Borrego, M., & Boklage, A. (2021). Self-efficacy and belonging: the impact of a university makerspace. International Journal of STEM Education, 8(1). https://doi.org/10.1186/s40594-021-00285-0

Aurigemma, Joshua, Sanjay Chandrasekharan, Nancy J. Nersessian, and Wendy Newstetter. "Turning experiments into objects: The cognitive processes involved in the design of a lab-on-a-chip device." Journal of Engineering Education 102, no. 1 (2013): 117-140.

Bandura, Albert. "Self-efficacy: toward a unifying theory of behavioral change." Psychological review 84, no. 2 (1977): 191.

Blikstein, Paulo. "Digital fabrication and 'making'in education: The democratization of invention." FabLabs: Of machines, makers and inventors 4, no. 1 (2013): 1-21.

Böhmer, Annette Isabel, Sheri Sheppard, Liza Kayser, and Udo Lindemann. "Prototyping as a thinking approach in design Insights of problem-solving activities while designing a product." In 2017 International conference on engineering, technology and Innovation (ICE/ITMC), pp. 955-963. IEEE, 2017.

Camburn, Bradley, Vimal Viswanathan, Julie Linsey, David Anderson, Daniel Jensen, Richard Crawford, Kevin Otto, and Kristin Wood. "Design prototyping methods: state of the art in strategies, techniques, and guidelines." Design Science 3 (2017): e13.

Carberry, Adam R., Hee-Sun Lee, and Matthew W. Ohland. "Measuring engineering design self-efficacy." Journal of Engineering Education 99, no. 1 (2010): 71-79.

Carbonell, R. M. (2019). Innovation, Design, and Self-Efficacy: The Impact of Makerspaces. in Proceedings of the 126th Annual Conference and Exposition of the ASEE, ASEE 2019.

Carfagni, Monica, Lorenzo Fiorineschi, Rocco Furferi, Lapo Governi, and Federico Rotini. "Usefulness of prototypes in conceptual design: students' view." International Journal on Interactive Design and Manufacturing (IJIDeM) 14 (2020): 1305-1319.

Chachra, Debbie, and Deborah Kilgore. "Exploring gender and self confidence in engineering students: A multi method approach." In 2009 Annual Conference & Exposition, pp. 14-614. 2009.

Coleman, Emma, Tripp Shealy, Jacob Grohs, and Allison Godwin. "Design thinking among first-year and senior engineering students: A cross-sectional, national study measuring perceived ability." Journal of Engineering Education 109, no. 1 (2020): 72-87.

Criteria for Accrediting Engineering Programs, 2022 – 2023, https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/, Accessed April 7, 2024

Dam, Rikke Friss, and Teo Yu Siang. "Design thinking: Get started with prototyping." Interaction Design Foundation (2020).

de Los Rios, Ignacio, Adolfo Cazorla, José M. Díaz-Puente, and José L. Yagüe. "Project–based learning in engineering higher education: two decades of teaching competences in real environments." Procedia-Social and Behavioral Sciences 2, no. 2 (2010): 1368-1378.

Dym, Clive L., Alice M. Agogino, Ozgur Eris, Daniel D. Frey, and Larry J. Leifer. "Engineering design thinking, teaching, and learning." Journal of engineering education 94, no. 1 (2005): 103-120.

Felder, Richard M., Gary N. Felder, Meredith Mauney, Charles E. Hamrin Jr, and E. Jacquelin Dietz. "A longitudinal study of engineering student performance and retention. III. Gender differences in student performance and attitudes." Journal of Engineering Education 84, no. 2 (1995): 151-163.

Fernandez, Todd, and Martin Jacobson. "Engineering students’ Performance of Prototyping: Process, Purpose, and Perception in the Design Classroom." International Journal of Engineering Education 38, no. 6 (2022): 1761-1778.

Froyd, Jeffrey E., Phillip C. Wankat, and Karl A. Smith. "Five major shifts in 100 years of engineering education." Proceedings of the IEEE 100, no. Special Centennial Issue (2012): 1344-1360.

Grau, Michelle Marie, Sheri Sheppard, Shannon Katherine Gilmartin, and Beth Rieken. "What do you want to do with your life? Insights into how engineering Students think about their future career plans." In 2016 ASEE Annual Conference & Exposition. 2016.

Greenhalgh, Scott. "The effects of 3D printing in design thinking and design education." Journal of Engineering, Design and Technology 14, no. 4 (2016): 752-769.

Hilton, Ethan C., Kimberly G. Talley, Shaunna F. Smith, Robert L. Nagel, and Julie S. Linsey. "Report on engineering design self-efficacy and demographics of makerspace participants across three universities." Journal of Mechanical Design 142, no. 10 (2020): 102301

Hulls, Carol CW, and Christopher Rennick. "Use of a cornerstone project to teach ill-structured software design in first year." IEEE Transactions on Education 63, no. 2 (2020): 98-107.

Interaction Design Foundation, Rikke Friis Dam, and Teo Yu Siang. "What is design thinking and why is it so popular?." (2021).

Lantada, A. Dıaz, H. Lorenzo Yustos, P. Lafont Morgado, Juan Manuel Muñoz-Guijosa, JL Munoz Sanz, and J. Echavarri Otero. "Teaching applications for rapid prototyping technologies." International Journal of Engineering Education 23, no. 2 (2007): 411.

Lauff, C. A., Kotys-Schwartz, D., and Rentschler, M. E. (March 23, 2018). "What is a Prototype? What are the Roles of Prototypes in Companies?." ASME. J. Mech. Des. June 2018; 140(6): 061102. https://doi.org/10.1115/1.4039340

Lippke, Sonia. "Self-efficacy." Encyclopedia of personality and individual differences (2020): 4713-4719.

Litzler, Elizabeth, Cate C. Samuelson, and Julie A. Lorah. "Breaking it down: Engineering student STEM confidence at the intersection of race/ethnicity and gender." Research in Higher Education 55 (2014): 810-832.

Marra, Rose M., Kelly A. Rodgers, Demei Shen, and Barbara Bogue. "Women engineering students and self-efficacy: A multi-year, multi-institution study of women engineering student self-efficacy." Journal of engineering education 98, no. 1 (2009): 27-38.

Michael, Jon, J. Booth, and Thomas E. Doyle. "Importance of first-year engineering design projects to self-efficacy: Do first-year students feel like engineers?." Proceedings of the Canadian Engineering Education Association (CEEA) (2012).

Milto, Elissa, Chris Rogers, and Merredith Portsmore. "Gender differences in confidence levels, group interactions, and feelings about competition in an introductory robotics course." In 32nd annual frontiers in education, vol. 2, pp. F4C-F4C. IEEE, 2002.

Morocz, Ricardo Jose, Bryan Levy, Craig Forest, Robert L. Nagel, Wendy C. Newstetter, Kimberly Grau Talley, and Julie S. Linsey. "Relating student participation in university maker spaces to their engineering design self-efficacy." In 2016 ASEE Annual Conference & Exposition. 2016.

Newman, Peter, Maria Angela Ferrario, Will Simm, Stephen Forshaw, Adrian Friday, and Jon Whittle. "The role of design thinking and physical prototyping in social software engineering." In 2015 IEEE/ACM 37th IEEE International Conference on Software Engineering, vol. 2, pp. 487-496. IEEE, 2015.

Parmar, Ashis Jalote. "Bridging gaps in engineering education: Design thinking a critical factor for project based learning." In 2014 IEEE frontiers in education conference (FIE) proceedings, pp. 1-8. IEEE, 2014.

Pearson, Heather Ann, and Adam Kenneth Dubé. "3D printing as an educational technology: theoretical perspectives, learning outcomes, and recommendations for practice." Education and Information Technologies (2022): 1-28.

Ponton, Michael K., Julie Horine Edmister, Lawrence S. Ukeiley, and John M. Seiner. "Understanding the role of self-efficacy in engineering education." Journal of Engineering Education 90, no. 2 (2001): 247-251.

Quan, Gina M., and Ayush Gupta. "Tensions in the productivity of design task tinkering." Journal of Engineering Education 109, no. 1 (2020): 88-106.

Spee, J., and R. V. Basaiawmoit. "Design thinking and the hype cycle in management education and in engineering education." In DS 84: Proceedings of the design 2016 14th international design conference, pp. 2111-2124. 2016.

The Cti’s Major Criteria And Procedures 2023, https://www.cti-commission.fr/en/fonds-documentaire, Accessed April 7, 2024

Whitcomb, Kyle M., Z. Yasemin Kalender, Timothy J. Nokes-Malach, Christian D. Schunn, and Chandralekha Singh. "Comparison of self-efficacy and performance of engineering undergraduate women and men." International Journal of Engineering Education 36, no. 6 (2020): 1996-2014.

Yu, Fei, Michele Pasinelli, and Alexander Brem. "Prototyping in theory and in practice: A study of the similarities and differences between engineers and designers." Creativity and Innovation Management 27, no. 2 (2018): 121-132.

Zancul, Eduardo de S., Luiz FC dos S Durao, Roseli de Deus Lopes, Davi Nakano, Paulo Blikstein, Gustavo G. Majzoub, and Danilo L. Dalmon. "An empirical study on design-based vs. traditional approaches in capstone courses in engineering education." International Journal of Engineering Education 33, no. 5, SI (2017): 1543.

WE CAN SEE INVENTION IN EVERYTHING: EFFECTS OF THE SIX-WEEK INVENTION FACTORY PROGRAM

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ABSTRACT

The evolving role of the engineer necessitates the development of innovation skills among engineering undergraduates. Short term intensive projects are an effective way to supplement curricular design and innovation activities. In this paper, we present the findings of a study investigating the effects of a six-week invention program for engineering undergraduates. While the structure of the program is similar to a typical hackathon, the extended duration and an explicit emphasis on patenting differentiates this program from other hackathons. Focusing on self-efficacy as it is known to have a relationship with performance, we ask two research questions. Firstly, we ask if the program had effects on participants' engineering design, innovation, public speaking and patenting self-efficacy, and secondly, we investigate participant perceptions regarding the program features, and their learning during the program. Through a combined quantitative and qualitative approach, we found that participants' self-efficacy increased, and uncovered multiple positive outcomes resulting from the program, including skill development and transformative identity formation. Based on our findings, we offer guidelines for adoption by other engineering educators.

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1 INTRODUCTION

The world's challenges necessitate engineers evolving into innovators. The initial phase of innovation involves sensing possibilities, envisioning realities, and proposing new outcomes through invention, which could manifest as a product, process, or patent (Denning and Dunham, 2006). This process aligns closely with design thinking and engineering design education (Coleman et al, 2019). Acknowledging this, engineering educators are integrating innovation-focused activities into curricula (for instance, Violante and Vezzetti, 2017; Barak and Usher, 2019; Liebenberg and Mathews, 2010) and promoting extracurricular events like hackathons, which are short-duration events where participants tackle problems and present solutions (Flus and Hurst, 2021). They offer practical experience and career opportunities for students (Garcia, 2022), while educators see benefits in skill development and industry-focused learning (Mehta et al, 2022). Hackathons are also linked to fostering innovative ideas (Heller et al, 2023), making them valuable for engineering undergraduates' innovation skill development. Although most hackathons prioritize pitching over patenting (Flus & Hurst, 2021), there is recognition within engineering education of the value of patent knowledge in enhancing design and innovation skills (Ozkul, 2008; Garris & Garris, 2017; Liebenberg and Mathews, 2010). Here we present a six-week extracurricular invention program called "Invention Factory" (IF) similar to a hackathon, but with a focus on provisional patent writing alongside identifying needs, designing solutions, prototyping, and pitching. The longer duration further differentiates this program from other hackathons, providing a platform for extended practice of design, prototyping, pitching, and patenting under the guidance of engineering instructors. In this work, we report on our study of the effect of this program on participants' self-efficacy for engineering design, innovation, public speaking, and patenting, and explore participants' perceptions of the program features and their own learning outcomes.

2 THEORETICAL FRAMEWORK

The "belief in one's own competences to perform an intended behaviour in spite of barriers" is referred to as self-efficacy (Lippke, 2020) and can affect motivation and performance during learning. Hence scholars argue for the examination and development of self-efficacy through appropriate curricular experiences as an important goal of engineering education (Ponton et al, 2001). Adopting Bandura's theory of self-efficacy (Bandura, 1977) in this work, we examine the impact of IF on participants' self-efficacy in engineering design, innovative thinking, public speaking, and patenting. Bandura suggests that self-efficacy depends on mastery experiences, vicarious experiences, social persuasion, and physiological and affective states. By engaging in the practical tasks of prototyping, pitching, and patenting, participants have the opportunity to acquire these skills, confront challenges, and ultimately experience success, which is a mastery experience. Teamwork, and exposure to peers and role models such as the facilitators and guest evaluators, may enhance participants' self-efficacy by witnessing the achievements of their peers. The program's emphasis on a supportive and affirming environment, with constructive feedback, encouragement, and recognition from facilitators and peers, aligns with the soc'al persuasion aspect of Bandura's theory. On the other hand, negative feedback and criticism can also lead to decreased self-efficacy. As participants engage in prototyping, pitching, and patenting activities, they may also encounter various physiological and affective states, such as excitement, anxiety, or satisfaction. Understanding and managing these emotions within the program context may contribute to the overall development of participants' confidence in their abilities. In summary, Bandura's social cognitive theory of self-efficacy offers a comprehensive framework to interpret the outcomes of IF.

3 CONTEXT AND INTERVENTION

IF is a six-week program wherein engineering undergraduates, in teams of two, prototype a potentially patentable product that addresses a real need, either consumer or societal or both. The main goal of the program is for engineers to recognize the opportunity to serve the world through engineering, and other goals include improving public speaking skills, acquiring the confidence to invent, developing awareness of how to protect intellectual property, project management skills, and learning how to work in teams. These learning goals are accomplished through participants 1) identifying a need and designing a solution that addresses the need, 2) demonstrating feasibility through a working prototype of the solution, 3) writing a provisional patent application for a utility patent that demonstrates the novelty and non-obviousness of the invention and 4) communicating the value of the product to various stakeholders.

IF is a project-based intervention which begins with facilitators establishing the norms of participation, such as working hours. Next, they form groups for a two-day ice breaking activity, which levels participants' prototyping skills and fosters connections among them, aiding in the identification of compatible partners. After the ice breaking, participants have five days to form teams, identify problems, brainstorm solutions, validate the novelty and prepare a six minute pitch. They delve into various facets of invention development, learning concepts about patents and patenting, ideation techniques, and prior art search. Facilitators offer guidance for ideation and pitching, addressing participants' concerns and anxieties regarding their initial pitches, while emphasizing effective communication strategies. Lectures on patenting along with interactive sessions to clarify any queries, help participants understand patent law and the process of drafting patent applications. At the end of week one, they present their pitches while facilitators give feedback on the problem and solution.

From the second week onwards, participants receive hands-on guidance from facilitators as they engage in the prototyping process. Collaborative efforts among teams facilitate the iterative refinement of prototypes, with participants offering feedback and assistance to one another. During this phase, participants pitch their inventions every week to guest evaluators from diverse backgrounds who provide critical feedback. These sessions are recorded and viewing the recordings with facilitators' who provide feedback on aspects such as script clarity, body language, and communication style, enable participants to refine their pitches further.

Starting from week three, structured tasks breaking down the patent application writing into parts guide participants through the drafting of patent applications, which they submit during week six. This structuring enhances participants' understanding of the patenting process, while also ensuring alignment in progress, enabling mutual support among peers and aiding in effective evaluation. Their understanding of patenting is tested by a mid-program assessment, and this also prepares them for the upcoming tasks. As the program draws to a close, teams prepare video pitches and live presentations for a panel of judges who award three prizes at each location to the best inventions. These final presentations require participants to distil the essence of their inventions into compelling narratives. The prospect of winning a prize motivates participants to deliver their best performances.

4 RESEARCH DESIGN AND METHODS

4.1 Research Questions

Based on the theoretical framework and existing literature about hackathons and short-term intensive projects, we hypothesized that self-efficacy for engineering design, innovation, public speaking and patenting would increase with participation in IF. Concretely, we ask two research questions about the effectiveness of IF:

1) What is the effect of IF on students' self-efficacy for engineering design, innovation, public speaking and patenting?
2) How do participants perceive IF?

4.2 Study Design

We employed a single group, repeated measures study to answer the first research question, conducting quantitative measurements of engineering design, innovation and public speaking self-efficacy at three points in time, namely, pre, mid, and post the program. As the participants took a patenting test at midpoint, to reduce the burden on them, the patenting self–efficacy measurement was done only pre and post program. We used a qualitative approach to answer the second research question conducting in-depth semi-structured interviews with participants at the end of the program. In addition, at one location of the program, researchers also observed the participants' daily activities during, and post working hours at the workspace, dorms, and cafeteria through participant observation to understand their perceptions as they develop throughout the program.

4.3 Participants

Engineering students of second year and above are invited to apply to IF and are selected on the basis of their motivation for innovation. Participants have diverse backgrounds, skill levels and a broad range of experiences, with approximately 45% from Mechanical Engineering and 15% from Electrical Engineering, and the rest from Civil Engineering, Chemical Engineering, Materials Science, Computer Science, Aerospace Engineering and Engineering Design. The program is conducted simultaneously at three locations and all 60 participants across all locations were invited to participate in this study. We had ethical approval for the study from our institutional ethics committee and participants provided informed consent. However not all participants completed all the questionnaires, and so the sample size for the quantitative study was 44.

4.4 Instruments Used

We used validated scales for innovation (Schar et al, 2017a), engineering design (Carberry et al, 2010) and public speaking self-efficacy (Morreale et al, 2007) for quantitative assessments. As no validated patenting self-efficacy scale was found, a specifically designed short survey consisting of five questions on a five-point Likert scale, was used to assess patenting self-efficacy. As an example, one of the questions was “I am confident in my ability to write a provisional patent.” The understandability of the questions in this survey were checked through pilot testing. A semi-structured interview guide was made for the participant interviews to capture perceptions about various aspects of the program and its effects.

4.5 Procedure for data collection and analysis

For the first RQ, we administered the self-efficacy questionnaires online; for three of the constructs (innovation, engineering design and public speaking) we did this at three time points, while for patenting self-efficacy we administered the questionnaire only pre and post program. 44 participants responded to the questionnaires at all time points, and we applied repeated measures ANOVA tests to examine differences in self-efficacy scores across the three time points. The self-efficacy score was calculated as the average of participants’ scores on all the items of the scale. For the second RQ, we conducted detailed semi-structured interviews with participants (N = 20, interviewed in teams), each ranging from a minimum of 45 to a maximum of 60 minutes, in addition to participant observations, to delve deeper into how they perceived specific program features and their own learning during the program. We analysed the transcribed interviews using thematic analysis to identify recurring themes and patterns within qualitative data. The data was first coded by one researcher (the second author of this paper) to identify the key themes through initial codes and categories related to the research question using Weft QDA software, and a code book was developed. Through a two-cycle coding process undergoing several iterations, the key themes were then refined through discussion between the two researchers until there was complete agreement regarding the themes, and we then together wrote the descriptions of the themes.

5 FINDINGS

5.1 The Effect of the ESP program on self-efficacy[2]

Our findings (Figures 1-4) show that there was a significant improvement in innovation self-efficacy, engineering design self-efficacy, public speaking self-efficacy and patenting self-efficacy scores across time ($p < 0.001$ for all four measures). Thus, participants self-efficacy on all four aspects of IF increased across the program.

5.2 Participants perceptions of the program and their learning

In terms of the program features, participants perceived that **icebreakers** were essential for fostering bonds, yet some participants found them inadequate, hindering peer interaction and partner selection, potentially affecting team dynamics as reported by Team 5, *“Because initially, in the dustbin task, we are divided into basically five groups. So, we are able to know only the five people of our group only and not the remaining 15 people.”* **Ideation was influenced by multiple factors** including facilitator feedback, personal experiences, socializing, and prior training, and participants perceived the need for extended ideation duration and facilitator diversity for better problem understanding as team 1 suggests *“if the program was for a longer time I would say a slower you know feedback would help maybe*

[2] ** denotes that $p < 0.05$, ** denotes $p < 0.01$ and *** denotes $p < 0.001$.*

because we'll get more time to think." Participants reported that **iterative processes and facilitator involvement were crucial for effective solution development,** emphasizing the critical role of timely and constructive feedback and support in refining ideas and prototypes, and contributing to project progress as Team 1 describes *"But yes their input at every step is required. I can't imagine them giving input once a week or twice a week. No I can't because I myself used to go to them and ask am I doing the right thing? What are the alternatives? What if I do this? It is very important that they come in."* They also appreciated the value of **diverse feedback from both facilitators and guest evaluators** as team 10 mentions, *"Yeah, so the feedback of guest evaluators was very important, because that was the thing that made us change the design system, [...] and those were real concerns, and they were people from different backgrounds, and they raised real concerns."* Participants reiterated that **refinement of pitches and communication expertise** were crucial for effective presentations, enhancing the overall program experience.

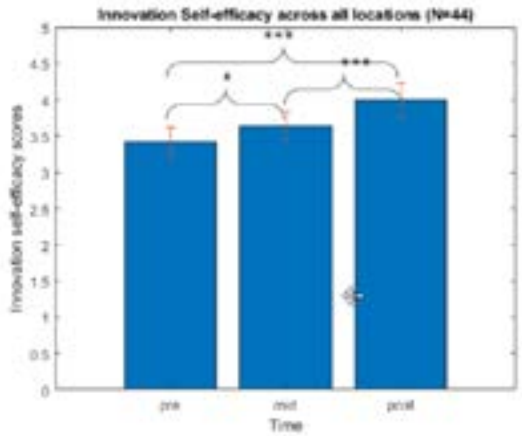

Fig. 1. Innovation self-efficacy

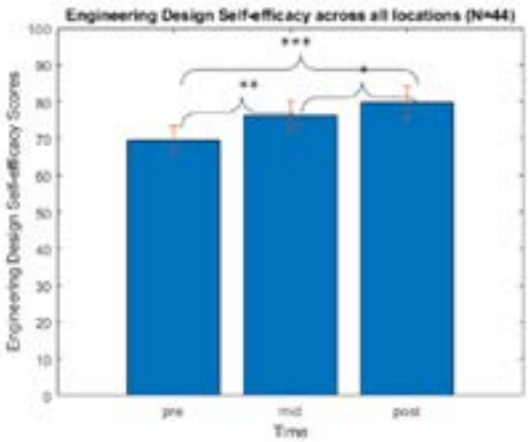

Fig. 2. Engineering Design self-efficacy

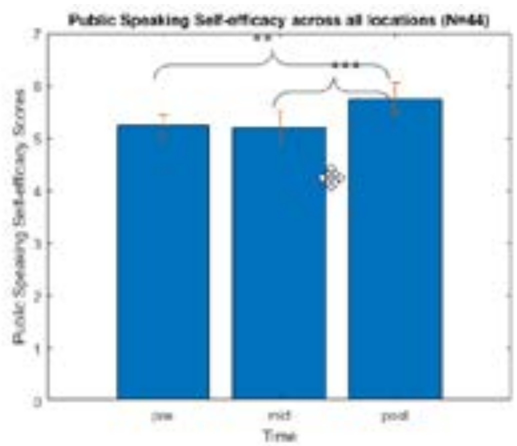

Fig. 3. Public Speaking self-efficacy

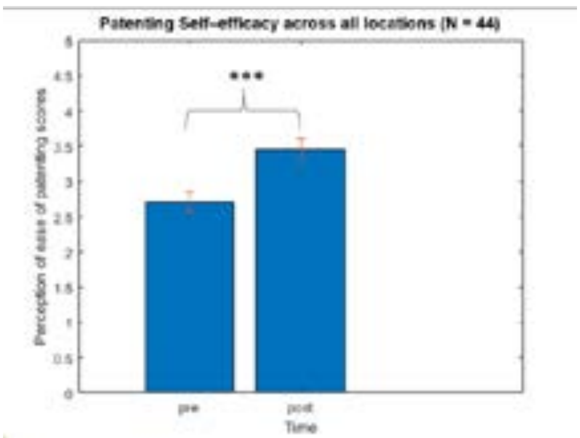

Fig. 4. Patenting self-efficacy

Regarding the culture of the program, participants acknowledged the **balance between competition and camaraderie**, highlighting the importance of fostering a collaborative learning environment as aptly described by team 10, *"we would not feel that kind of, you know, there is a negative feeling between teams, there was no such feeling in [location name], however everybody was working on the prototype, so that* *was the thing that you could be best friends even if you are competing, that was a great learning for me."* However, **cultural diversity posed challenges in communication** for some participants, necessitating inclusive strategies to address language barriers and foster participation as highlighted by team 8, *"Yeah, like, yeah, when there are group discussions, you know, we would sit together, and the initial phases, they would start speaking English, obviously, because we are there, so they consider us, but when the talking gets into deeper and deeper, there are jokes, they tell jokes and all, obviously, they will get into their mother tongue."* The **importance of prior relationships in team dynamics, collaboration, and supporting each other** was emphasized. Tolerance for different perspectives and going through an iterative process of discussing and refining ideas as a team was recognized as key to a successful collaboration as team 9 described, *"Like, as a partner, I like him pretty much. And, like, he supported my ideas. And also, he made my ideas into reality. Like, I was not that good with CAD modelling and everything. But, like, I had a good, like, tinkering mind. [...] So, I used to tell him and he used to make the things from my life. So, we both actually complemented each other in this journey."*

Commenting on their own evolution during the program, participants explained that engagement in IF **influenced their identity formation**, shaping their aspirations as impactful professionals, innovators, and entrepreneurs as succinctly put by Team 1 *"We can see invention in everything. If I don't do this I don't do that. Much better than the first week of inventions actually."* Participants acknowledged that **they were able to identify problems and gained a deeper understanding of them** only after engaging in IF as team 10 describes *"Throughout the program, so observing the problem was one more thing that I have learnt, so whenever, initially, before joining the program, when I walk through and I see a problem, then it was only a problem for me, [...] but now looking at the problem, I start thinking more, how can I solve it and how can I innovate it, even I see a solution to it, then I start thinking like, how can I improve it or things like that."* Participants recognized this as an **opportunity to apply their theoretical knowledge** as team 5 mentions, *"It helps us a lot in academics also. Basically, the concepts we learn during the classes. The program basically helps us to apply. Basically, in our project, we had gears. So, we have learned a lot about the gears also during the [program name] time,"* Next, they reported that they developed a range of skills from **CAD drawing to making observations, taking critical feedback, independence, professionalism and teamwork** as articulated by team 9, *"So, my first learning would be teamwork. Firstly, as an individual, you can't do everything alone. So, you need a team or a partner that could complement you and also how to do work and how to take work from them."* Importantly, participants spoke about **facing difficult situations and learning how to adapt** to them as team 8 elaborates, *"it was obviously one and a half months, and it was a journey of emotions, lots of emotions, frustration, anger, happiness, everything in between. [...] Yeah, definitely, to adapt to situations, adapt to scenarios as per his demands. [...] We had to face each and every emotion. We had to hold our horses, and then we had to strike hard against each and every time. We faced so many challenges, issues, failures.*"

6 DISCUSSION AND IMPLICATIONS

In this paper, we present a six-week extracurricular undergraduate engineering program focusing on identifying problems, prototyping, pitching and writing a provisional patent application for a solution. Our study found statistically significant increases in participants scores on engineering design, innovation, public speaking and patenting self-efficacy scales across the program, which indicates that participants self-efficacy for these aspects increased during the program. This agrees with research documenting the effects of participation in experiences such as design, making, entrepreneurship, innovation and leadership activities, which have been shown to result in an increase in students engineering design and innovation self-efficacy over time (Morocz et al, 2016; Andrews et al, 2021; Carbonell, 2019; Hilton et al, 2020; Hulls, 2020; Dungs et al, 2017; Schar et al, 2017b). Our qualitative findings suggest that students perceive the strength of the program lies in the environment which is conducive to immersing themselves in problem identification, solution development, pitching and patent writing across six weeks. They valued features such as guided ideation, an extended duration of prototyping with timely and constructive facilitator feedback, regular pitching with training for making presentations and critical guest evaluator feedback. They also appreciated the culture of the program, specifically the balance of camaraderie and competition, and collaborative aspects. We argue that together these features of the learning environment were sources of own and vicarious mastery, and verbal persuasion leading to the development of self-efficacy (Bandura, 1977). Further, participants reported developing an identity as an innovator, a deeper understanding of problems, and development of various skills including applying theoretical knowledge in practice. These findings resonate with previous findings which indicate that participating in hackathons positively impacts content learning (Pakpour et al, 2022), knowledge of socio-scientific issues (Pakpour et al, 2022; Medina Angarita and Nolte, 2020), knowledge of new technologies and industry relevant skills (Medina Angarita and Nolte, 2020), innovation self-efficacy (Gerber, 2012) and sense of being an engineer (Kusano and Johri, 2014). Finally, participants noted that the proverbial “rollercoaster” of six weeks, with emotional highs and lows, and the need to adapt to challenges was an important learning. This emotional arousal could have been another source of self-efficacy (Bandura, 1977).

Together our findings suggest that such a program can be an effective way to improve engineering students design and innovation self-efficacy. Therefore, we recommend such a program to engineering educators as a way to support the development of students engineering design and innovation self-efficacy. The program can be either within or outside the curriculum, and the guidelines below will help educators conduct such a program in their institution. Firstly, have sufficient time and focussed ice breaking activities to help participants get acquainted with each other and identify potential partners. Secondly, support ideation through design-thinking ideation techniques and provide constant feedback as students ideate. Thirdly, have facilitators with a wide range of experiences in innovation and train them to provide support and feedback to participants, giving specific examples of the kind of support to be provided in various situations, such as when to intervene and how, and when to step back. Next, provide participants with easy access to materials and prototyping tools so that they can iterate between designs and prototypes seamlessly. Fifth, have guest evaluators who come from diverse backgrounds (engineers, designers, homemakers, lawyers) and do not repeat evaluators in order to maximise diversity of feedback. Finally, have a communications expert who regularly provides feedback on participants' pitches and their communication skills.

While our study found statistical increases in self-efficacy, we are careful to generalize our findings because this was a pre-experimental field study of a specific program with the goal of studying if there was any effect of participation, and so we included all participants in our sample and did not have a control group. Further as our sample was not selected randomly but through volunteering, we could have self-selection bias resulting from only motivated participants volunteering. However, the detailed qualitative findings of participant perceptions regarding the program explain and triangulate the statistical findings. In future work, we plan to perform an experimental study to validate and generalize these preliminary findings.

7 ACKNOWLEDGEMENTS

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REFERENCES

Andrews, M. E., Borrego, M., & Boklage, A. (2021). Self-efficacy and belonging: the impact of a university makerspace. International Journal of STEM Education, 8(1). https://doi.org/10.1186/s40594-021-00285-0

Bandura, Albert. "Self-efficacy: toward a unifying theory of behavioral change." Psychological review 84, no. 2 (1977): 191.

Barak, Miri, and Maya Usher. "The innovation profile of nanotechnology team projects of face-to-face and online learners." Computers & Education 137 (2019): 1-11.

Carberry, Adam R., Hee-Sun Lee, and Matthew W. Ohland. "Measuring engineering design self-efficacy." Journal of Engineering Education 99, no. 1 (2010): 71-79.

Carbonell, R. M. (2019). Innovation, Design, and Self-Efficacy: The Impact of Makerspaces. in Proceedings of the 126th Annual Conference and Exposition of the ASEE, ASEE 2019.

Coleman, Emma, Tripp Shealy, Jacob Grohs, and Allison Godwin. "Design thinking among first-year and senior engineering students: A cross-sectional, national study measuring perceived ability." Journal of Engineering Education 109, no. 1 (2020): 72-87.

Denning, Peter J., and Robert Dunham. "Innovation as language action." Communications of the ACM 49, no. 5 (2006): 47-52.

Dungs, Carolin Christin, Sheri Sheppard, and Helen L. Chen. "Extracurricular College Activities Fostering Students' Innovation Self-efficacy." In 2017 ASEE Annual Conference & Exposition. 2017.

Flus, Meagan, and Ada Hurst. "Design at hackathons: new opportunities for design research." Design Science 7 (2021): e4.

Garcia, Manuel B. "Hackathons as extracurricular activities: Unraveling the motivational orientation behind student participation." Computer Applications in Engineering Education 30, no. 6 (2022): 1903-1918.

Garris Jr, Charles A., and Charles A. Garris III. "The United States patent system and engineering education: an alliance for innovation." Technology & Innovation 19, no. 2 (2017): 509-524.

Gerber, Elizabeth M., Jeanne Marie Olson, and Rebecca LD Komarek. "Extracurricular design-based learning: Preparing students for careers in innovation." International Journal of Engineering Education 28, no. 2 (2012): 317.

Heller, Ben, Atar Amir, Roy Waxman, and Yossi Maaravi. "Hack your organizational innovation: literature review and integrative model for running hackathons." Journal of Innovation and Entrepreneurship 12, no. 1 (2023): 6.

Hilton, Ethan C., Kimberly G. Talley, Shaunna F. Smith, Robert L. Nagel, and Julie S. Linsey. "Report on engineering design self-efficacy and demographics of makerspace participants across three universities." Journal of Mechanical Design 142, no. 10 (2020): 102301

Hulls, Carol CW, and Christopher Rennick. "Use of a cornerstone project to teach ill-structured software design in first year." IEEE Transactions on Education 63, no. 2 (2020): 98-107.

Kusano, Stephanie Marie, and Aditya Johri. "Student autonomy: Implications of design-based informal learning experiences in engineering." In 2014 ASEE Annual Conference & Exposition, pp. 24-1110. 2014

Liebenberg, Leon, and Edward Henry Mathews. "Integrating innovation skills in an introductory engineering design-build course." International Journal of Technology and Design Education 22 (2012): 93-113.

Lippke, Sonia. "Self-efficacy." Encyclopedia of personality and individual differences (2020): 4713-4719.

Medina Angarita, Maria Angelica, and Alexander Nolte. "What do we know about hackathon outcomes and how to support them?–A systematic literature review." In Collaboration Technologies and Social Computing: 26th International Conference, CollabTech 2020, Tartu, Estonia, September 8–11, 2020, Proceedings 26, pp. 50-64. Springer International Publishing, 2020.

Mehta, Neha, Siddarth Singh Bist, and Priya Shah. "Hackathons: what do engineering educators think about it?." Higher Education, Skills and Work-Based Learning 12, no. 5 (2022): 983-1001.

Morocz, Ricardo Jose, Bryan Levy, Craig Forest, Robert L. Nagel, Wendy C. Newstetter, Kimberly Grau Talley, and Julie S. Linsey. "Relating student participation in university maker spaces to their engineering design self-efficacy." In 2016 ASEE Annual Conference & Exposition. 2016.

Morreale, Sherwyn P. "The competent speaker speech evaluation form (2nd ed.)." Washington, DC: National Communication Association. (2007).

Ozkul, Tarik. "Using patents as a tool for reinforcing constructivist learning environment in engineering education." International Journal of Education and Information Technologies 2, no. 2 (2008): 157-166.

Pakpour, Nazzy, Sahar Nouredini, and James Tandon. "Engaging engineering students in public health responses to disease outbreaks through hackathons." IEEE Transactions on Education 65, no. 4 (2022): 638-646.

Ponton, Michael K., Julie Horine Edmister, Lawrence S. Ukeiley, and John M. Seiner. "Understanding the role of self-efficacy in engineering education." Journal of Engineering Education 90, no. 2 (2001): 247-251.

Schar, Mark, S. Gilmartin, Angela Harris, Beth Rieken, and Sheri Sheppard. "Innovation Self-Efficacy: A Very Brief Measure for Engineering Students." In Proceedings for the American Society for Engineering Education Annual Conference, June 25-28. Columbus, OH. 2017.

Schar, Mark, S. Gilmartin, Beth Rieken, S. Brunhaver, H. Chen, and Sheri Sheppard. "The Making of an Innovative Engineer: Academic and Life Experiences that Shape Engineering Task and Innovation Self-Efficacy." In Proceedings of the American Society for Engineering Education Annual Conference, June 25-28. Columbus, OH. 2017

Violante, Maria Grazia, and Enrico Vezzetti. "Guidelines to design engineering education in the twenty-first century for supporting innovative product development." European Journal of Engineering Education 42, no. 6 (2017): 1344-1364.

THE EMOTIONAL JOURNEY OF COMPUTER SCIENCE STUDENTS IN TEAM PROJECTS: THE TURBULENCES AND THE INTERPLAY BETWEEN THE ACADEMIC EMOTIONS

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ABSTRACT

Although there is a growing interest in understanding the emotions experienced by computer science students in educational settings, a significant gap persists in the current literature concerning the emotional dynamics and turbulences in long-term team projects. In this qualitative longitudinal study, we aimed to delve into the emotional experiences of 34 computer science students engaged in team projects. We used the experience sampling method and collected the data through online diaries after each team meeting. Through qualitative analysis of the diaries, we revealed the predominant emotions experienced by participants, the emotional turbulence encountered by team members, and the overall emotional trajectories of the teams. Our findings showed a dynamic emotional trajectory marked by turbulences in emotions such as excitement, frustration, stress, satisfaction, and pride: initial excitement often gave way to frustration and stress as teams navigated project complexities, yet this was mitigated by satisfaction and pride upon achieving milestones. Also, social emotions such as warmth, guilt, anger, and admiration emerged within the team dynamics. Our findings emphasize the significance of students' emotional experiences in team projects.

1. INTRODUCTION

In computer science education (CSE), students are frequently assigned team projects to address complicated issues and foster vital teamwork skills essential for their future careers. Teamwork, however, has many dimensions, including emotions. For example, according to Tuckman's stages of group development, emotions play a critical role in forming, storming, norming, performing, and adjourning stages of teamwork (Bonebright 2010). Indeed, research evidence shows that when students engage in team projects, they often encounter a spectrum of emotions (Atiq and Batra 2024) during the process, including academic emotions. Academic emotions encompass various psychological experiences that occur during the learning process and can be categorized into four groups: topic (subject-related), achievement (success-related), epistemic (knowledge-related), and social (social-related) emotions (Pekrun and Linnenbrink-Garcia 2012).

For instance, at the outset, students may experience topic emotions such as interest if they are drawn to the project subject, as well as achievement emotions such as hope or anxiety as they anticipate success or failure. Moreover, they may encounter epistemic emotions like surprise, curiosity, and boredom as they navigate new knowledge and understanding (Muis et al. 2015). Social emotions, such as warmth, trust, and anger, may also emerge based on interactions (Tormey 2021). It is important to note that these emotional categories are not rigidly separated, and emotions can overlap. For example, anger can be both an epistemic and social emotion. Also, one may experience more than one emotion at a given time: for example, excitement about a task, but also confusion. Additionally, emotions can be categorized as positive or negative based on their valence and activation (Scherer 2005).

Recent years have witnessed an increasing interest in understanding the role of emotions in engineering education (Lönngren et al. 2023, 2024), including CSE (Atiq and Barta 2024; Bosch et al. 2013; Girardi et al. 2021; Zhuang et al. 2022). Studies have shed light on the emotional aspect of learning programming, for example, revealing its profound influence on student performance (Bosch et al. 2013). Moreover, investigations into emotions such as confusion and frustration have sought to pinpoint instances where computer science (CS) students may require assistance during their learning journey (Zhuang et al. 2022). More recently, Atiq and Batra (2024) unveiled that positive and negative emotions experienced by the first-year students varied during programming tasks. However, there remains a gap in literature concerning the emotional dynamics of team projects, which are intrinsic to learning in CSE.

Since emotions are viewed as episodic events (Shuman and Scherer 2014), the timing of an emotional experience holds significance. This means widening the focus from specific emotions [normally understood as short-term episodes] to also include a focus on wider affective states. Indeed, while researchers often distinguish between emotions, moods, and affective states, this is something of an (artificially) imposed categorization since, in lived experience, many people often do not distinguish between them when asked about their feelings.

This affective aspect has been extensively explored in certain disciplines, notably mathematics (Muis et al. 2015), where learning activities like exercises and quizzes are typically completed individually within single class sessions lasting minutes or hours, rather than spanning days or weeks. Even when studies extend over longer durations, the brief period of each learning activity, often a single or double class session, remains central to the learning process in these fields. In contrast, project work in CS operates within a different temporal framework, extending over weeks or months instead of only minutes. Moreover, the social aspect is distinct, as interaction is integral to the learning process rather than an external or incidental component. Thus, there exists a gap in the current literature regarding an understanding of the emotional dynamics and turbulences inherent in team projects, which are characteristic of learning experiences in CS. The term ‘emotional turbulence’ means the different emotions experienced by students throughout their journey, reflecting changes in intensity and valence over time (Kellam et al. 2018). Despite the prevalence of emotional turbulence in team projects, existing literature also lacks long-term research design addressing this, particularly in CSE. This qualitative longitudinal study based on experience sampling aims to examine what emotions CS students experience in team projects and the complex interactions between emotions, particularly during emotional changes. The research question in this study was therefore as follows:

RQ: What emotions do computer science students experience during team projects and what are the underlying dynamics of academic emotions in this context?

2. METHOD

Since we were interested in what emotions were experienced by CS engineering students in team projects, qualitative methods were the most appropriate way to address our research question (Maxwell 2012). We used a qualitative longitudinal research (QLR) design. QLR is designed to capture significant moments, aspects of experiences, behaviors, actions, or transitions within a continuous, long-term framework (McLeod and Thomson 2012; Neale et al. 2012). By focusing on processes and the dynamic events that drive change, QLR allows researchers to understand how and why experiences occur and how and why they evolve (Lin 2023). We employed the experience sampling method, which is a structured diary technique utilized to appraise subjective experiences in daily life (Larson and Csikszentmihalyi 2014).

Experience sampling method enables participants to report on their thoughts, emotions, behaviors, and environment multiple times over a period (Van Berkel et al. 2017).

2.1. Data collection tool

We used an online short diary. Participants were asked to provide self-reports, answering questions such as “What were you feeling today in teamwork?” and “Why were you feeling those emotions?” Following each team meeting, participants received a link to an online, personalized diary and were requested to respond to the questions about the emotions they experienced during the day’s team meeting at last within 12 hours. Completing the diary took 5 to 10 minutes.

2.2. Participants and process

A total of 34 CS students from two technical universities in Switzerland participated in this study. Among them, 30 students belonged to one university, while the remaining four were from the other. The participants were in nine different teams. The researchers assembled seven teams from the first university, aiming for diversity within each team regarding culture, language, and gender. Teams consisted of a minimum of four and a maximum of five members. These teams were given a six-week project task by the researchers, unrelated to any coursework. The task assigned was to develop a language learning app. Participants had autonomy in choosing the languages to teach via the app, the development approach, and the programming languages to use. Weekly two-hour team meetings were held over the six weeks, with researchers solely observing. The task was not graded, however, participants had to present their app to the other teams in the sixth week of the project and the app had to function effectively. Students from the second university were in two teams and were fulfilling a course requirement and would be graded on their project by their instructors. The task was to develop software. Researchers were not involved in this team formation, project assignment, or evaluation. Initially, six students from these teams agreed to participate, but one member from each team withdrew during the process. They met every 15 days as part of their course requirements and collaborated on semester team projects.

Overall, of the 34 participants, there were 23 men and 11 women. Most participants, 23 out of 34, were bachelor’s students in their first or second year. The participants were from different countries including China, Switzerland, Morocco, Tunisia, Lebanon, Turkey, and France, among others. Language diversity was also evident, with participants speaking a range of mother tongues including, Chinese, German, Arabic, French, Turkish, and others. English emerged as the most widely spoken second language, with French being another prominent.

2.3. Data analysis procedures

The diaries of each participant were carefully analyzed by the first two authors and emotions were labeled independently to increase the reliability of the labeling (first step). After the labeling step, the self-reported reasons for why the participants experienced those emotions during that moment in the teamwork were considered to categorize them in terms of academic emotions (second step). After analyzing the participants’ emotional experiences week by week, we aimed to see the emotional change of each participant (third step) as well as the teams’ emotional trajectory (fourth step). For example, the emotions experienced by the members of Team-1 are presented in Table 1. The data analysis procedures, which include four steps (labeling, categorizing, week by week changes, and team's trajectory), were followed for each participant and team. In the following section, we present a general overview of findings derived from these procedures.

Table 1. Emotional turbulence of team members and emotional trajectory of Team 1

Teams	Participants (CODE)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
		Emotion (intensity) [a]: [Academic Emotions] [b]	**Emotion (intensity) [Academic Emotions]**	**Emotion (intensity) [Academic Emotions]**	**Emotion (intensity) [Academic Emotions]**	**Emotion (intensity) [Academic Emotions]**	**Emotion (intensity) [Academic Emotions]**
TEAM-1	**(P1T1M)**	Satisfied (3) [AE] Stressed (3) [TE, EE] Relieved (3) [SE] [Confidence][c] [TE]	Guilty (2) [AE, SE] Impatient (2) [EE] Satisfied (2) [EE, AE] Relaxed (2) [AE, EE]	Excited (3) [AE] Nervous (3) [EE, SE]	Excited (4) [AE] Happy (4) [AE, SE] Stressed (4) [EE, SE, TE]	Stressed (4) [SE, EE, AE] Relaxed (4) [AE, SE, EE] Satisfied (4) [AE, SE, EE] Fulfilled (4) [AE, SE, EE]	NA (No Answer)
	(P2T1W)	Dissatisfaction (2) [AE, SE, TE]	Satisfied (3) [AE, SE, EE]	Worried (4) [EE, SE]	Anxious (4) [EE, SE, AE]	Happy (4) [EE, SE, AE]]	NA
	(P3T1M)	Excited (3) [TE, AE] Frustrated (3) [TE, EE]	Confident (3) [AE, SE] Frustrated (3) [EE]	Happy (3) [EE, SE, AE]] Fatigue (3) [sleepiness]	Happy (3) [AE, EE] Frustrated (3) [EE]	Happy (4) [AE] Fulfilled (4) [AE] Proud (4) [AE, SE]	Proud (3) [AE] Sad (3) [SE] Satisfied (3) [AE] Happy (3) [AE] Nervous (3) [AE, SE]
	(P4T1M)	Good (3) [SE] Excited (3) [SE]	Sad (1) [No classification]	Neutral [No classification]	Fatigue (2) Unenthusiastic (2) [No classification	Good (3) [AE] Appreciated (3) [SE]	Interested (4) [TE, SE] Excited (4) [AE]

[a] Intensity (1-weak; 2-mild; 3- moderate; 4-strong; 5-intensive)

[b] Academic Emotions: [EE]= Epistemic Emotion; [SE]= Social Emotion, [TE]= Topic Emotion; [AE]= Achievement Emotion

[c] The participants did not explicitly mention this emotion in their responses to the first question of the diary. However, the authors labeled them interpreting the participants' responses to the other questions and placed them on the table. These emotions were indicated within square brackets without specifying their intensities.

3. RESULTS

In this study, we sought to investigate the emotions experienced by CS students during team projects, as well as to explore the underlying dynamics of academic emotions within this context. In this section thus we present the emotions mostly felt by the participants, the emotional turbulence experienced by team members, and the emotional journey of the teams.

3.1. The emotional experiences: Turbulences and trajectories

As seen in Table 2, the participants mostly experienced multiple emotions each week, both positive and negative.

In Week 1, for example, participants primarily experienced positive emotions such as excitement (27%), comfort, satisfaction, and happiness. However, some participants also had worries and stress, stemming from concerns about project expectations and deadlines. Additionally, fewer participants reported annoyance (4%). Overall, the first week was characterized by a mix of positive (65%) and negative (35%) emotions. In Week 2, satisfaction (17%) was the most prevalent. This was attributed to various factors such as achieving goals or completing tasks successfully. Additionally, comfort and excitement were common, since participants were settling into their roles and tasks. Happiness was also prominent, thanks to positive interactions within the team. However, some participants reported frustration (6%) and inadequacy, due to challenges or setbacks encountered during the week. Isolation (5%) was also present, due to lack of communication with team members. Overall, while positive (67%) emotions prevailed, there were also instances of negative (33%) emotions.

Table 2. The seven most felt emotions (f and %)[a] by the participants (n=34) week by week

Week 1 Total Entries (N=97)	**Week 2** Total Entries (N=78)	**Week 3** Total Entries (N=70)	**Week 4** Total Entries (N=87)	**Week 5** Total Entries (N=77)	**Week 6** Total Entries (N=90)
Excited (26, 27%)	Satisfied (13, 17%)	Happy (9, 13%)	Happy (26, 30%)	Happy (18, 23%)	Happy (24, 27%)
Comfortable (10, 10%)	Comfortable (11, 14%)	Satisfied (7, 10%)	Satisfied (13, 15%)	Satisfied (12, 16%)	Comfortable (12, 13%)
Satisfied (8, 8%)	Excited (9, 12%)	Frustrated (6, 9%)	Comfortable (8, 9%)	Stressed (9, 12%)	Proud (10, 11%)
Happy (7, 7%)	Happy (9, 12%)	Comfortable (5, 7%)	Excited (7, 8%)	Comfortable (7, 9%)	Satisfied (9, 10%)
Worried (6, 6%)	Frustrated (5, 6%)	Worried (5, 7%)	Motivated (7, 8%)	Excited (7, 9%)	Relaxed (8, 9%)
Stressed (6, 6%)	Inadequacy (5, 6%)	Excited (3, 4%)	Stressed (4, 5%)	Relaxed (3, 4%)	Excited (7, 8%)
Annoyed (4, 4%)	Isolated (4, 5%)	Disappointed (3, 4%)	Relaxed (3, 3%)	Worried (3, 4%)	Stressed (5, 6%)
Other (30, 31%)	Other (22, 28)	Other (30, 43)	Other (18, %21)	Other (17, %22)	Other (17, 19%)
In total 63 (65%) Positive and 34 (35%) Negative Emotions	In total 52 (67%) Positive and 26 (33%) Negative Emotions	In total 38 (54%) Negative and 30 (43%) Positive Emotions and 2 Neutral	In total 72 (83%) Positive and 14 (16%) Negative Emotions and 1 Neutral	In total 55 (71%) Positive and 21 (27%) Negative Emotions and 1 Neutral	In total 77 (86%) Positive and 13 (14%) Negative Emotions

[a] Frequency and percentages are based on the total entries.

In Week 3, participants experienced a range of emotions, with negative emotions (54%) being more prevalent than positive (43%) ones. Frustration (9%), worry, and disappointment were particularly notable, since participants encountered challenges during this period. Despite the presence of some positive emotions such as happiness (13%) and satisfaction (10%), they were outweighed by the negative ones. In Week 4, participants experienced predominantly positive emotions, with happiness (30%) being particularly prevalent. This indicates a shift from the previous weeks since the team overcame previous challenges and achieved significant progress in their project work. Excitement was also notable, reflecting a sense of accomplishment and engagement within the team. While there were fewer instances of negative emotions such as stress (5%), their presence suggests that the week was not entirely free from challenges or stressors. Overall, while positive (83%) emotions prevailed, there were also instances of negative (16%) emotions.

In Week 5, participants reported positive and negative emotions as they approached the final stages of their project. While happiness (23%) and satisfaction (16%) were prevalent, due to progress, stress (12%) and worry (4%) were also notable due to the impending presentation to other teams in the following week (Week 6). Overall, the combination of positive (71%) and negative (27%) emotions reflected the complexity of the team's experiences as they prepared to present their work to the other teams. In Week 6, happiness (27%) was prevalent, because of a sense of accomplishment with their progress. Additionally, pride (11%) emerged as a notable emotion in this week, indicating a sense of achievement and confidence in their work. Despite these positive emotions, some participants reported stress (6%), due to final presentations. The overall balance of positive (86%) emotions outweighed the negative (14%) ones. As seen in Figure 1, over the course of six weeks, 34 participants, in nine teams in the project reported a wide range of positive and negative emotions, and experienced emotional turbulences, reflecting the dynamic nature of teamwork.

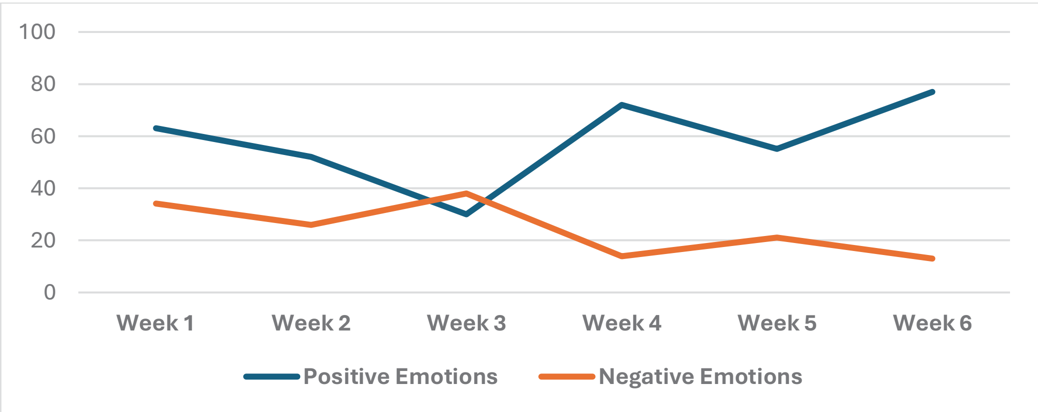

Fig. 1. Emotional journey of the teams

The journey began with positive emotions such as excitement and satisfaction, and negative emotions such as annoyance and stress. As the study progressed over subsequent weeks, notably from the second to the fourth, a mix of emotions emerged, reflecting periods of heightened turbulence characterized by frustration, stress, and worry. These emotional turbulences were influenced by a multitude of challenges encountered by participants. These challenges encompassed various aspects such as difficulties in effective team communication, obstacles in coding tasks, instances of team members' absenteeism, challenges in equitable workload distribution, the presence of unmotivated teammates, and the looming presence of impending deadlines. These antecedents were consistently reported by the participants, indicating the multifaceted nature of emotional experiences within the context of team projects among CS students. As the project concluded, positive emotions such as pride, accomplishment, and fulfillment prevailed, reflecting the participants' collective efforts and achievements.

3.2. The interplay between the academic emotions

The academic emotions experienced by the nine teams throughout their projects were influenced by a multitude of factors, spanning topic, achievement, epistemic, and social dimensions. Overall, the emotional journey of the teams reflected the emotions related to the task subject, the challenges related to coding, team dynamics, and collaboration challenges. Topic emotions, for example, mainly reported during the first week, varied among teams depending on their interest, familiarity, and experiences with the project task, that is, developing a language app. While many members of Team 5, for example, reported excitement in building a language app, many in Team 4, expressed stress, dislike, and nervousness related to the task's topic. The progress made on the projects, completion of coding tasks, and effective management of pressure and deadlines were significant antecedents shaping achievement emotions. For example, Team 4 reported the achievement emotions as they organized their coding tasks, and Team 9 reported hope and relief as they made progress in their coding work despite facing challenges.

Epistemic emotions were frequently reported in Weeks 2, 3, and 4. They were related to the coding process such as debugging and merging codes, or interfaces: frustration and surprise with debugging codes, and anxiety and boredom about the app requirements were reported. Team 2, for instance, reported frustration related to adapting the new coding interfaces and merging the different interfaces, while Team 6 experienced stress and anxiety due to barriers hindering their coding progress. Social emotions were shaped by factors, such as team dynamics, collaboration effectiveness, and support levels. Team 5, despite initial challenges, for example, reported warmth, trust, unity, and admiration within the team, fostering a positive atmosphere for collaboration, and overcoming challenges together. Team 6, in contrast, reported anger and stress due to various team dynamics such as taking the leadership, and collaboration styles, indicating the impact of team dynamics on social emotions.

4. SUMMARY AND ACKNOWLEDGEMENTS

In conclusion, the participants reported various emotions simultaneously throughout each week, illustrating the dynamic nature of team projects. Our findings align with existing studies on the emotions of CS students by Atiq and Batra (2024), Bosch et al. (2013), Girardi et al. (2021), and Zhuang et al. (2022). However, we offer unique insights by exploring the emotional dynamics in team projects over six weeks. Our study delves into the interplay between topic, achievement, social, and epistemic emotions within collaborative contexts, providing a comprehensive understanding of group dynamics. By capturing the participants' emotional journey that shows the evolution of emotions across weeks during the stages of group development (Bonebright 2010), we highlight both challenges and successes, offering valuable perspectives for supporting students' emotional experiences in team projects. For example, throughout the study, participants experienced a wide range of emotions, encompassing both positive and negative aspects. While confronting challenges, such as coding difficulties, they experienced negative emotions like anxiety and frustration, alongside positive emotions such as excitement, relief, and pride as they worked towards their project objectives. Additionally, our study indicates that participants' emotional responses to the same event varied, evidencing the subjective nature of emotional experiences (Scherer 2005).

In terms of academic emotions, the journey began with topic emotions, such as excitement and interest directly tied to the project task. Alongside these, participants experienced social emotions, including warmth and trust from positive team dynamics. Conversely, there were instances of annoyance and exclusion stemming from certain team interactions, highlighting the complexity of social dynamics within teams. As the project progressed, a dynamic interplay between social and epistemic emotions emerged. Participants grappled with feelings of isolation and inadequacy, reflecting social emotions, while also experiencing frustration due to encountering coding problems or merging issues, which are examples of epistemic emotions (Pekrun and Linnenbrink-Garcia 2012). Towards the finalization of the project, a mix of achievement and social emotions became prevalent. Participants felt a sense of accomplishment and happiness upon successful project completion, coupled with social emotion of pride in presenting their app to others. In short, this emotional turbulence underscores the significance of acknowledging and managing emotions in academic settings, especially within CSE. It highlights the importance of fostering supportive environments that cater to both academic, social, and emotional development (Tormey 2021).

Based on our findings, several didactic strategies can help manage the emotions that arise during team projects. Educators can address emotions in lectures by discussing emotional dynamics, focusing on worries that peak around week 3 and stress related to end-of-semester presentations. Introducing common emotional dynamics at the start of group work can better prepare students. By doing this, they can make students aware of emotional and group dynamics, helping them use this knowledge to improve their teamwork. For a more direct approach, a system could be developed to evaluate and summarize recorded emotions on a dashboard. This would allow lecturers to monitor the emotional state of their students and provide timely support when necessary.

4.1. Future steps

In this study, we have outlined the initial findings concerning the emotions experienced by computer science students in the team projects. Moving forward, our focus will shift toward understanding the social meanings attributed to these emotions within the teams. We aim to investigate how these social interpretations relate to team members' social identity, team learning, and overall satisfaction with the team project experience.

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REFERENCES

Atiq, Zahra. and Batra, Rakhi. "How do first-year engineering students' emotions change while working on programming problems?" *ACM Transactions on Computing Education*, 24, no.2 (2024):1-30. https://doi.org/10.1145/3643865

Bonebright, Denise. A. "40 years of storming: a historical review of Tuckman's model of small group development." *Human Resource Development Internationa,l* 13, no. 1 (2010): 111-120. https://doi.org/10.1080/13678861003589099

Bosch, N., D'Mello, S., and Mills, C. "What emotions do novices experience during their first computer programming learning session?" In *International Conference on Artificial Intelligence in Education*, 11-20. Springer, Berlin, Heidelberg, 2013. Retrieved from https://pnigel.com/papers/bosch-csl1-aied13.pdf

Girardi, D., Lanubile, F., Novielli, N., and Serebrenik, A. "Emotions and perceived productivity of software developers at the workplace." *IEEE Transactions on Software Engineering*, 2021. Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9449979

Kellam, Nadia., Karen, Gerow., Gregory Wilson., Joachim, Walther., and Joshua, Cruz. "Exploring emotional trajectories of engineering students: A narrative research approach." *International Journal of Engineering Education*, 34, no. 6 (2018): 1726-1740. Retrieved from https://www.ijee.ie/latestissues/Vol34-6/02_ijee3672.pdf

Larson, R., and Csikszentmihalyi, M. "The Experience Sampling Method." In: *Flow and the Foundations of Positive Psychology*. Springer, Dordrecht, 2014. https://doi.org/10.1007/978-94-017-9088-8_2

Lin, P. Y. "Qualitative Longitudinal Research." In Okoko, J.M., Tunison, S., Walker, K.D. (eds) *Varieties of Qualitative Research Methods*. Springer Texts in Education. Springer, Cham, 2023. https://doi.org/10.1007/978-3-031-04394-9_62

Lönngren, J., Bellocchi, A., Berge, M., Bøgelund, P., Direito, I., Huff, J. L., Mohd-Yusof, K., Murzi, H., Abdul Rahman, N. F., and Tormey, R. "Emotions in engineering education: A configurative meta-synthesis systematic review." *Journal of Engineering Education*, 1-40 (2024). https://doi.org/10.1002/jee.20600

Lönngren, J., Direito, I., Tormey, R., and Huff, J. L. "Emotions in engineering education." In A. Johri (Ed.), *International handbook of engineering education research*, 156-182. Routledge, 2023. https://doi.org/10.4324/9781003287483-10

Maxwell, J. A. "Qualitative research design: An interactive approach." Sage Publications, 2012.

McLeod, J., and Thomson, R. "*Qualitative longitudinal research*." In Goodwin J. (Ed.), Sage biographical research (Vol 1, pp. 319–342). Sage, 2012.

Muis, K. R., Psaradellis, C., Lajoie, S. P., Di Leo, I., and Chevrier, M. "The role of epistemic emotions in mathematics problem solving." *Contemporary Educational Psychology*, 42 (2015): 172-185. https://psycnet.apa.org/doi/10.1016/j.cedpsych.2015.06.003

Neale, B., Henwood, K., and Holland, J. "Researching lives through time: an introduction to the Timescapes approach." *Qualitative Research* 12, no. 1 (2012): 4-15. https://doi.org/10.1177/1468794111426229

Pekrun, R., and Linnenbrink-Garcia, L. "Academic emotions and student engagement." In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement,* 259–282. Springer Science + Business Media, 2012. https://doi.org/10.1007/978-1-4614-2018-7_12

Scherer, K. R. "What are emotions? And how can they be measured?" *Social Science Information,* 44, no. 4 (2005): 695-729. https://doi.org/10.1177/0539018405058216

Shuman, V., and Scherer, K. R. "Concepts and structures of emotions." In R. Pekrun & L. Linnenbrink-Garcia (Eds*.), International handbook of emotions in education*, 13–35. Routledge/Taylor & Francis Group, 2014.

Tormey, R. "Rethinking student-teacher relationships in higher education: a multidimensional approach." *Higher Education*, 82, no. 5 (2021): 993-1011. https://doi.org/10.1007/s10734-021-00711-w

Van Berkel, N., Ferreira, D., and Kostakos, V. "The experience sampling method on mobile devices." *ACM Computing Surveys* (CSUR) 50, no. 6 (2017): 1-40. https://doi.org/10.1145/3123988

Zhuang, Y., Wang, L., Zheng, Z., Hu, H., Wu, H., and Tao, X. "Towards Emotion-awareness in Programming Education with Behavior-based Emotion Estimation." Paper presented at the 2022. IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC), 2022. https://doi.org/10.1109/COMPSAC54236.2022.9842520

STUDENT RESEARCH SOCIETIES: THE WIDEST FORM OF TALENT DEVELOPMENT

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Conference Key Areas*: Continuing education and life-long learning in engineering, Engineering skills, professional skills, and transversal skills*
Keywords*: High Impact Practice, Student Research Societies, Pandemic*
ABSTRACT

The form of talent development in higher education has existed for over seven decades and has consistently adapted to educational changes and met challenges. The Student Research Societies (SRS) were initiated by talented students who, with the help of their mentors, want to achieve more than what regular education could offer. The inception was followed by dynamic horizontal and vertical expansion. Nowadays, more than 10,000 students participate in the scientific student society movement in Hungary. A legally codified structure deeply embedded in higher education has emerged.

Students prepare scientific papers on topics of their choice with scholarly ambition, engage in research group activities, and present their findings at institutional SRS events. Based on recommendations from a professional jury, authors of worthy papers can participate in the biennial national conference. The National Conference of Student Research Societies (NCSRS) hosts competitions in 16 thematic sections accompanied by numerous community programs. Since 2023, the SRS has become an international event within the framework of the European Engineering Learning Innovation and Science Alliance program.

The SRS is a HIP that significantly enhances both students' learning experiences and outcomes, enriching many with the joy of research and scientific collaboration.

This paper examines the last decade of the Technological Sciences Section, analyzing the satisfaction surveys of the 2019, 2021, and 2023 NCSRS events. We compare the measurement results of the online event held during the pandemic in 2021 with those before and after COVID-19, examining how the pandemic has impacted scientific student association activities.

1 INTRODUCTION

Talent development in higher education can manifest in various forms. Specialized colleges within the public education system can be viewed as counterparts to those special collegiate groups whose material surpasses that of regular courses, deepening and broadening them. However, there are forms unique to higher education, such as specialized collegiate groups. Within these self-organized societies, students can delve into specific fields of study and, functioning as a professional community, engage with issues that interest them. In addition to contributing to the unfolding of talented students and facilitating their acquisition of valuable experiences beyond the compulsory curriculum, members of these specialized collegiate groups also engage in supportive activities. They organize consultations for their peers, participate in university programs promoting disciplines, and visit high schools for career orientation purposes, among other activities. Thus, they offer not only academic but also personal and professional development opportunities for students.

Another important pillar of university talent development is scientific student society activities. The Student Research Societies (SRS in Hungarian TDK) built upon university self-educational societies, have a history spanning more than seven decades. This activity, often referred to as a proper introduction to scientific research, is characterized by the relationship between the student and their mentor.

1.1 Brief history of the SRS movement

The Student Society movement in Hungary emerged in the early 1950s, spurred by teachers and students seeking greater academic freedom. Initially led by Natural and Technological Science Societies, it soon expanded to other fields, fostering research and creative endeavors despite bureaucratic constraints.

The movement gained momentum with the first National Conference of Student Research Societies (NCSRS) in 1955, bolstering student engagement in scientific research. Despite political pressures, it maintained its domestic character, contributing to the elevation of academic standards.

By the 1970s, the movement saw rapid growth, necessitating operational regulations and standardized rewards. The establishment of the National Conference of Student Research Societies (NCSRS) in 1973 further structured the movement's activities.

In subsequent decades, universities actively supported student scholarly pursuits, reflected in the expanding NCSRS (National Conference of Student Research Societies) participation. László Leindler's insights underscored the transformative journey of students towards becoming researchers, emphasizing the role of mentorship and language proficiency.

Structural changes in the 1980s, including the reorganization of NCSRS, marked a shift towards institutionalization and autonomy. The 1990s witnessed further evolution, with increased participation and diversification of sections (Anderle 2011).

Government support in 2013 formalized state backing for Student Societies, aligning with structural changes in higher education. The transition to a three-cycle system highlighted the need for early talent identification, addressed through initiatives like the National Excellence Program.

The New National Excellence Program and the Roska Tamás Scientific Lecture Institution provided additional support, fostering interdisciplinary collaboration and internationalization. By the third millennium, the movement stabilized, embracing online platforms for organization and outreach.

The expansion of NCSRS to Hungarian institutions outside of Hungary (i.e. neighboring nations) in 2013. Since 2023, NCSRS has also been organized for member universities of the European Engineering Learning Innovation and Science Alliance (EELISA). This has underscored the movement's global reach and commitment to innovation. Despite administrative challenges, the movement persevered, adapting to technological advancements and societal needs.

In conclusion, the Hungarian Student Society movement has evolved into a dynamic platform for academic growth and international collaboration, driven by a commitment to excellence and social responsibility.

1.2 National conference of student research societies 2013-2023

The NCSRS is an event of outstanding importance on a national level, combining multiple elements of talent nurturing and development. It is a conference where students can present their scientific achievements, which may have taken several years to accomplish. However, it is also a competitive event, as the awarding process follows strict rules. Also, it serves as a community-building occasion with numerous cultural and sports programs. And all of this is just the pinnacle of the complex talent nurturing process, which can begin when a high school student meets their mentor or when a university student selects an SRS topic of interest. (See Figure 1)

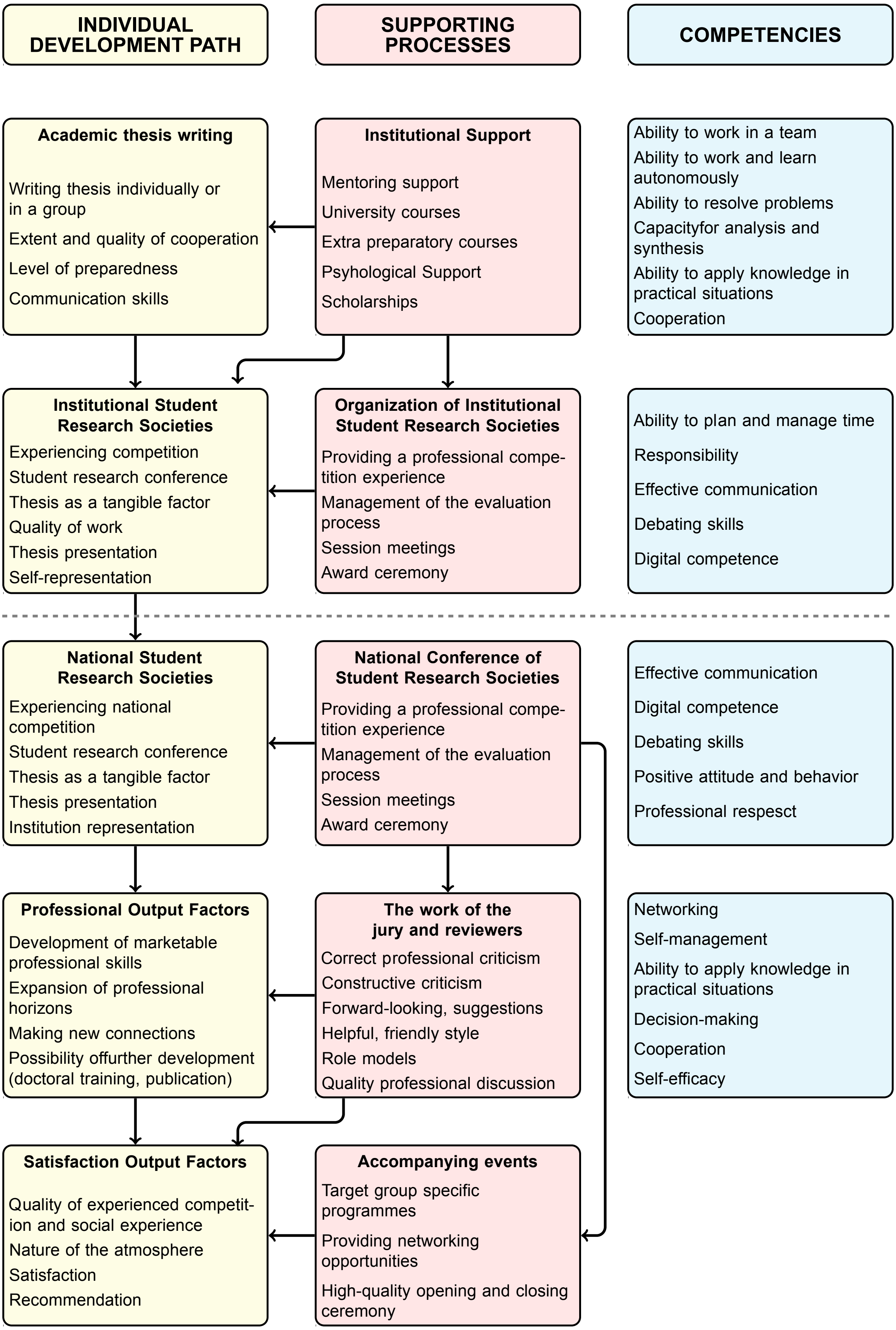

Figure 1: The multifaceted nature of SRS activities.(Koloszár et al. 2024)

In addition to competencies, it is worth discussing the rich array of abilities and skills that are developed through SRS activities. For our analysis, we will use the work of Kolchina and colleagues, who examined which skills are developed in the context of various activities of student societies (Kolchina et al. 2021). Study of the soft skills development in the framework of the activities of student communities. Propósitos y Representaciones, 9(2), 34. The preparation of scientific student papers and the presentation of results significantly contribute to the development of both hard and soft skill groups such as Professional skills (according to the specifics of the activity), Analytical/Research skills, Flexibility/Adaptability skills, and Leadership skills.

1.3 Competition and conference combined

Over the more than seventy years, a ritual has been established for how the biennial conferences, each lasting 3-4 days, unfold. Beyond the opening and closing events, there are many activities that enrich such an event. Personal encounters can facilitate the birth of new relationships and friendships, while cultural, sports, and other activities can alleviate the tension of competition and provide entertainment. The NCSRS differs from a large-scale conference series not only because of the competition but also because it offers a much wider range of optional programs. Besides the traditional city tours, it's common, for example, for choirs to form, performing at the closing event, and there are running races and communal folk-dance classes.

Just as scientific conferences are of fundamental importance to researchers, providing opportunities for meeting and networking with professionals working in similar fields, the same applies to students. NCSRSs foster scientific dialogue among students, where they can discuss their new ideas, theories, and research findings. Throughout the evaluation process and during the presentation of results, they can receive constructive feedback, contributing to the further development and refinement of research projects. Additionally, conferences offer opportunities to learn about new research directions and trends, as well as to expand professional networks and establish collaborations (Carter et al. 2019)(Kondratenko et al. 2022). Students can leverage the experiences gained here in the job market: they can work on real problems in their projects, learn to work in teams, and improve their presentation skills. Such supplementary events accompanying the competition also benefit supervisors, where they can share their experiences and challenges related to supervision. Such academic interactions are essential for the development of the scientific community and the dissemination of knowledge.

Daniel Lynch and his colleagues analyzed the impact of case study competitions on logistics and supply chain on the experiences of participating students, jury members, and alumni of the competitions. Using both quantitative and qualitative analyses, the study demonstrates how these competitions influence students' careers and educational experiences (Lynch et al. 2022). It is not uncommon for students to work independently or with peers on a research project and then present their findings. Many universities around the world organize conferences and competitions for this purpose. What makes the practice in Hungary unique is that these competitions culminate every two years in a single large event involving all higher education institutions in the country.

2 METHODOLOGY

2.1 The evaluation process

The organizers send the submitted entries to at least two reviewers, who evaluate them on the online platform. The presentations of the papers are organized into thematically optimal sections, each containing a minimum of 5 and a maximum of 15 papers. Sectional juries determine the ranking based on written evaluations and oral presentations. According to the rules of NCSRS, one-third of the presented papers in each section can receive first, second, or third place. Only one first place can be awarded in a section. Second and third places may be awarded multiple times, but the number of students ranked second or third may not exceed one third of the total number of entries in a section. Only first place winners in each section are eligible to compete for the most prestigious student awards, the Pro Scientia, Pro Arte, and Junior Pro Scientia Gold Medals. A total of ca. 50 of these are awarded biennially (Szendrő and Cziráki 2009).

The question arises: how does the regulation of the number of winners affect the students? Does it dampen the spirits of participants that even though they might have produced the best paper in their field, they did not receive the first prize? Mihaly Csikszentmihalyi analyses the utility of competition in the context of achieving the "flow" state in his book "Flow: The Psychology of Optimal Experience. (Csikszentmihalyi 1990). When a student is fully immersed in research activities, they can experience "flow." According to Csikszentmihalyi, competition is beneficial when it promotes this state, supporting individual challenges and skill development. However, if competition causes excessive stress or hinders individual development, it goes against the experience of "flow" and becomes detrimental.

3 RESULTS

3.1 Satisfaction measurements

By processing the results of satisfaction surveys, we examined the extent to which participants were satisfied with the professional implementation of the conference and how much their participation in the NSRS contributed to their professional development. The National Council of Student Research Societies deems it essential that the continuous improvement efforts receive feedback. Therefore, in 2019, 2021, and 2023, an online satisfaction survey was conducted. Below, we will analyze the results obtained in the three Technological Sciences Section of the NCSRS. We will specifically address how the pandemic has impacted the SRS activities within the Technological Sciences Section. Respondents were asked to rate the extent to which the statements applied to them and to answer questions. (In 2019 and 2023, a Likert scale ranging from 1 to 6 was used, and in 2021, a Likert scale ranging from 1 to 10 was employed in the measurements, which we considered in our calculations.)

The questions analyzed across all sections and years were as follows (See Table 1):

Q1: *I am satisfied with my own performance.*

Q2: *I had the opportunity to learn about research and research results of people my age.*

Q3: *By learning about others' research, I gained a lot of knowledge.*

Q4: *By learning about others' research, I got many new ideas for continuing my own research.*

Q5: *I felt the section I participated in was professionally coherent.*

Q6: *My own presentation fits professionally into the section.*

Q7: *I received useful feedback from the jury.*

Q8: *After my presentation, the jury asked questions.*

Q9: *During the section meeting, the jury treated me as a partner during my presentation and subsequent discussion.*

Q10: *The written critiques I received for my work were fair and helpful.*

Q11: *I can learn from the written critiques; they help me in my further work.*

Q12: *I gained useful professional connections.*

Table 1: The distribution of responses from the 2021 survey.

	1	2	3	4	5	6	7	8	9	10
Q1	0.66%	3.29%	2.63%	2.63%	3.29%	7.24%	9.87%	29.61%	13.82%	26.97%
Q2	0.66%	1.32%	3.95%	3.95%	5.26%	5.92%	7.24%	31.58%	9.21%	30.92%
Q3	2.63%	3.95%	7.24%	4.61%	11.84%	10.53%	17.76%	17.76%	10.53%	13.16%
Q4	11.84%	10.53%	15.79%	9.87%	9.87%	11.18%	11.18%	9.21%	3.95%	6.58%
Q5	4.61%	3.95%	11.18%	4.61%	10.53%	14.47%	11.84%	15.13%	9.21%	14.47%
Q6	4.61%	1.97%	11.18%	5.92%	3.95%	10.53%	7.24%	13.16%	13.16%	28.29%
Q7	7.24%	3.95%	6.58%	5.92%	3.95%	6.58%	9.87%	15.79%	9.21%	30.92%
Q8	3.95%	5.92%	5.26%	3.95%	2.63%	1.32%	4.61%	16.45%	7.89%	48.03%
Q9	2.63%	1.97%	3.29%	2.63%	1.32%	3.95%	5.26%	23.03%	13.16%	42.76%
Q10	1.97%	3.29%	3.95%	3.29%	4.61%	4.61%	8.55%	17.76%	15.13%	36.84%
Q11	3.29%	3.95%	7.89%	3.29%	6.58%	4.61%	5.92%	15.13%	12.50%	36.84%
Q12	21.05%	9.87%	11.18%	7.89%	10.53%	7.24%	7.24%	9.21%	6.58%	9.21%

We can conclude that the majority of students were very satisfied with the professional execution of the event. However, it should be noted that despite the organizers emphasizing the importance of students building valuable professional connections and being open to learning about their peers' work, 21.05% of respondents felt they did not gain useful professional experience (Q12), and 11.84% felt they did not receive new ideas for continuing their own work. In the second part of our analysis, we were curious to see if satisfaction changed due to the online nature of the conference during the pandemic, and how participants' opinions evolved when things returned to "norma". The distribution of responses to individual questions was not normal, so we used the Mann-Whitney U test to examine if there was a significant difference in responses to the questions in the various surveys. At a significance level of 0.05, the critical value is 1.96. The obtained Z values were always smaller than 1.96 in absolute value, indicating no significant difference between the responses to the examined questions in the two conferences compared.

The questions analyzed (see Table 2) across the Technological Sciences section in 2021 were the following:

S1: *The lockdowns have made it difficult to conduct scientific work at the appropriate level.*

S2: *I didn't have access to the necessary tools for my research.*

S3: *Maintaining communication with my supervisor has become more difficult.*

S4: *My supervisor had more time to assist with my research.*

S5: *I had more time for my SRS research.*

S6: *I gained better access to literature and databases.*

S7: *I wouldn't have even started my SRS if it weren't for the coronavirus and the resulting lockdowns.*

S8: *The institutional/departmental SRS conference was held online, and participating in it was a positive experience for me.*

Table 2: The distribution of responses from the 2021 survey about Covid-19 related questions in the Technological Sciences section

	1	2	3	4	5	6	7	8	9	10
S1	15.12%	12.79%	11.63%	5.81%	10.47%	16.28%	6.98%	13.95%	1.16%	5.81%
S2	25.58%	8.14%	12.79%	4.65%	3.49%	17.44%	5.81%	11.63%	1.16%	9.30%
S3	25.58%	11.63%	11.63%	8.14%	6.98%	12.79%	10.47%	9.30%	1.16%	2.33%
S4	25.58%	15.12%	18.60%	17.44%	11.63%	4.65%	1.16%	4.65%	1.16%	0.00%
S5	19.77%	19.77%	10.47%	6.98%	16.28%	11.63%	4.65%	6.98%	2.33%	1.16%
S6	52.33%	20.93%	9.30%	5.81%	4.65%	1.16%	2.33%	0.00%	2.33%	1.16%
S7	77.91%	6.98%	2.33%	2.33%	5.81%	0.00%	1.16%	2.33%	0.00%	1.16%
S8	11.63%	6.98%	3.49%	11.63%	10.47%	10.47%	6.98%	13.95%	10.47%	13.95%

It is evident that the audience's commitment to SRS is strong (S7) and that the pandemic did not significantly hinder student research work, although it did pose some challenges.

Figure 2: The most important numbers of the last six NCSRS conferences of the past decade

Figure 2 above where the x-axis represents the years, while the y-axis represents the number of submissions. Yellow represents the first, grey the second, brown the third, and mauve indicates the number of special prize winners. For first prizes, we also included the number of Pro Scientia, Pro Arte, and Junior Pro Scientia Gold medalists. It is worth noting that the Covid-19 pandemic did not deter the talents; the number of participants did not decrease. Detailed analyses revealed that while there was a decline in experimental fields due to closures, growth was observed in other scientific areas. This can also be explained by the fact that other activities, even entertainment opportunities, were restricted during online education, especially during quarantine, which created the opportunity for students to focus on preparing their submissions. For the Technological Sciences Section, we also marked the number of first, second, and third-place winners corresponding to the color codes used in the previous figure (see Figure 3).

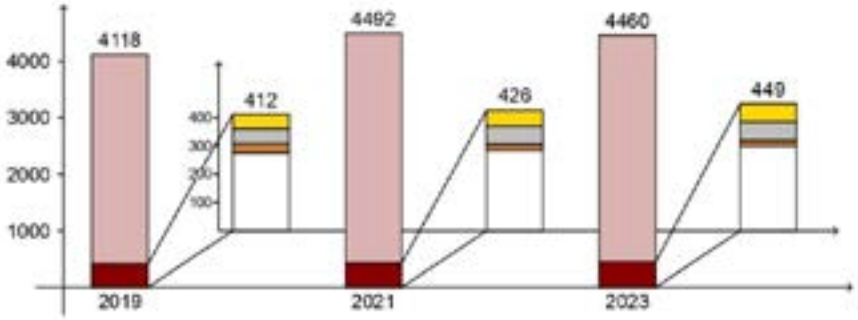

Figure 3: The number of participants in NCSRS (higher bars) and within that, the number of participants in the Technological Sciences Section across the years of satisfaction measurement

Engaging in scientific work as a student can significantly influence participation in doctoral programs. The research experiences gained through SRS activities enhance students' scientific skills and even increase their chances of enrolling in doctoral programs. As a result, students are better prepared for the challenges of doctoral studies and the world of scientific research.

4 SUMMARY

The SRS is a Higher Impact Practice (HIP) in pedagogy that significantly enhances both students' learning experiences and outcomes. From the perspective of modern engineering education, these conferences align with the trend of employing student-centered, project-based learning methodologies that focus on solving real, multifaceted engineering problems. The SRS movement supports the development of skills such as teamwork, communication, global awareness, professionalism, and social responsibility. Additionally, the conferences contribute to the internationalization of education and address future challenges in engineering training. SRS participants acquire individual and collaborative learning and research experiences that they can later leverage in academia and the job market. In the mentor-mentee relationship, the supervisor guides the student's progress, considering their individual abilities and needs.

All of this is practically implemented across virtually every higher education institution in Hungary, deeply embedded in academic activities. The SRS (Student Research Societies) is not only part of the research activities between student and mentor instructor but also deeply integrated into higher education. Participation in the SRS movement (as supervisors, organizers, reviewers) is a factor in academic advancement, and achievements in the NCSRS influence institutional accreditation. While science is important at the NCSRS, what is even more crucial is conveying to students the joy of understanding the world a little bit better and showing them how to stay engaged in this "flow" for as long as possible. This is also an educational task within higher education, setting an example, and perhaps, it's the most beautiful aspect of it all. In their work titled "The XXXIII National Conference of Student Research Societies: SRS Remains the Main Base for Scholar Training," Cziráki

Szabina, Szabó István, and Szendrő Péter conclude with the following thought (Cziráki, Szabó, and Szendrő 2019):

"The enduring success of SRS is built on a slow evolution while respecting traditions and addressing an existing demand for students' acquisition of additional knowledge. Of course, committed educators and researchers are needed who tirelessly strive to assist young talents. Thanks to them, students gain broader knowledge and skills, thus better positioning themselves for research careers or employment in other sectors upon completion of their higher education studies. Therefore, the saying 'SRS is eternal!' is not just a slogan but a fact."

5 Acknowledgement

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6 REFERENCES

Anderle, Ádám. 2011. “Tudományos diákköri konferenciák Magyarországon (1951-2001).” *Országos Tudományos Diákköri Tanács* XXII. (1-4.): 442.

Carter, Joelle D., Monica G. Burke, and Aaron Hughey. 2019. “The Influence of Business Case Study Competitions on Students’ Perceptions of Learning.” *Business and Professional Communication Quarterly* 82 (4): 475–94. https://doi.org/10.1177/2329490619829900.

Csikszentmihalyi, Mihaly. 1990. “Flow: The Psychology of Optimal Experience.” *Harper & Row*, January, 8.

Cziráki, Szabina, István Szabó, and Péter Szendrő. 2019. “XXXIII. Országos Tudományos Diákköri Konferencia: A TDK továbbra is a tudósképzés legfőbb bázisa.” *Magyar Tudomány* 180 (9): 1406–15. https://doi.org/10.1556/2065.180.2019.9.17.

Kolchina, Vera, Dmitry Lukashenko, Marina Sergeeva, and Regina Cherepakhina. 2021. “Study of The Soft Skills Development in The Framework Of The Activities Of Student Communities.” *Propósitos y Representaciones* 9 (March). https://doi.org/10.20511/pyr2021.v9nSPE2.1182.

Koloszár, László, Ágnes Wimmer, Katalin Takácsné György, and Ariel Mitev. 2024. “Tournament Rituals and Experiential Competence Development in Higher Education: A Case of a Unique Conference Series.” *The International Journal of Management Education* 22 (1): 100929. https://doi.org/10.1016/j.ijme.2023.100929.

Kondratenko, Iryna, Tamara Skoryk, Nataliya Drozhzhina, and Iryna Tsurkanenko. 2022. “Art Competitions as a Means of Students’ Creative Growth.” *Revista Romaneasca Pentru Educatie Multidimensionala* 14 (4 Sup.1): 58–67. https://doi.org/10.18662/rrem/14.4Sup1/659.

Lynch, Daniel, Nestor Arguea, Stephen LeMay, Scott Keller, and Bob Kimball. 2022. “Student Experience, Career Influence, and Supply Chain Competitions: A Mixed-Method Analysis of Students, Judges, and Alumni.” *Marketing Education Review* 32 (4): 298–310. https://doi.org/10.1080/10528008.2022.2052323.

Szendrő, Péter, and Szabina Cziráki. 2009. “A tudományos diákkörök szerepe a tehetséggondozásban.” *Educatio* XVIII. (2.): 10.

Evaluation of a strategy training to promote mechanical-mathematical modeling competence in problem solving in Technical Mechanics 1

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ABSTRACT

This research project assessed a strategy training's efficacy in enhancing problem-solving skills among 59 mechanical engineering students at Ruhr West University of Applied Sciences in statics (TM1). Aimed at reducing high failure rates and subsequent student demotivation, the training employed structured tasks based on the problem-solving model in statics (cf. Müller-Slany 2018) and incorporated extensive collaborative reflection processes. It not only encouraged students to apply this process to new problems but also emphasized the importance of independent task completion. In addition to the deliberate execution of schema steps, the intensive reflection on results and problem-solving steps for each task is a key factor in improving problem-solving competence.

An experimental design has shown the intervention group's significant learning gains, with a 15.1% increase in knowledge and 14.8% in application. Correlation,

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variance and regression analyses showed that understanding the problem-solving scheme and the university entrance qualification grade were crucial for applying the scheme effectively, with math grade, prior knowledge, and the strategy training itself as the strongest predictors of scheme understanding, demonstrating the training's direct and indirect effects on problem-solving skills in statics.

Qualitative interviews highlighted the intervention group's deeper reflection on the problem-solving process, leading to a 19.3% higher solution rate in problem-solving in statics and a methodical application of the problem-solving scheme. These findings confirm the significance of structured strategy training in improving statics problem-solving skills. Future research should explore the training's long-term effects and its applicability across various academic and practical scenarios.

1 INTRODUCTION

This intervention study examines the effectiveness of a strategy training to promote problem-solving skills among 59 mechanical engineering students at the Ruhr West University of Applied Sciences in the subject of Technical Mechanics, aiming to counteract the high failure rates that lead to demotivation and dropout (Heublein et al. 2017). Students often lack the ability to transfer acquired knowledge to unknown problems (Bennett, 2005). The developed strategy training aims to bridge this gap.

1.1 Starting Position

The high dropout rate in engineering degree programs is particularly pronounced in mechanical engineering, where disproportionately high dropout rates are often attributed to performance issues and motivational deficits encountered during foundational courses, such as technical mechanics (Musekamp et al. 2014). These findings highlight the challenges in TM education and underscore the need for targeted learning methods to support students

1.2 Theoretical Background

In statics, problems can be successfully solved using a structured problem-solving scheme that always includes the same steps (Beer et al. 2013, Müller-Slany 2018, Gross et al. 2011). Statics tasks are solved through mathematical-mechanical modeling by creating and applying (conceptual) models. These models are solved using mathematical principles, such as formulating and solving equations, to achieve a task result and subsequently reflecting on it (Trump and Borowski 2015).

This process begins with a precise problem definition and the creation of free-body diagrams, which provide a visual basis for the formulation of mathematical equations. These equations enable the description and calculation of forces at rest or motion state.

The entire process involves transforming a real problem into a physical model, followed by mathematical model formation, and finally solving and reflecting to confirm the validity of the results in the context of the given problem. Model formation and the associated careful selection of assumptions are often not actively taught in TM1 education. The focus is on solving tasks in which the physical model is already given (Müller-Slany 2018, Gross et al. 2011, Kautz, Brose and Hoffmann 2018, Direnga 2021).

Research shows that mathematical abilities and subject-specific knowledge are key predictors of modeling competence in mechanics (Brandenburger 2016, Dammann and Lang, 2019, Müller et al. 2018, Fleischer et al. 2019). The university entrance qualification grade and the modeling ability have also been demonstrated to significantly influence performance in TM (Dammann and Lang, 2019). Müller et al. (2018) specifically investigated the role of physical-mathematical modeling on academic success in physics, finding that both mathematical and physical prior knowledge, as well as discipline-specific mathematical modeling, enhance academic success. Direnga (2021) further demonstrated that explicit practice with tasks aimed at training conceptual understanding in TM leads to better exam grades in TM1.

Therefore, teaching should be aimed at promoting these modeling and reflection competences by using an explicit strategy training. With this approach, the learners can not only improve their subject knowledge but also develop a deeper understanding of mechanics, which is essential for future engineering challenges (Musekamp et al. 2014).

1.3 Current state of research

Expertise research indicates that beyond inherent abilities, intensive training and high motivation are required for expertise in any domain, including TM (Gruber and Mandl 1992, Friege 2001). This suggests a necessity for educational interventions that go beyond traditional knowledge transmission, focusing on the application of knowledge through structured problem-solving processes (Wirtz and Strohmer 2013, Renkl, 2010).

The empirical evidence is scarce on long-term strategies that enhance learners' problem-solving abilities in TM1, often relying on conservative teaching formats that limit active engagement with the content (Kautz, Brose and Hoffmann 2018). Innovative teaching approaches that include reflection tasks, coaching by instructors, and active demonstration of heuristics are recommended to foster problem-solving skills in TM1 (Direnga 2021, Schmidt et al. 2020, Woitkowski 2020, Schukajlow et al. 2015).

2 METHODOLOGY

2.1 Research Questions and Hypotheses

This study assesses the effect of strategy training on problem-solving skills and aims to identify crucial factors that contribute to success in solving problems of statics. The following research questions are to be investigated:

- RQ1: How does strategic training influence mechanical engineering students' problem-solving skills in TM1?
- RQ2: What key factors contribute to successful problem-solving in statics?

The primary objective is to assess the strategic training's direct impact on enhancing problem-solving skills, with a focus on understanding the underlying schema and its application to statics problems. To answer these research questions the following assumptions can be formulated.

- H1: Strategic training significantly improves students' problem-solving skills in TM1 by enhancing both knowledge and application of the problem-solving schema.
- H2: Prior knowledge in mechanics, mathematics competence, the university entrance qualification grade and the knowledge about the problem-solving schema are significant predictors of success in problem-solving within statics.

These hypotheses are derived from existing research findings (Brandenburger 2016, Dammann et Lang 2019, Direnga 2021, Müller et al. 2018 and Schukajlow et al. 2015).

2.2 Research Design

This study takes place at the Ruhr West University of Applied Sciences. Using a 2x1 experimental control group design, the intervention's effectiveness is assessed by comparing the experimental group, experiencing the intervention, with a control group following the standard curriculum. By using pre-post design measurements, the initial level of students' problem-solving competence in TM1 can be captured as a control variable. Additional control variables are entrance grades, prior knowledge and schema knowledge. Using the analysis of descriptive data along with normalized learning gains and additional correlational, variance, and regression analyses, the hypotheses will then be investigated. Additionally, a qualitative approach is supplemented to reinforce the quantitative findings through structured interviews that include think-aloud protocols during the problem-solving process of a statics task.

2.3 Description and implementation of the intervention

The participants in the study were students of the Mechanical Engineering program at Ruhr West University of Applied Sciences, who were randomly assigned to groups to ensure the study's validity. The experimental group consists of 30 participants, while the control group includes 29 participants. The participants had an average age of 21.6 years with a male predominance. Data was anonymized, with informed consent obtained through Moodle and seminars. Participation and completion of the tests were mandatory components of the evaluation portfolio for passing the module. The developed intervention uses visual assistances as advance organizers and a structured and continuously repeated provision of exercises and solutions according to the specific problem-solving scheme in statics. By using the combination of structured worked examples, discussions, coaching, and independent completion of tasks through the students with pre-structured exercises, they are guided to reflect on and apply the problem-solving process to new problem situations (Bennett 2005).

The strategy training took place weekly in 95-minute sessions, with mandatory participation within the module framework. Required materials included weekly provided exercise tasks and prepared PowerPoint slides with processed solutions.

These were visually separated according to the schema steps, as well as the given pre-structured exercise tasks, consistently presented for each task and worked example. Initially, students received a brief review of the lecture content on the blackboard, followed by the presentation of the adapted problem-solving process for the weekly changing topic. This was succeeded by the joint discussion and reflection on an example task with a structured solution. After this introduction, students were shown the pre-structured task and began working independently while the instructor acted as a coach. The instructor encouraged peer discussions and observed the students' problem-solving process, always referring to the given schema and providing guidance. Once the majority of the students had solved the task, their solution, including all problem-solving steps, was compared with the prepared PowerPoint slide, and the solution was collectively reflected upon.

2.4 Description and test instruments

To evaluate the efficacy of strategy training two test instruments were developed and piloted. The Performance Test (LT) provides 17 items, each requiring processing through the application of individual problem-solving steps for solving statics tasks. These are open-ended but pre-structured tasks according to the schema steps from the four common topic areas of statics (force systems, bearings, internal forces and trusses). The items are presented in a Moodle test, with students being allotted 90 minutes to complete. The free body diagram is created via drag-and-drop elements, while other inputs for equations are entered directly into the system. Each item is processed step-by-step in the system, ensuring the entire problem-solving process per item is captured in Moodle, allowing overall problem-solving competence to be assessed based on the application of problem-solving steps cumulatively per task.

The Schema Recognition Test (SET) aims to measure the knowledge and understanding of the specific problem-solving schema in statics through 29 multiple-choice and 3 matching questions, implemented in a Moodle test, too. The items query the declarative knowledge about the schema by describing each of the problem-solving steps and their respective disciplinary relevance, as well as analysing (partially) computed tasks through the indication of the next required step or the matching of steps in a non-hierarchically organized solution template. A completion time of 90 minutes is also allocated for this test. The piloting phase yielded results for the LT and the SET. For the LT in the summer semester of 2023, an item reliability of 0.70 and a person reliability of 0.72 were reported with Rasch analysis, with four items of misfit and 63.8% missing responses, explaining 62.8% of the variance across 26 items. In the winter semester of 2023/2024, the LT has shown improved reliability scores (for items of 0.93 and for persons of 0.84) with two items of misfit, 39.5% missing responses and a 65.6% variance explanation across 17 items. The SET from semester 2023, which consists of 32 items, had an item reliability of 0.77 and a person reliability of 0.71. The SET inthe winter semester 2023/2024 demonstrated an item-reliability of 0.90 and a person-reliability of 0.72 across 32 items.

3 RESULTS

3.1 Results through analyses to research hypotheses

The strategy training exhibited a strong effect on the schema knowledge in TM1, with the intervention group showing a significant higher learning gain of 15.1% in schema knowledge, thereby, the intervention demonstrates a large effect size (Cohen's $d = -0.995$) through the group comparison of the sum scores in the SET, explaining 20.5% of the variance in the test. In terms of application, the strategy training also resulted in significant group differences, with a learning gain of 14.8%, a significant high effect size of Cohen's $d = -0.813$ and 14.6% variance explained in LT.

By comparing the sum scores of the groups off the pre- and post-performance tests, it can be seen that the strategy training group initially performed worse on average in the pre-test but achieved significantly higher average scores in the post-test (46.8| 28.3). The results are shown in table 1:

Table 1 Results on effects of intervention (RQ1)

Differences in	t-Test[2]	Normalized Gain	ANOVA
Schema knowledge	$t = -3.81$ $d = -0.995$	$\Delta g = 0.151$	$\eta^2 = 0.205$
Schema application	$t = -3.12$ $d = -0.813$	$\Delta g = 0.148$	$\eta^2 = 0.146$

The following diagram in fig.1 also shows the impact of strategy training on the problem-solving competence in statics (LT). It illustrates the group differences in the sum scores of the pre- and post-performance tests.

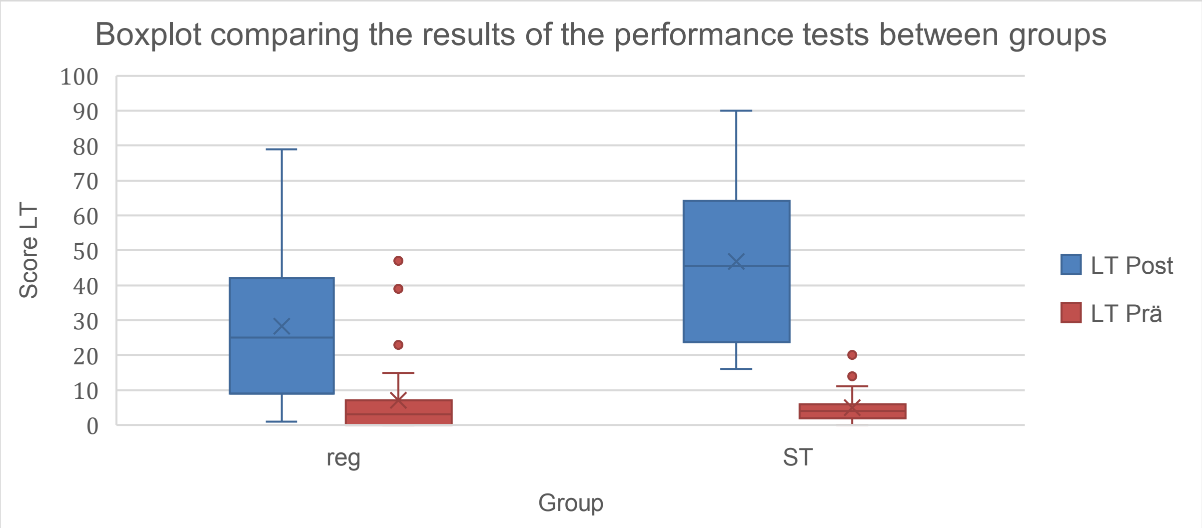

Fig. 1. Boxplots results on performance tests per group

The increased learning gain of the intervention group (ST) is also descriptively evident from the boxplots. The results from the interviews ($N = 10$) underline that the intervention group exhibits a deeper comprehension of the schema, which translates into more adept application in mechanical problem-solving tasks. This proficiency is due to their deliberate execution of the prescribed steps.

As a result of the schema's structure, there is a notably enhanced capacity for reflection — an integral, automatic component of the schema's final step. This is evidenced by a 19.3% improvement in the schema application success rate, assessed using a coding manual aligned with the schema steps, and a marked increase in reflective instances, with an average of 14 additional reflection moments at the given task. With these results hypothesis 1 can be confirmed completely.

To answer research question 2, the results of the final regression models and the relationship between schema knowledge and application are presented in figure 2.

[2] Here, the t-test is used to assess the difference in post-results of both tests between both groups.

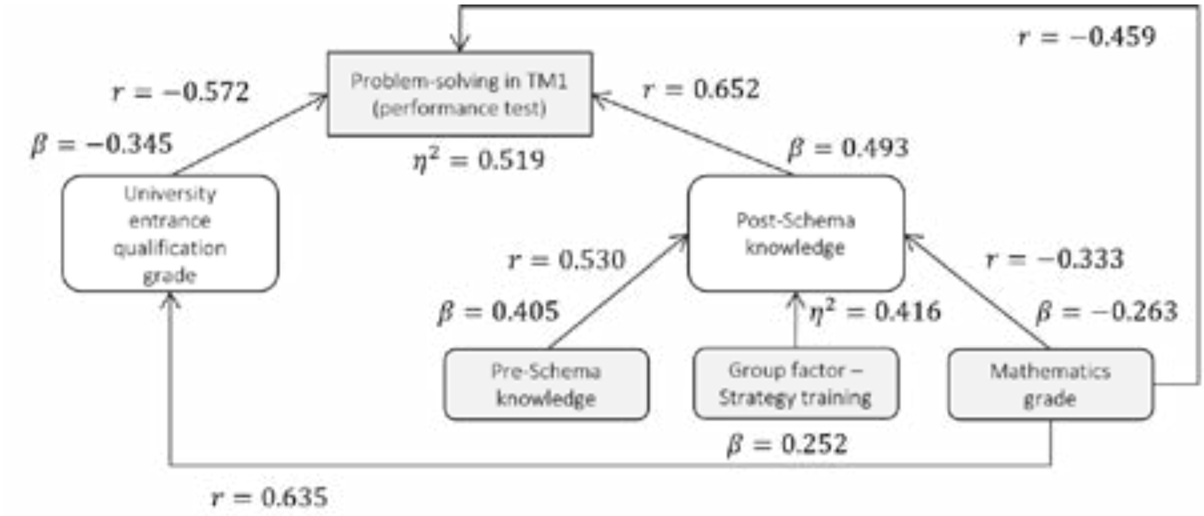

Fig. 2. Results on main predictors on problem-solving in statics (RQ2)

The final regression models for knowledge and performance tests connected through various control variables (prior knowledge TM1, school grades in mathematics, physics and university entrance qualification, schema knowledge and interest as well as self-concept) showcased the strength of post-schema knowledge (SET2) as the most influential factor ($\beta = 0.493$), with the highest correlation ($r = 0.652$) to the performance test. The other significant predictor is the university entrance qualification grade ($\beta = -0.345$ $r = -0.572$), both factors explain 51.9% of the variance in LT.

The other control variables do not represent significant predictors when these two dominant factors are included in the model. However, univariate ANOVAs have indicated that when considered individually, control variables such as prior knowledge, mathematics grade, the university entrance qualification grade, self-concept, the group (strategy training), and schema knowledge are significant influencers. Contrary to expectations, interest and physics grade show no significant nor weak influence on the performance test.

In the final regression model for the post-schema knowledge test, the math grade and pre-schema knowledge are significant predictors, with the group factor also exerting a notable influence. Specifically, post-schema knowledge, which is heavily affected by the group factor ($\beta = 0.252$), is a strong predictor of the performance test. This suggests that the group factor has a direct, significant effect on post-schema knowledge and an indirect effect on the performance test through schema knowledge, underlining the importance of targeted strategy training in improving problem-solving abilities. These results underscore the initial mentioned current state of research (Dammann et Lang 2019, Müller et al. 2018, Brandenburger 2016).

3.2 Discussion of results

In the discussion of results regarding the impact of strategy training on problem-solving competence in statics, it has been observed that strategy training positively influences the application of the problem-solving schema in TM1 (H1), revealing significant performance differences in the performance test between the two groups. The effect was mediated by the students' knowledge of the schema, which emerged as a stronger predictor. This indirect effect highlights the essential role of schema knowledge for effective problem-solving in TM1, thereby justifying the importance of strategy training that focuses on this schema. Students participating in strategy training showed enhanced abilities to reflect on their problem-solving process and outcomes. This suggests that strategy training fosters a deeper understanding. However, the anticipated influence of physics grades on problem-solving competence was not substantiated (H2), suggesting a disconnect between school-level physics and TM1's specific requirements. Conversely, mathematics competence proved to be a significant predictor (H2), emphasizing the foundational role of mathematical skills in engineering problem-solving. The study faced limitations, including a small sample size and the potential influence of the instructor on intervention outcomes. Additionally, the reliance on a single complex task for qualitative analysis might limit the generalizability of the qualitative findings.

4 SUMMARY AND ACKNOWLEDGEMENTS

An experimental control group design with a longitudinal approach implemented in a statics course of mechanical engineering ($N = 59$) showed, based on the results of the self-developed knowledge and performance tests, that the intervention group showed a significantly higher learning gain of 15.1% for the knowledge and 14.8% for the performance tests. The group comparison indicated a strong influence on the problem-solving competence of the students in the knowledge test (Cohen's $d = -0.995, \eta^2 = 0.205, p < 0.001$) and in the performance test (Cohen's $d = -0.813, \eta^2 = 0.146, p = 0.003$). The analysis identified understanding of the problem-solving scheme and the university entrance qualification grade as the main factors for the successful application of the scheme ($\eta^2 = 0.519, p < 0.001$). For scheme understanding, the math grade, prior knowledge, and the strategy training itself ($\eta^2 = 0.416, p < 0.001$) were the strongest predictors. These results demonstrate the direct influence of the intervention on knowledge and an indirect influence on the application of the scheme in problem-solving in TM1. Qualitative data from interviews emphasize that the intervention group reflected more intensively and profoundly on the results and the problem-solving process. The results show a 19.3% increased solution rate in problem-solving in TM1 for the intervention group, with an average increase of 14 units in the number of reflection moments. In addition to more intense reflection and the associated self-correction during the calculation process, a much stronger methodical application of the problem-solving scheme was evident. So, the study underscores the importance of structured strategy training for improving problem-solving skills in statics. Future research should focus on evaluating the long-term effects of the training and investigating the transferability of the approach to other academic and practical contexts. The findings suggest that deeper understanding and application of a problem-solving scheme through targeted educational interventions can be significantly improved, which has far-reaching implications for teaching methods in technical domains.

REFERENCES

Beer, F., and Johnston, E., and Mazurek, D.*Vector Mechanics for Engineers: Statics*. 10th ed. New York: McGraw-Hill Education, 2013.

Bennett, J. *Bringing science to life*: *the research evidence on teaching science in context*. University of York: Department of Educationa Studies, 2005.

Brandenburger, M. *Was beeinflusst den Erfolg beim Problemlösen in der Physik?: Eine Untersuchung mit Studierenden*. Berlin: Logos-Verlag, 2016.

Dammann, E. and Lang, M. „Unterschiede des mathematischen Wissens bei Studierenden des Bauingenieurwesens zu Studienbeginn.“ *Journal of Technical Education,* vol. 7, no.1 (2019): p. 53 – 65. ISSN: 2198-0306.

Direnga, J. *Assessing the effectiveness of research-based active learning materials for introductory engineering mechanics*. Hamburg: Hamburg Advances in Science and Engineering Education Research, vol. 2, 2021. https://doi.org/10.15480/882.3229

Fleischer, J., and Leutner, D., and Brand, M., and Fischer, H., and Lang, M., and Schmiemann, P., and Sumfleth, E. „Vorhersage des Studienabbruchs in naturwissenschaftlich-technischen Studiengängen.“ *Zeitschrift für Erziehungswissenschaften, vol.* 22 (2019): p. 107-1097.

Friege, G. *Wissen und Problemlösen: Eine empirische Untersuchung des wissenszentrierten Problemlösens im Gebiet der Elektrizitätslehre auf der Grundlage des Experten-Novizen-Vergleichs*. In: Studien zum Physiklernen, vol. 19, Logos-Verlag, 2001.

Gross, D., and Hauger, W., and Schröder, J., and Wall, W. *Technische Mechanik 1*. 11th ed. Berlin Heidelberg: Springer Verlag, 2011.

Gruber, H., and Mandl, H. *Das Entstehen von Expertise*. In H. Gruber, H. Mandl & A. Renkl (Hrsg.), *Wege zum Können: Determinanten des Kompetenzerwerbs*. Bern: Huber, 1992.

Heublein, U., and Ebert, J., and Hutzsch, C., and Isleib, S., and König, R., and Richter, J., and Woisch, A. *„Motive und Ursachen des Studienabbruchs an baden-württembergischen Hochschulen und beruflicher Verbleib der Studienabbrecherinnen und Studienabbrecher.“ DZHW Projektbericht*, 2017.

Kautz, C., and Brose, A., and Hoffmann, N. *Tutorien zur Technischen Mechanik*: *Arbeitsmaterialien für das Lehren und Lernen in den Ingenieurwissenschaften.* 1.ed. Heidelberg: Springer Vieweg, 2018.

Musekamp, F., and Spöttl, G., and Mehrafza, M., and Heine, J., and Heene, M. “Modeling of Competences for Students of Engineering Mechanics.” *iJEP,* vol. 4, no. 1 (2014): S.8. http://dx.doi.org/10.3991/ijep.v4i1.2917, 2014.

Müller-Slany, H. *Aufgaben und Lösungsmethodik Technische Mechanik: Mit Strategie Lösungen systematisch erarbeiten.* 2.ed. Wiesbaden: Springer Vieweg, 2018.

Müller, J. and Stender, A., and Borowski, A., and Dammann, E., and Lang, M., and Fischer H. E. „Mathematisches Wissen von Studienanfängern und Studienerfolg.“ *Zeitschrift für Didaktik der Naturwissenschaften (ZfDN),* 2018. https://doi.org/10.1007/s40573-018-0074-y

Renkl, A. *Instruction based on examples*. In S. R. Plass, and R. Moreno, and R. Brünken (Eds.), *Cognitive Load Theory*. Cambridge: Cambridge University Press, 2010.

Schmidt, J. and Libre, N. “Implementation and Evaluation of Active-learning Techniques: Adaptable Activities for a Variety of Engineering Courses.” Paper presented at *ASEE Virtual Annual Conference Content Access*, *virtual, 2020*. DOI:10.18260/1-2—34766

Schukajlow, S., and Kolter, J., and Blum, W. “Scaffolding mathematical modelling with a solution plan.” *ZDM Mathematics Education*, vol. 47, no. 7 (2015): pp. 1241-1254. https://doi.org/10.1007/s11858-015-0707-2.

Trump, S., and Borowski, A. "Modellieren physikalischer Problemstellungen – Zwischen Strukturiertheit und Individualität." In *Authentizität und Lernen: Tagungsbericht*, edited by Martin Maurer, 143-148. Universität Potsdam, 2015. Accessed June 13, 2024. https://www.pedocs.de/volltexte/2016/12125/pdf/Maurer_2015_Authentizitaet_und_Lernen_Tagungsbericht.pdf.

Wirtz, M. A., and Strohmer, J. *Wissen*. In M. A. Wirtz (Hrsg.), *Dorsch – Lexikon der Psychologie*, 16th ed. Bern: Hogrefe, 2013.

Woitkowski, D. “Tracing Physics Content Knowledge Gains Using Content Complexity Levels.” *International Journal of Science Education,* vol. 42, no.10 (July 2020): p. 1585-1608.

PUBLISH OR PERISH: HOW DO CAREERS OF EUROPEAN ENGINEERING EDUCATION RESEARCHERS EVOLVE?

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***Conference Key Areas**: Engineering Education Research, Capacity Building*
***Keywords**: Engineering Education Research, bibliometric research, research careers*

ABSTRACT

The field of Engineering Education Research (EER) in Europe has been steadily growing. Many publications have already focused on the growth of Engineering Education Research (EER) from different perspectives: journals published in, topics handled, methodologies applied, the globalisation of the field, etc. This paper presents an exploratory longitudinal bibliometric study of 54 European researchers in EER, focusing on three indicators: yearly publications, yearly citation, and current h-index. Based on a descriptive approach two conclusions are drawn. First, on average, EER researcher's average h-index is lower than that of researchers in other engineering disciplines. Second, researchers who begin their careers directly in EER demonstrate faster research output than those who start in other fields, while currently the latter group is still the largest. Future work will supplement this descriptive research with qualitative and quantitative investigations into factors influencing yearly research output, including group size, location, and historical context within the EER community.

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1 CONTEXT

Throughout the last 30 years, the research focusing on Engineering Education is gradually growing in Europe (Bernhard 2018, Edström et al. 2018, Malmi et al. 2018, Lima and Mesquita 2018). The evolution of the European Journal of Engineering Education (EJEE) acts as a nice illustration. The journal, founded in 1976, originally focused on teachers sharing their experiences (de Graaff 2017). Thanks to the growth of the Engineering Education Research (EER) community, the number of research papers in EJEE has also systematically grown (Malmi et al. 2018). The success of EJEE was acknowledged by the impact factor it received in 2022.

In the US, the development of the EER field already started in the beginning of the 20th century (Williams et al. 2023). The Journal of Engineering Education (JEE), founded in 1893, culminated in a fully developed citation pattern in recent years (Wankat, Williams and Neto 2014). The tradition of EER in Australia is comparable to the one of Europe: it started around 1980, leading to the first publication in the Australasian Journal of Engineering Education in 1991 (Godfrey and Hadgraft 2009). In Africa few institutions recognise EER as valid research within engineering, but efforts are ongoing to strengthen the research field, including the creation of the Engineering Education Research Network in Africa in 2020 (Matemba et al. 2023).

Within Europe, Sorby et al. (2014) describe the history of EER in Portugal and Ireland. Wint et al. (2022) mapped the EER landscape in Ireland and the UK, and Wint & Nyamapfene (2023) focused more explicitly on the development of EER in UK. Edström et al. (2018) investigated the emergence of an EER-community in the Nordic countries. Very recently, Valentine and Williams (2024) compared the publishing behaviour in different countries in Europe in the time period 2019-2020, but without a longitudinal lens applied.

In this paper, instead of focusing on the EER-topics researched (Borrego 2007, Borrego and Bernhard 2011), the EER-methods used (Malmi et al. 2018), who's working in the field (Williams, Neto and Wankat 2014, Edström et al. 2018), the ratio of educational to non-educational publications (Valentine and Williams 2024), the evolution of the journals (Wankat, Williams and Neto 2014), or the globalisation of the field (Williams, Wankat and Neto 2018), we focus on **how European EER-researchers' output evolves over their career**. The long-term goal is to have a better insight (1) into the careers of EER researchers because this will enable researchers and evaluators to make better estimates of their own and others' careers, instead of just comparing with other engineering disciplines; and (2) into the dimensions that influence careers, so that targeted decisions can be made by researchers. We present and discuss here the results of a first exploratory study where we analysed EER researchers' profiles and their research output. Two research questions (RQ) are answered:

RQ1. What characterizes the European EER-researchers?
RQ2. How does the research output of an EER-researcher evolve in time?

2 METHODOLOGY

2.1 Methodologies used in similar research

Most research aiming to describe the characteristics of the field of research of EER in Europe uses quantitative research methodologies, such as bibliometric analyses based on citation analysis, reference discipline, author geographical location, author affiliation, and author disciplinary field data (Williams, Neto and Wankat 2014, Wankat, Williams and Neto 2014, Wankat, Williams and Neto 2014, Malmi et al. 2018, Williams, Wankat and Neto 2018, Lima and Mesquita 2018). Wint and Nyamapfene (2022) conducted qualitative research, more specifically semi structured interviews. Several authors used mixed methods, such as document analysis of publications supplemented with faculty interviews or narratives (Borrego 2007, Sorby et al. 2014, Edström et al. 2018, Wint et al. 2022). Longitudinal studies are however missing and are therefore the basis of our descriptive analysis implemented in this study.

2.2 Selection of European EER researchers

The goal was to compose a list of EER researchers who:

- published in EER journals (≥1 paper in an EER journal);
- are currently affiliated with a European higher education institute;
- are still active in EER (≥ 1 EER journal of conference publication after 2020).

EER researchers were selected by starting from a list of all members of the SEFI Special Interest Groups and the senior participants at the SEFI Doctoral Symposium (from 2018 to 2024), and then snowballing for additional names. The first criterion focuses on EER journals, which are aiming to improve engineering education through research methodologies. According to Malmi et al. (2018, 171) “EER can be characterized as a field which seeks to (1) build deep understanding of student learning in engineering sciences, (2) identify theoretical underpinnings for innovations in engineering education, and (3) evaluate these innovations to build empirical evidence and better understanding of their impact on students’ learning processes and learning outcomes.” The affiliation was checked through the institute's websites and the researcher's LinkedIn pages. The publications were searched through Scopus, as elaborated in the next section. 54 researchers were finally included in this study.

2.3 EER-researcher profiles and bibliometric research

This exploratory study is based on the EER-researcher profiles and a bibliometric study with Scopus as the research database. For each researcher the following indicators were retrieved:

(i1) country, defined as the country of the European higher education institute the researcher is affiliated to;
(i2) number of yearly citations at the beginning of the EER career and after every 5^{th} year after the start, until and including 2023;
(i3) number of yearly publications at the beginning of the EER career and after every 5^{th} year after the start, until and including 2023;
(i4) h-index on March 29^{th} 2024;

(i5) whether the researcher started their research career in EER (“no transition”) or in another research field (“transition”);

For (i2) and (i3) the beginning of the EER-career of the researcher was defined as the year of the first EER-publication (in a journal or in conference proceedings).

2.4 Analysis

To answer RQ1, descriptive statistics are provided regarding the countries in which EER researchers are active, the length of their EER-careers, their current h-indices, and most cited papers in EER and outside EER (for transition-researchers).

RQ2 is answered by tracking the number of yearly citations and publications of the EER-researchers throughout their EER-career. A linear regression is used to identify a trend for the number of citations and publications as a function of the number of active EER-years. The group of “non-transition” and “transition” EER-researchers is compared and a cross-sectional study of the h-indices is done.

3 RESULTS

The following two sections present the results related to the two research questions.

3.1 What characterizes the European EER-researchers? (RQ1)

The 54 researchers belong to 12 different countries within Europe (Fig. 1). The UK, The Netherlands, Sweden, and Denmark are the countries with the highest number of engineering education researchers associated to their national institutes. Two thirds of the researchers (N=37) have made a transition from another field of research to EER during their academic career, while the remaining one third started their research career directly in EER (N=17). In Sweden, UK, the Netherlands, Portugal, and Norway one can find the largest percentage of “transitioners” among the EER researchers. In Denmark and Switzerland, the opposite can be observed.

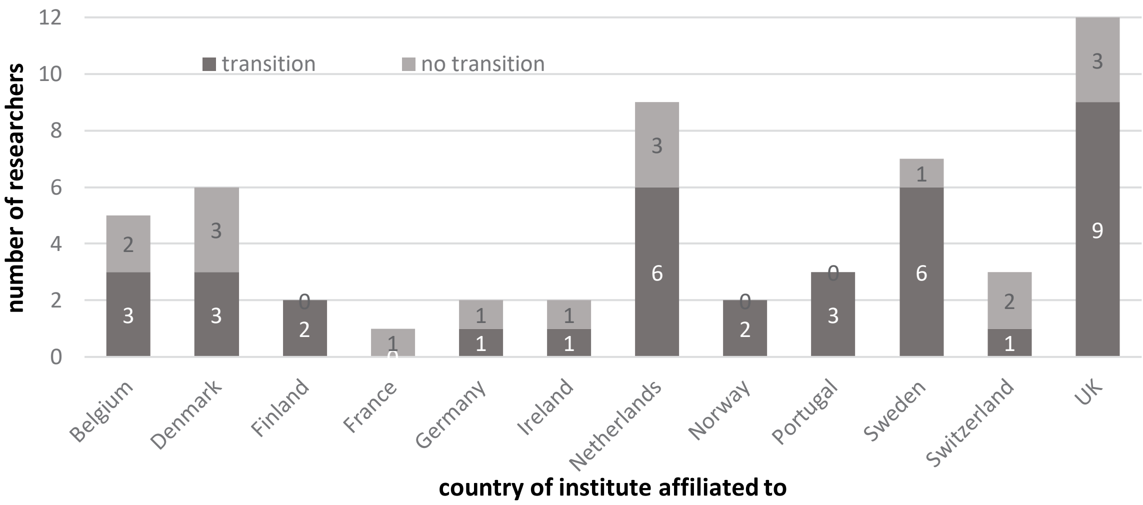

Fig. 1. Number of EER-researchers per country. The different shades indicate whether the number of EER-researchers started their career in another research area (dark: “transition”) or directly in EER (light: “no transition”).

Fig. 2 shows that most researchers have between 5 and 10 years of experience in EER. Among these researchers almost 60% are ‘non-transitioners’. In all the other categories the researcher who made the transition from another research area clearly outnumber the researchers that started their career in EER.

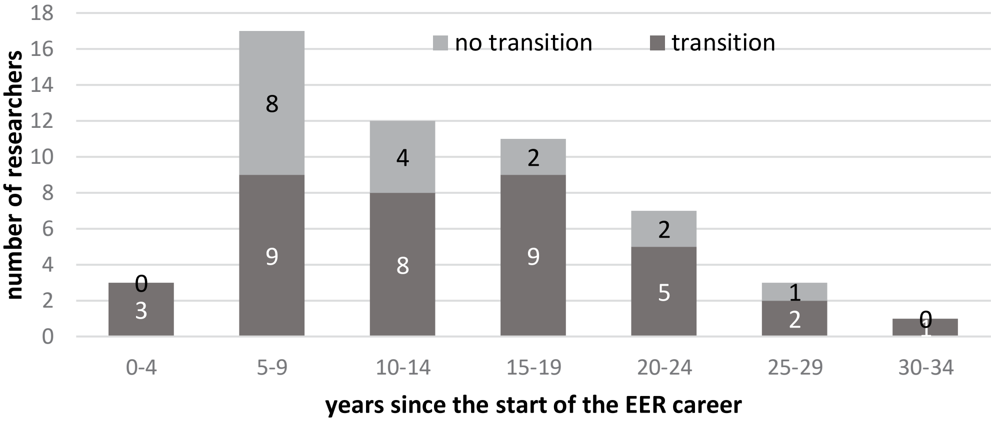

Fig. 2. Number of EER-researchers as a function of the current duration of their EER career*.* *The* different shades *indicate whether the number of EER-researchers started their career in another research area (*dark*: "transition") or directly in EER (*light*: "no transition").*

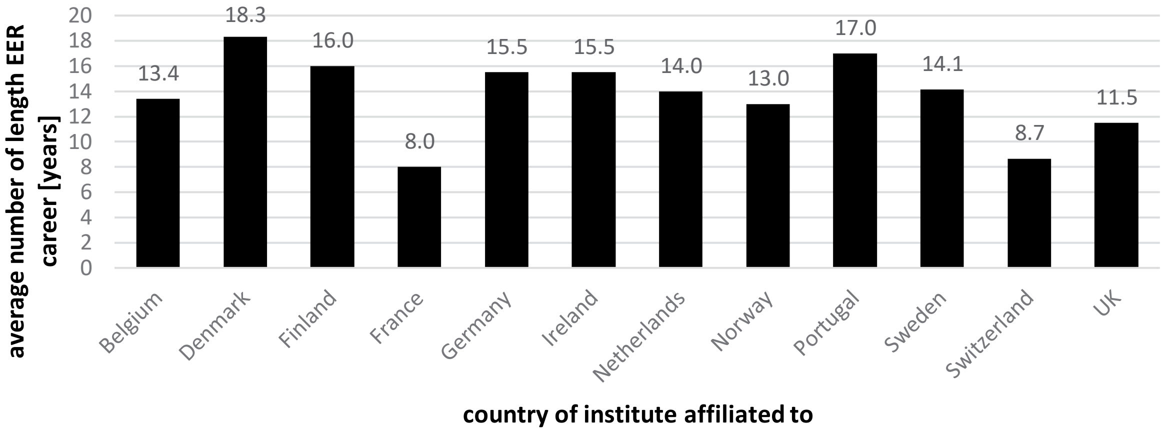

Fig. 3. Average number of years of length of EER career in years per country. Researchers are linked to the country of the institute they are affiliated to.

The EER researchers in Denmark and Portugal are on average the most experienced, as shown in Fig. 3.

The average h-index on March 29th 2024 of the 54 EER-researchers considered in this paper is 9.9. Researchers who started their scientific career in EER have on average lower average h-index ("no transition", average h-index of 8.2) compared to the researchers who started their research career in another research field ("transition", average h-index of 10.8).

The three highest cited EER-publications of the 54 authors respectively count 647, 629, and 295 citations and are about CDIO or/and PBL. For the authors who made the transition, the difference between their highest cited publication in EER and the highest cited publication outside EER can be computed and averaged across all researchers involved. The result is minus 87, indicating that researchers receive a higher number of citations for publications originating from their research career before entering EER.

3.2 How does the research output of an EER-researcher evolve over time? (RQ2)

To answer this research question, we counted the number of yearly publications and citations as researchers progressed throughout their EER career. Fig. 4 shows the number of researchers included in the analysis at the different time slots shown in Figures 5 and 6, associated with the different moments throughout their EER career.

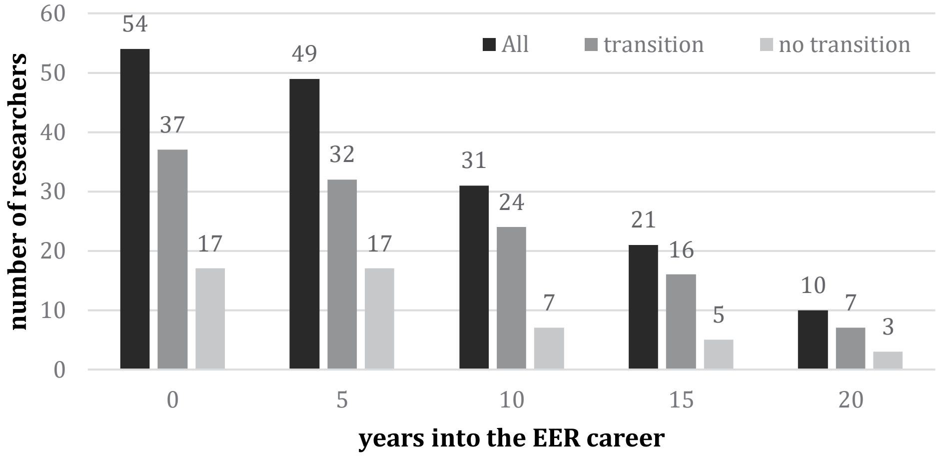

Fig. 4. Number of researchers included in this analysis, at different moments throughout their EER career.

Fig. 5 and Fig. 6 show the evolution of the research output over time using the number of yearly publications and citations, respectively. The time is defined as the number of years the researchers were into their EER career (for each researcher, year zero corresponds to the year of the publication of the first EER-paper). The research output, both in terms of number of papers and in number of citations, on average increases over time for the two types of researchers (transition and no transition). This is showcased in Table 1 by the positive slopes of the regression lines for the six graphs in Fig. 5 and Fig. 6.

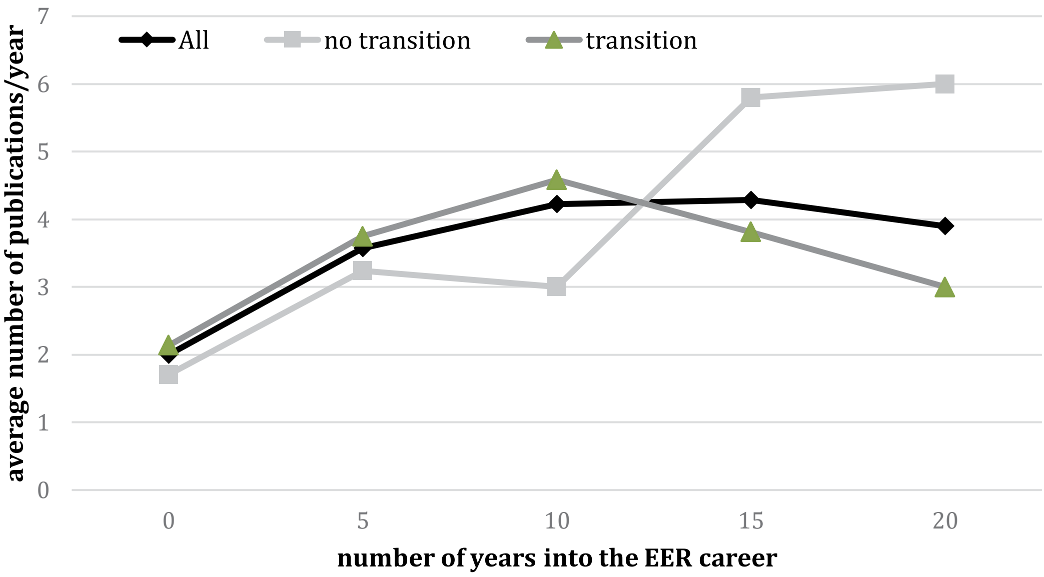

Fig. 5. Average number of publications/year as function of the number of years in the researcher's EER career.

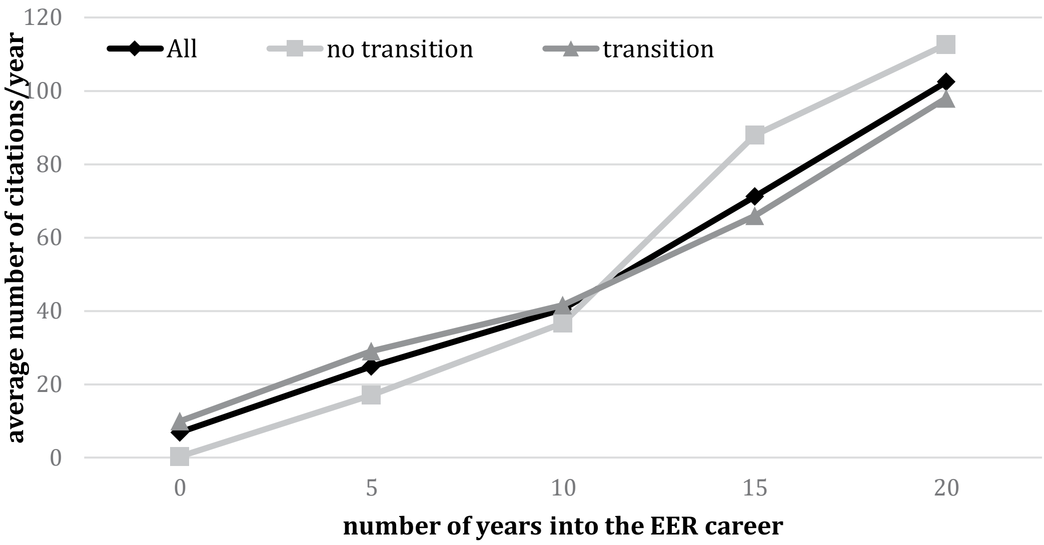

Fig. 6. Average number of citations/year as function of the number of years in the researcher's EER career.

As expected, the current h-index of researchers grows together with the duration of their EER career, as shown in Fig. 7.

Table 1: The slopes of the regression lines for the data in Fig. 5 and Fig. 6.

	all researchers (N=54)	researchers who started in EER (N=17)	researchers who made the transition (N=37)
number of publications/year	0.090	0.22	0.036
number of citations/year	4.7	5.9	4.3

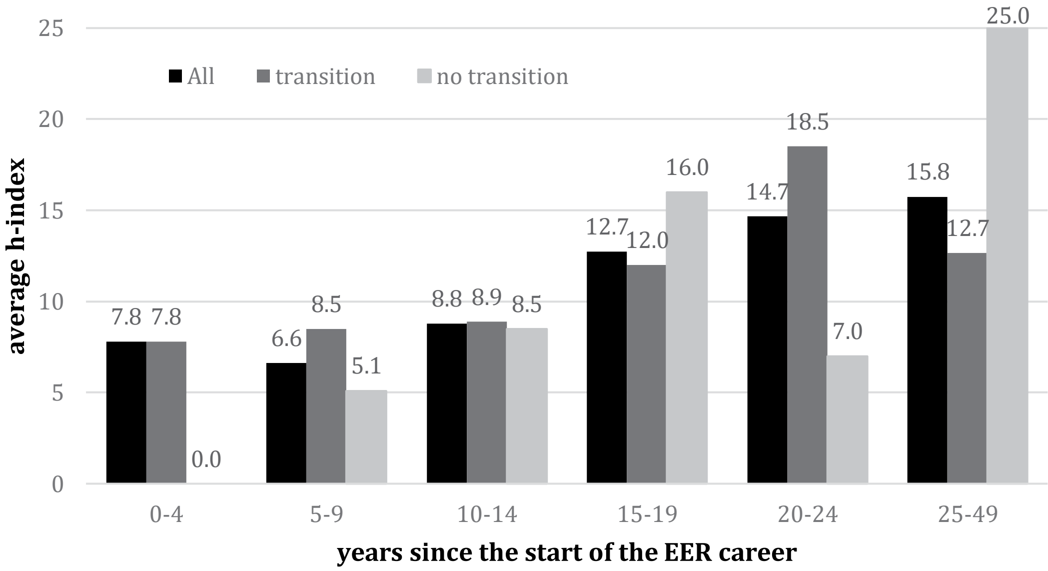

Fig. 7. Cross-sectional study of the average current h-index as a function of the length of the EER-career.

4 DISCUSSION

The 54 researchers included in this research are strictly selected from the SEFI community. As such, a well-defined and diverse subset of the larger EER-research community in Europe is obtained. The precise definition of an EER researcher remains an open topic, making it a valuable area for future investigation. In the paper of Wint and Nyamaphfene (2022), 122 UK EER-authors and 17 Ireland EER-researchers are identified. Edstrom et al. (2018) included in their study a pool of 223 EER-authors: 60 from Danish institutes, 88 from Finland, 7 from Norway, and 69 from Sweden. Valentine and Williams (2024) have 895 unique authors. This study uses a strict definition of EER researchers with close connection to SEFI, resulting in a smaller but more homogeneous research pool.

The 54 included researchers belong to countries where EER started to develop at different moments in different contexts, resulting in research groups of different sizes and with a mix of researchers directly starting their research career in EER or transitioning into EER from other research fields (Fig. 1) and length of their EER career (Fig. 3). Denmark for example counts relatively more experienced researchers and half of them started their career in EER. As can be seen in Table 1, researchers who start directly in EER on average proceed faster in their research output compared to researchers transitioning into EER from other research fields. This is a very promising conclusion for future researchers, and also confirmed by Gardner and Willey (2018) and Borrego (2007) who identified some hurdles experienced by non-EER-researchers who made the transition to EER. Dart, Trad and Blackmore (2021) confirm that many researchers transition to EER after completing technical engineering qualifications and they also identified some inhibitors in the transition.

The increase of the yearly publications and citations and the h-index over time (Fig. 7) is not surprising when considering active researchers (Lima and Mequita 2018, Györffy et al. 2022). Regarding the evolution of the number of publications over the career, Gingras et al. (2008) found a turning point at the age of 40 for the average annual number of papers in the top 10% cited journals. They attribute this decrease after 40 to the increase of the number of less experienced members in the research group. Most EER-research groups are however not yet large enough to see this effect. What we do see in the data, is the effect of previous research in another research field, apparent for instance in the regression model's non-zero yearly citation count in year zero (Fig. 6). Remark that the considerable higher yearly citation of transitioning EER researchers only remains present at the beginning of the EER-career (Fig. 6). A possible explanation is the field-specific publication and citation habits (Stapleton 2023). Humanities and social sciences have the least age-related growth of the independent yearly citation (Györffy et al. 2022).

The irregularities in Fig. 5 and Fig. 6 are caused by the relatively small sample and by consequence by the output of individual researchers. Williams et al. (2014) highlighted the potential of longitudinal research, but also mentioned the need of larger samples.

This descriptive research can be supplemented with qualitative and quantitative research in order to investigate the influence on the yearly research output of additional tasks and responsibilities within the institution; the institutional support for this type of research; the position of the researcher as an innovator or early adopter in the institution; the background of the researcher (discipline, PhD in EER, ...); etc.

REFERENCES

Bernhard, J. (2018) Engineering Education Research in Europe – coming of age, European Journal of Engineering Education, 43:2, 167-170, https://doi.org/10.1080/03043797.2017.1412854.

Borrego, M. (2007). Development of Engineering Education as a Rigorous Discipline: A Study of the Publication Patterns of Four Coalitions. Journal of Engineering Education, 96 (1), 5–18. https://doi.org/10.1002/j.2168-9830.2007.tb00911

Borrego, M. (2007). Conceptual Difficulties Experienced by Trained Engineers Learning Educational Research Methods. Journal of Engineering Education (Washington, D.C.), 96(2), 91–102. https://doi.org/10.1002/j.2168-9830.2007.tb00920.x

Borrego, M, & Bernhard, J. (2011). The emergence of Engineering Education Research as an Internationally Connected Field of Inquiry. Journal of Engineering Education, 100 (1), 14-47. https://doi.org/10.1002/j.2168-9830.2011.tb00003.x

de Graaff, E. (2017). Ten years in engineering education research: looking back ahead. European Journal of Engineering Education, 42(6), 587–590. https://doi.org/10.1080/03043797.2017.1408942

Edström, K.,Kolmos, A., Malmi, L., Bernhard, J., & Andersson, P. (2018) A bottom-up strategy for establishment of EER in three Nordic countries – the role of networks, European Journal of Engineering Education, 43:2, 219-234. https://doi.org/10.1080/03043797.2016.1190956

Gardner, A. & Willey, K. (2018). Academic identity reconstruction: the transition of engineering academics to engineering education researchers, Studies in Higher Education, 43:2, 234-250. https://doi.org/10.1080/03075079.2016.1162779

Gingras Y, Larivière V, Macaluso B, Robitaille J-P (2008) The Effects of Aging on Researchers' Publication and Citation Patterns. PLoS ONE 3(12): e4048. https://doi:org/10.1371/journal.pone.0004048

Godfrey, E., & Hadgraft, R. (2009). Engineering Education Research: Coming of age in Australia and New Zealand. Journal of Engineering Education, 98(4), 307–308. https://doi.org/10.1002/j.2168-9830.2009.tb01028.x

Győrffy, B., Weltz, B., Munkácsy, G., Herman, P., & Szabó, I. (2022). Evaluating Individual Scientific Output Normalized to Publication Age and Academic Field through the Scientometrics.org Project. Methodology, 18(4), 278–297. https://doi.org/10.5964/meth.9463

Lima, R.M., & Mesquita, D. (2018). Engineering Education (Research) in European Countries – an overview based on publications in journals, 3rd International Conference of the Portuguese Society for Engineering Education, Aveiro, Portugal, 2018, pp. 1-6, https://doi.org/10.1109/CISPEE.2018.8593489

Malmi, L., Adawi, T., Curmi, R., de Graaff, E., Duffy, G., Kautz, C., Kinnunen, P., & Williams, B. (2018) How authors did it – a methodological analysis of recent engineering education research papers in the European Journal of Engineering Education, European Journal of Engineering Education, 43:2, 171-189. https://doi.org/10.1080/03043797.2016.1202905

Matemba, E., Smith, L., Wolff, K., Inglis, H., Mogashana, D., Jansen, L., … Nyamapfene, A. (2023). Reflecting on a community of practice for engineering education research capacity in Africa: who are we and where are we going? Australasian Journal of Engineering Education, 28(1), 74–84. https://doi.org/10.1080/22054952.2023.2233340

Sorby, S., Oliveira, J.M., Williams, B., Duffy, G., & Brabazon, D. (2014). A history of Engineering Education Research in Portugal and Ireland. Paper presented at ASEE, Indianapolis, 2014. http://dx.doi.org/10.18260/1-2--19947

Stapleton, A. (2023, June 5). What is a good H-index for each academic position? https://academiainsider.com/what-is-a-good-h-index-for-each-academic-position/

Valentine, A., & Williams, B. (2024). Scientometric analysis of the publishing behaviour of EU + UK authors in engineering education and further afield. European Journal of Engineering Education, 49(2), 389–410. https://doi.org/10.1080/03043797.2023.2287126

Wankat, P. C., Williams, B., & Neto, P. (2014). Engineering education research in European Journal of Engineering Education and Journal of Engineering Education: citation and reference discipline analysis. European Journal of Engineering Education, 39(1), 7–17. https://doi.org/10.1080/03043797.2013.867316

Williams, B., Neto, P., & Wankat, P. C. (2014). Taking a Snapshot: Four Bibliometric Indicators to Track Engineering Education Research Evolution. International Journal of Engineering Pedagogy (iJEP), 4(4), pp. 16–22. https://doi.org/10.3991/ijep.v4i4.3843

Williams, B., Wankat, P. C., & Neto, P. (2018) Not so global: a bibliometric look at engineering education research, European Journal of Engineering Education, 43:2, 190-200, https://doi.org/10.1080/03043797.2016.1153043

Williams, B., Struck Jannini, A. V., Main, J. B., & Knight, D. (2023). JEE in the 21st century: A brief history of the journal and retrospective of three past editors. Journal of Engineering Education (Washington, D.C.), 112(4), 848–851. https://doi.org/10.1002/jee.20558

Wint, N., Murphy, M., Valentine, A., & Williams, B. (2022). Mapping the engineering education research landscape in Ireland and the UK. Paper presented at SEFI 50th Annual conference of The European Society for Engineering Education, Barcelona: Universitat Politècnica de Catalunya, 2022, p. 862-871. https://doi.org/10.5821/conference-9788412322262.1276

Wint, N., & Nyamapfene, A. (2023). The development of engineering education research: a UK based case study. European Journal of Engineering Education, 48(2), 197–220. https://doi.org/10.1080/03043797.2022.2121686

Phronesis in a Complex World: Normative Education and Climate Change Ethics

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Conference Key Areas: *Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing* & Engineering ethics education
Keywords: *Climate Change; Ethics; Phronesis; Educational Psychology; Moral Development*

ABSTRACT

Climate change is a complex and wicked problem, both its problem definition as its proposed solutions are controversial and relate to many different interlinked socio-political domains. However, this complexity should not lead to inertia, the crisis is urgent and we need to act. Educators are thus tasked with maintaining a challenging balance between teaching technical knowledge while also fostering a sense of ethical responsibility in students. They need to do this for a problem on which the ethical approaches are up for debate. This paper reflects critically on the notion of Phronesis (practical wisdom) as it is introduced as a pedagogical approach for ethics in higher education on the moral dilemmas of climate change. Phronesis is not in itself a theory on how to act, but rather it provides the domains necessary for moral development in students for the ethical reflection and practices regarding the complexities of the modern world. Education for responsible engineers should teach students to (1) recognize morally salient elements of the world; (2) recognize how these are integrated (3) integrate these in one's moral identity and lastly (4) be affectively invested in this moral identity. This paper argues that Phronesis can work as a didactical tool for systematically and purposefully engineering moral education, while also showing its limits compared to more classical approaches of rationalistic models of teaching ethics. In doing so, it tries to bridge a gap between the content and focus of moral education in climate change. (234 words)

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Introduction

Climate change is a problem emblematic of wicked problems in the Anthropocene: greatly urgent, complex and unprecedented (Tromp, 2018; Incropera, 2016). This dire nature of climate change requires innovate ways of knowledge production and transfer. In other words, higher education institutes (universities and colleges) play a fundamentally important part in the way we think about, and act on, climate change. Mitigation of, and adaptation to, climate change requires highly specific technical knowledge, but, as is inherent to wicked problems, also a knowledge of society, humanity and ethics. The transfer of technical knowledge is a strong element in engineering education, but there is a division of labor where normative reflection on novel technologies is not traditionally a central part part of engineering curricula (i.e. Chech, 2013). However, the integration of the normative with the technical is fundamental for tacking climate change issues. As Reimers (2021) puts it:

The motivation to invent more sustainable ways of life requires more than an understanding of the science of climate change, the capacity to design technological innovations, or an ethical framework that help us aspire to live in more inclusive and sustainable communities, it requires an understanding of social systems and the development of ethical reasoning that can help us integrate critical thinking about the current impact of climate change, our moral imagination, the personal motivation to act and our competency to act in effective ways. (p. 4).

However, currently there is no clear framework for integrating ethics into climate change curricula. There is not a clear conceptual framework for distinguishing the technical and the normative, or even if a demarcation between technical science and values is even tangible (Douglas, 2009).

Furthermore, ethics in engineering education might be superfluous when it is only a form of abstract theory, as the point of ethical reasoning is to make more responsible decisions (act differently) in the world. As Midgley (2000) puts it: “gaining knowledge is not just collecting and storing facts, but becoming trained in handling them” (p.54). So, on the one hand there is the theoretical dimension of understanding the normative dilemmas of climate change, but on the other hand the university needs to provide students personal tools for the internalization of normative reasoning.

This approach is also framed as a requirement for a combination of academic (technical) knowledge with Phronesis (Tassone et. al., 2016). So, there is a conceptual ethical goal of mapping out the normative topoi in climate change on the one hand, and the effective didactical and pedagogical approaches of integrating ethics in higher engineering education on the other.

This article aims to provide a theoretical background for the development and feasibility of Phronesis in climate change education. It aims to map the normative dimensions of climate change as a reference point for the meaning of Phronesis in the age of the Anthropocene. Specific pedagogical practices may be drawn from that, but the translation of climate change normativity to specific educational practices is a different level of analysis. Thus the main research question of this article is: what should be the normative and pedagogical focus of higher education curricula regarding climate change? This article will start with a conceptual description of Phronesis, secondly it will integrate this concept in the normative problems of climate change. Lastly, this will culminate in normative pedagogical guidelines that may ground pedagogical strategies.

Education and Phronesis

The concept of Phronesis is rooted strongly in virtue-ethical theory. Rather than focusing on deductive ethics, starting from a general ethical rule and applying that rule to a specific situation, the concept signifies an inner mental state of virtue regarding a practical context. To be more specific, Phronesis refers to a form of practical knowledge (Kakkori & Huttunen, 2007, p. 20). For Aristotle, the cultivation of Phronesis is a necessary condition for an effective praxis of other virtues. In this regard, Phronesis is qualitatively different from the other virtues, as a person might be virtuous in one sphere of life, and not so much in others, but without an attitude of Phronesis a virtuous life is unreachable (Dunne, 2005, p. 52). The virtue-ethicist character of practical knowledge does not necessarily lead to a meta-ethical stance of moral particularism. Phronesis is categorized by Aristotle as a form of intelligence, but is eccentric as it is a prerequisite for ethical life (or conversely, living an ethical life is a signifier for the mastering of Phronesis) (ibid.). As a form of intelligence, certain ethical principles may guide ones' attitude in moral contemplation regarding a specific situation. However, the meaning and implementation of those principles is dependent on the particularities of that given situation.

In this sense, practical knowledge or virtues rationality is the anti-thesis to the instrumental rationality that is dominant in neo-liberal discourse. Its focus on the affective, narrative, and contextual nature of the human condition and its focus on practice, rather than providing some ultimate ontological conceptualization of 'the good', makes it a rather descriptive concept of the psychological attributes and competences of a virtues person, which has a plurality of normative dimensions as its starting point (Duvenage, 2015, p. 80). This 'mediating character' (between abstract meta-ethical principles and practical behavior) makes it applicable for educational purposes, as the basis for a pedagogical theory of moral development. Furthermore, it is specifically relevant for engineering education, as implementing abstract ethical principles in concrete, hands-on technology is one of the main challenges in engineering (Floridi, 2019).

The way in which Phronesis might have pedagogical usefulness is that it is a possible bridge between moral theory and moral practice. The simple fact that a person holds moral belief A, or is familiar with an ethical theory prescribing A, does not automatically mean that their actions will align with this belief. On the contrary, there is even some evidence that moral behavior is not that strongly related to moral believe at all (i.e. Haidt, 2001). Simply learning about moral theory, therefore, might not be a very effective way of educating ethics. Moral theory runs the risk of becoming a tool for moral confabulation or rationalization, rather than a tool for moral decision-making (Floridi, 2019). Action A is justified by Moral Theory A, retroactively in this model. This is opposite of the goal of moral education where Moral Theory A grounds the motivation behind Action A.

The great benefit of a moral pedagogy of Phronesis, therefore, is that it opens up pedagogical room for the cultivation of moral identity and emotion. This line of reasoning is well explained by Darnell et al. (2019) who build on the Aristotelian notion of Phronesis and sub-divide it into four different cognitive and affective functions, here summarized as:

Table 1: four dimensions of Phronesis

Constitutive Function	An ability to perceive the morally salient elements of a given situation and what is necessary to respond appropriately.
Integrative Function	Integrating different components of the good life to act wisely when ethically salient values are in conflict.
Blueprint	An integration of a conception of the good in one's moral identity.
Emotional Regulation	To be affectively invested in, and in line with, one's ethical convictions (not to be confused with 'limiting one's emotions)

Although Darnell et al. relate their psychological model of moral decision-making to moral pedagogy, it is not their main concern. However, it is indictive of how theoretical insight from moral psychology might inform effective moral education. This approach of Phronesis has a strong focus on moral affect, which is in contrast with the influential classical Kohlbergian model of moral development, which is focused more strongly on the cognitive understanding of moral principles. A discussion on the stages of moral development in the Kohlbergian paradigm is beyond the focus of this paper. The point is that this influential paradigm takes a classical rationalist approach to moral theorizing, which is criticized widely to fall short when it comes to moral practices (i.e. Carpendale, 2000). However, as Darnell et al. (2019) note, neo-Kohlbergians put more emphasis on the role of affect and moral identity in moral pedagogy. They conclude that the neo-Kohlbergian paradigm is not fundamentally incommensurable with their Aristotelian four-component operationalization of Phronesis.

So, the concept of Phronesis is useful when it comes to the translation of moral convictions into practice. Teaching ethics is not a merely cognitive endeavor, students have to be emotionally engaged with the material, and learn ethical principles not as external to themselves (for instance as part of a given ethical theory). Rather, teaching ethics is, at least partly, like teaching a competence that is more than the ability to regurgitate abstract ethical theory. However, Phronesis as practical wisdom has only been discussed on the conceptual level. Especially if we accept that moral competency involves one's attitudes and actions towards their surroundings, the concept of Phronesis should be applied to a real-life normative context. The next section will therefore discuss the normative dimensions of climate change. This will not only provide a context for a discussion on Phronesis, but also provide a framework for the content of climate change ethics education.

Ethics in Climate Change

There is no one ethics of climate change, as climate change is not one thing. It is a set of processes that are interlinked and over-determined. Climate Change has no one single moral object or subject. The moral complexity of climate change goes even deeper than a multitude of moral subjects with conflicting interests: there is strong disagreement on what even the moral subjects are. Often, normative discourse on climate change discusses future generations, but as future generations do not exist, per definition, it is not clear why we should have moral obligations towards them (Beyleveld, Düwell & Spahn, 2015). Climate Change drives horrendous extinction-rates, but species themselves are just biological categories, it is not clear why and if a collection of animals should be morally considered, especially when this conflicts with the interests of individual animals (Marris, 2020). All of this is not to say that future generations or species should not be morally considered, it is just to say that any discussion of climate change will sink into ethical and ontological quicksand when focused on one single aspect of its normative consequences.

Considering this complexity the discussion of the ethics of climate change will be extremely course-grained and, therefore, limited. It is not meant as an in-depth discussion of what humanities way forward in our geological predicament ought to be. The point of the discussion is to provide an overview of the basic moral approaches that arise in the face of the Anthropocene that can be the starting point of pedagogical approaches to climate change, especially when it comes to the cultivation of Phronesis as discussed above.

The starting point of the discussion is Miller and Eggleston's (2020) overview study *Moral Theory and Climate Change*. Instead of taking one aspect of climate change as a starting point, their study focuses on dominant ethical-theoretical frameworks and their applicability to climate change. This 'theory-first' approach fits the aim of this article well, as it provides a range of guiding principles, or normative foci, to consider the wide range of ethical dilemmas that arise on the warming planet. Studies that take a more 'bottom-up' approach are very suitable for fleshing out the moral conflicts within any given particular situation, but do not provide an overview of the different ethical principles that might guide our moral reasoning a-priori. Therefore, the top-down/theory-first approach fits better with the aim of providing the normative theoretical background in climate change ethics education.

The most salient distinction in the ethics of climate change on the theoretical level is the conceptual distinction between the personal and the systemic level. Almost all moral theories admit that the global and political/economic nature of climate change asks for a multi-leveled approach: combining both personal and political ethics. Following this multi-leveled approach, table 2 (appendix) will provide an overview of the different normative frameworks regarding climate change, this will be used to reflect on the meaning, feasibility and applicability of Phronesis in the teaching of climate change ethics.

Almost all scholars recognize the difficulty of applying ethics to a problem that has a) grave moral consequences and b) is outside the sphere of influence of any single actor. This does not mean that climate change is a classical collective action problem. I.e., climate change is different from providing a moral justification for paying for one's train ticket -even though deflecting from paying has no measurable effects on the world.

Gardinger (2006) explains well how climate change is different from a standard collective action problem. An extensive discussion on moral game theory is far beyond the scope of this paper, but the way in which climate change is a rather unique moral problem, or a "perfect moral storm" is in that is involves 1) a dispersion of causes and effects 2) a fragmentation of agency and 3) institutional inadequacy. In other words: to know what should be done, one should at least know what can be done, but the causal pathways driving climate change are very dispersed. Furthermore, as discussed, the moral scope is very opaque. And lastly, there are no institutional agents to restrict deflecting behavior adequately. This leaves a difficult moral-theoretical lacune, as focusing on one single aspect of climate change can actually be a way of deflecting, as it can be a way of avoiding the more costly necessities of mitigating climate change. Behaving ethically can be a way to behave unethically in climate change.

Being a Phronemos in the Anthropocene

Following the focus on policy-changes (rather than individual ethics) dominant in the (meta-) ethical paradigms, the conceptualization of phronesis as presented in the first part of this paper might not seem the right approach to moral education at first-glance. Or, it might have limited applicability, for instance in education for students in politics, but not as a more engineering-oriented approach to teaching climate-change ethics. Following table 2, most ethical theories leave little room for individual agency in the context of climate change, apart from -unsurprisingly- the virtue-ethicist approach. The great downside of the virtue-ethicist approach, however, is that it provides no framework on which virtues are central to the moral problem of climate change, or what it actually means in practice to live these virtues.

However, following Gardingers concerns of moral theorizing in climate change, Phronesis as a didactical approach might still be rather useful. The moral lacune of climate change asks for a re-orientation between the different moral schema's that philosophical theory has generated. This might be analogous to Kuhn's ideas of paradigm shifts. After a period of 'normal ethics' focused on puzzle-solving (how does theory x apply to moral problem z), we slowly get in a phase of 'crisis ethics' (with the anomaly of climate change). This means that in developing new technologies, we might have to think differently about their function. More fundamentally, engineering education is also about re-considering the role of oneself as an engineer. Moving beyond notions of instrumental rationality as explained in the theoretical framework, towards a reflective agent following virtues of environmental sustainability (Jordan & Kristjánsson, 2013)

Constitutive function

Different ethical theories may provide normative foci for interpreting the problem of climate change, in other words, have a constitutive function (as defined in table 1), rather than being treated as ethical-epistemic starting points that are incommensurable with each other. In more educational terms, this means that on a cognitive level, inquiry-based learning might appropriate when it comes to climate change ethics. Of course, recognizing salient values is extremely difficult and prone to biases. Here, ethical theory can, again, serve as a scaffolding-method of guiding the inquiry, rather than as a starting point of moral education. It is important to note that 'passive-learning', that is just learning the main concepts of a certain ethical theory has little effectiveness in higher education, especially engineering education (Newberry, 2004). A more pedagogically sound approach to teaching ethical theory is case-based learning. That is, teaching ethical theory in the way they are relevant in applied cases (Haws, 2013). However, as both these authors note, case-study based learning is not in itself sufficient for engineering education, as it does not necessarily foster sense of emotional engagement with the content. In other words, and to illuminate more the link with climate change: theory focused pedagogy is a necessary but insufficient method for cultivating sustainable virtues in engineering education students.

Integrative function

Regarding the problem of fragmentation of agency, educational practices can focus specifically on the level of analysis and, in effect, short-comings of any particular moral theory or normative focus. The rationalistic focus of Kantianism, for example, might be critiqued for being very anthropocentric[2] and individualistic. Pedagogically, methods like participatory simulations can be a way to get students familiar with the conflicts of values between different theories, and the levels of analysis that they play out on (Jacobson & Wilensky, 2006). To stay with the example of Kantian anthropocentrism and methodological individualism: a participatory simulation can involve an institutional actor, forcing students to re-think state-responsibility and animal representation while also getting familiar with Kantian theory cognitively. This is thus a different pedagogical method than case-based learning, as presented above. This approach fits more with the pedagogical goal of intellectual engagement than emotional engagement (Newberry, 2004). However, it is important pedagogically for engineering students to understand that ethics is more than the application of rules (as might be the risk with case-based learning only). Doing ethical heuristics, as is the case with participatory simulation, fosters a sense of understanding of the plurality of ethical approaches. However, as Haws (2013) notes, it might leave the impression that ethics is mainly about argument rather than acting. Further, some ethical theories might be easier to implement this way than others.

Blueprint

On the more affect-side of moral education, integrating values in one's moral identity is an important part in teaching ethics on a general level (see also Newberry, 2014). However, when it comes to climate change ethics, it is not clear what a moral identity might constitute in everyday life. Here, the virtue-ethics perspective of table 2 is obviously very relevant (a blueprint of the good life might entail a concern for all sentient beings, for instance), but again, there is no clear framework for which values are central in climate change ethics, especially in the very constructivist virtue-ethicist tradition. However, following the constitutive and integration functions that treats moral theory as foci, role-modeling can be a starting point for the development of moral identity in higher education.

Concretely this means that students may identify role models based on the value constitution and integration functionalities. Coming back to table 2., this means that positive role-models might serve as an exemplar for moral identity, giving blueprint a different meaning. There is some evidence that role-modeling has positive effects on the development of a moral identity in pedagogical practices (see Sanderse, 2013 for an overview). However, the concept of role-modeling presupposes a very prescriptive teacher-student dynamic as it treats explicitly the teacher herself as a role model. This might conflict with an ideal of neutrality that is still widely regarded in education, especially when it comes to higher education issues (Hess, 2002). Plenary class discussions, which are an important aspect in ethics education in general (ibid.) might not always be the right approach in fostering affective engagement through pedagogy. There is some evidence that students get defensive, rather than open-minded, when discussing topics that are affectively important for them (de Clerck & Rutten, 2014). Pedagogical tools that focus more on empathy than argument such as rhetorical listening might overcome such shortcomings. However, climate change is a

[2] Obviously, there are prominent exceptions like Regan (1983), if you like replace "Kantianism" with "traditional Kantian ethics".

difficult case as much of its effects regard people that are far away spatially or temporarily.

Emotional regulation

Moral education specifically centers around emotion. The links between moral belief and moral action are, at least partly, regulated by affect. The specific functions of affect in shaping moral behavior are touched upon in the first section of this article, but largely beyond the scope of this paper. When it comes to climate change ethics, emotions are integral as well. Especially salient for emotional regulation in the context of Phronesis is the role emotions play in changing attitudes and behavior towards climate change. Empirical research shows that learning about climate change has affectional effects, leaning towards negative emotions, often clustered under the term 'eco-anxiety'. However, this does not necessarily lead to a reduced sense of efficacy, it might even increase it (Maran & Begotti, 2021). The same study caveats that excessive exposure to information on climate change might also lead to 'eco-paralysis. This means that pedagogically, these emotions should be mitigated constructively. There is some qualitative evidence that collective action has a positive effect on mitigating eco-paralysis. In pedagogical terms, this urges teachers to focus on empowerment (see for instance Tassone, 2017 for empowerment pedagogy in higher education).

In this sense, Phronesis is both conceptually and practically a useful lens for moral education. On the other hand, Phronesis is centered strongly around individual moral development, as argued in the second section of this paper this is a too limited focus when it comes to climate change, both ethically and emotionally. The important paper by Newberry (2004) shows that pedagogy on emotional engagement is limited by what he calls the 'gravitational pull' of engineering curriculum. Students respond to what is being deemed important institutionally, and if practical ethics is a minor part of this, students respond accordingly affectively. In other research (Loonstra & Tassone, 2024) I have mapped the learning domains of a technical university as they are reflected in the intended curriculum. Indeed, affect-oriented learning goals are least dominant. A true change towards emotional engagement with ethics follows probably from an institutional change in the goals of the university, more even than specific pedagogical approaches..

Conclusion

Climate change is one of the most urgent problems of modernity. It touches upon virtually every sphere of life and is characterized by great wickedness. The anthropogenic nature of climate change and its dire effects make it a difficult normative problem. Technical knowledge and values are deeply intertwined, or at least extremely difficult to separate. Universities, as knowledge-producing institutions, have an important role to play in providing students with the right tools to understand climate change, and respond to it ethically. This practice-oriented goal of ethical competency asks for an integration of moral theory and affect in pedagogical practices.

This article has provided a conceptual analysis of Phronesis, an Aristotelian notion of the framework of education focused on moral pedagogy specifically. Phronesis is the counter-part of Kohlbergian approaches that were long paradigmatic in moral education, but are criticized for being too rationalistic. Phronesis can be understood as a form of practical wisdom, stemming from the cultivation of values in one's moral identity. Following Phronesis, moral education should focus on the cultivation of a 1) constitutive function 2) integrative function 3) moral blueprint and 4) emotional regulation. To analyze the ethical and practical feasibility of Phronesis in moral education it was juxta-positioned with the most prominent ethical schools of thought (utilitarianism, deontology and virtue-ethics) and their response to the climate crisis.

Phronesis has a strong focus on individual moral development, and might therefore, following the focus of the most dominant ethical approaches to climate change ethics, not be very well-suited for moral education on systemic issues. However, this article proposes that, as the most paradigmatic approaches to climate change ethics come with great intra theory-shortcomings as well (analogous to a Kuhnian crisis-science), the concept of Phronesis might be very useful as a method of a pedagogical re-orientation of ethics as well. On the constitutive dimension, ethical theory might serve as lens to distinguish between values. This follows a logic of inquiry-learning where students perform their own normative analysis with moral theory as a scaffolding tool. Case based learning is an important pedagogical strategy. On the integrative dimension, the problem of reconciling conflicting values can be important regarding the multi-leveled and multi-faceted dimensions of climate change. Mirroring complex-problem pedagogy, participatory simulation can provide a practice-like setting for weighing the strengths and short-comings of normative foci. The blue-print dimension is where Phronesis falls short as an approach to moral education in climate change, as it is too individualized and has limited practical applicability in the context of climate change ethics. Role-model approaches of moral education might be an approach to deal with these shortcomings, but come with other normative problems. Other pedagogical approaches such as rhetorical listening, do not suffer from these weaknesses, but are little concrete. Lastly, the emotional-regulation dimension is very salient when it comes to climate change ethics, but has to be embedded in a broader theory of empowerment and social change to be morally effective and affectionally appropriate. This translate to the university where institutional changes regarding the intended curriculum are important in fostering attitudes.

Bibliography

Beyleveld, D, M Düwell, en A Spahn. 2015. „Why and how should we represent future generations in policymaking.” *Jurisprudence* 549-566.

Carpendale, Jeremy. 2000. „Kohlberg and Piaget on stages and moral reasoning.” *Developmental Review* 181-205.

Darnell, Catherine, Leigh Gulliford, Karel Kristjansson, en Philip Paris. 2019. „Phronesis and the knowledge-action gap in moral psychology and moral education: A new synthesis?” *Human Development* 101-129.

de Clerck, Amber, en Kris Rutten. 2024. „RHETORICAL LISTENING AS A PEDAGOGICAL TOOL IN HIGHER EDUCATION: EXPLORING THE BLACK PETE DEBATE IN FLANDERS.” *International Journal of Listening* 1-16.

Dunne, J. 2005. „Virtue, phronesis and learning.” In *Virtue ethics and moral education*, door David Carr en Jan Sleutel, 66-71. Edinburgh: Routledge.

Duvenage, Pieter. 2015. „Practical wisdom (phronesis) and hermeneutical politics.” *Phronimon* 77-96.

Floridi, Luciano. 2021. „Translating Principles into Practices of Digital Ethics: Five Risks of Being Unethical.” *Ethics, Governance, and Policies in Artificial Intelligence* 81-90.

Gardinger, S. 2006. „A perfect moral storm: Climate change, intergenerational ethics and the problem of moral corruption.” *Environmental values* 397-413.

Haidt, J. 2001. „The emotional dog and its rational tail: a social intuitionist approach to moral judgment.” *Psychological Review* 814-834.

Haws, David. 2001. „Ethics Instruction in Engineering Education: A (Mini) Meta-Analysis.” *Journal of Engineering Education* 222-227.

Hess, Diana. 2012. „Discussing Controversial Public Issues in Secondary Social Studies Classrooms: Learning from Skilled Teachers.” *Theory & Research in Social Education* 10-41.

Incropera, Frank. 2015. *Climate Change: A Wicked Problem.* Cambridge: Cambridge University Press.

Jacobson, M, en U Wilensky. 2006. „Complex systems in education: Scientific and educational importance and implications for the learning sciences.” *The Journal of Learning Sciences* 11-34.

Jordan, Karen, en Kristján Kristjánsson. 2017. „Sustainability, virtue ethics, and the virtue of harmony with nature.” *Environmental Education Research* 1205-1229.

Kakkori, L, en R Huttunen. 2007. „Aristotle and pedagogical ethics.” *Paideusis* 17-28.

Leigh, Andrew. 2021. *What is the Worst That Could Happen? Existential Risk and Extreme Politics.* Melbourne: The MIT Press.

Maran, Daniela Acquadro, en T Begotti. 2021. „Media exposure to climate change, anxiety, and efficacy beliefs in a sample of Italian university students.” *International journal of environmental research and public health* 1-11.

Marris, Emma. 2021. *Wild Souls.* New York: Bloomsbury Publishing USA.

Midgley, Mary. 2000. „The Use and Uselessness of Learning.” In *Utopias, Dolphins and Computers: Problems in Philosophical Plumbing*, door Mary Midgley, 45-58. London: Routledge.

Miller, D, en B Eggleston. 2020. *Moral Theory and Climate Change: Ethical Perspectives on a Warming Planet. .* New York: Routledge.

Newberry, Byron. 2004. „The Dilemma of Ethics in Engineering Education.” *Science and Engineering Ethics* 343-351.

Reimers, Fernandes. 2021. *Education and Climate Change: The Role of Universities.* Harvard: Springer.

Sanderse, Wouter. 2013. „The meaning of role modelling in moral and character education.” *Journal of Moral education* 28-42.

Tassone, Valentina, Harm Biemans, Perry Brok, en Piety Runhaar. 2021. „Mapping course innovation in higher education: a multi-faceted analytical framework.” *Higher Education Research and Devlopment* 2458-2472.

Tromp, Coyan. 2018. *Wicked Philosopy.* Amsterdam: Amsterdam University Press.

Appendix

Theory	Conception of ethics	Personal requirements in Climate Change	Systemic requirements in Climate Change
Act Utilitarianism	The ethical nature of an act is dependent on the maximalization of utility in its consequences.	The only real influence an individual can reasonably have on climate change is limiting procreation, as all other behaviors mitigating climate change are effectively meaningless compared to having fewer children.	Implement a temporal discount rate of 0 in financial models of mitigation efforts (as temporal closeness is morally irrelevant). Implement a supply-side Carbon Tax (as this is probably more effective than a Cap and Trade System). Finance adaption strategies for the least well-off by raising the highest marginal tax rates (following the principle of diminishing marginal returns).
Rule Utilitarian	The ethical nature of an act is dependent on its adherence to an ideal-theoretical moral rule.	All greenhouse gas (GHG) mitigating behaviors that do not reasonably conflict with other fundamental values, most prominently: limiting meat-consumption, fossil-fuel travel methods and	Implement a demand-side incentive system to promote alternatives to GHG-emitting activities via taxes. Implement a carbon-offsetting program (individual carbon-offsetting is logistically and societally too complex to be internalized as an ideal-theoretical rule).
Deontology	The ethical nature of an act is dependent on it being derived from that maxim through which you can at the same time will that it become a universal law. (conceptual principle of non-contradiction)	Problematic, as not-mitigating climate change is not conceptually contradictory. Possible solution: broader definition: do not act according to those maxims that are practically unsustainable.	Principle of right: Any action is right if it can coexist with everyone's freedom in accordance with a universal law, or if on its maxim the freedom of choice of each can coexist with everyone's freedom in accordance with a universal law. States ought to provide financial support for

		(prudence principle of non-contradiction) Duty to pressure government for systemic solutions.	mitigation and adaptation efforts to those countries that will be affected by climate change to the extent that the freedom of their citizens is severely limited. Or: implement an unconditional open-border policy rendering everyone free to escape the asymmetrical global effects of climate change.
Virtue ethics	The ethical nature of an act is necessarily dependent upon the virtuous nature of its actor.	Cultivate the right values for a virtues disposition towards nature (i.e. compassion for suffering, a will to justice for all parts of the environment, and a sense of reverence for and protectiveness towards the enchanted in nature) Or: Try to live *as if* in possession of those virtues, i.e. by mimicking a positive role-model (as climate change is a problem of great urgency, not well-suited for the time intensive practice of cultivating values).	The polis should be led responsibly: balancing the conflicting values.

(Based on Miller & Eggleston, 2020)

NARRATIVE ETHICS AND NARRATIVE PEDAGOGY IN ENGINEERING ETHICS EDUCATION: A ROAD NOT (YET) TAKEN

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ABSTRACT

The paper explores the potential of using narrative-centered pedagogies in Engineering Ethics Education (EEE), drawing insights from their successful application in nursing and business ethics education. While traditional methods in EEE focus on fostering moral reasoning through case-study analysis and teaching ethical theories, increasingly, there is a need for fostering soft ethical skills, such as moral sensitivity and creativity, which, in turn, demand new teaching approaches. Initially developed for nursing ethics, narrative pedagogy emphasises understanding experiences through storytelling and dialogue, contrasting with the decision-oriented focus of EEE. While narrative pedagogy allows for understanding stakeholders' motivations, there is a gap in translating this understanding into ethical decisions, which engineering students must make. Drawing from a literature survey of the existing research in ethics education, the paper describes three kinds of narrative pedagogy to be used for EEE. Despite its theoretical potential, narrative pedagogy has not been deployed in EEE due to a lack of systematic research on its effectiveness. The paper calls for more experimentation and documented case studies in teaching to explore the potential narrative pedagogy in EEE. Without such experiments, the theoretical potential of narrative pedagogy in EEE may remain unproven.

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1 INTRODUCTION

1.1 Narrative ethics and narrative pedagogy in Engineering ethics education

Recently, there has been a growing interest in diversifying the methods used in teaching ethics in professional domains, such as engineering, design, nursing, business, law, etc. While standard teaching methods focused overwhelmingly on the fostering of rationality by promoting moral reasoning and moral deliberation as the main competencies that students were expected to acquire (Zhu and Clancy 2023), more recently, there has been a growing interest in developing methods for targeting skills and competencies that are more contextual and holistic, such as moral sensitivity, moral perception, moral imagination, moral creativity, empathy, etc. (Lönngren et al. 2023). While these latter competencies do not necessarily exclude rationality and reasoning, these are demonstrably focused on the a-rational part of ethics, namely what is left outside the mere rational exercise of reasoning about ethical issues as problem-solving attempts. For the purposes of this paper, I will designate these a-rational skills and competencies with the overarching term *soft ethical skills*.

While the need to foster soft ethical skills in engineering ethics education (EEE from now on), and in general in professional ethics education, is widely acknowledged, ethics instructors find that the methods for fostering these skills are rather unclear. For reasoning-focused skills, there is already a well-established pedagogy in EEE consisting of case-study analysis, discussions, and deliberations, paired with teaching ethical theories that are used to devise an acceptable solution (Jalali et al. 2022). However, such traditional methods cannot be used in the soft ethical skills pedagogy, which target another domain of thinking and feeling altogether (Tormey et al. 2022). Soft ethical skills demand new methods in teaching ethics, and ethics instructors will find themselves confronted with the need to think outside the box when devising methods for such elusive yet ambitious goals (Martin et al. 2021). It is clear that the same methods used for teaching moral deliberation and reasoning cannot work for moral sensitivity, imagination, and creativity. Still, there are already promising ideas and directions for pursuing a systematic approach to soft ethical skills pedagogy: arts-based methods, theatre, role-plays, stakeholder direct engagement, etc. (Frey 2015). These ideas either promote embodied pedagogy – i.e., using the body to express and enact ethical situations (van Grunsven et al. 2024) – or *narrative pedagogy*, which I will analyse next as a promising pedagogical approach that has been yet underexplored in EEE.

More than two decades years ago, Martha Nussbaum (1997) argued convincingly for the important role that reading fictional narratives plays in cultivating moral imagination through narrative imagination, i.e., the capacity to "put oneself in another person's shoes and to understand their emotions and desires" (Wright 2002). While Nussbaum argued that narrative imagination is necessary for everyone to become a world citizen (1997), we can extend this argument from citizens to any professional dealing with stakeholders, either directly or indirectly. Based on Nussbaum's ground-breaking work and on similar works (Newton 1995), the inquiry into the ethical and educational potential of literary narratives gained quite some momentum, branching out into *narrative ethics* (Netwon 1995; Adams 2008; Pehlan 2014), a distinctive field of research, at the intersection of philosophy and literary studies. Recognising the potential of narrative ethics, various educational researchers working on professional ethics education have coined different strands of narrative-centred pedagogy, most remarkably in nursing ethics. However, in EEE, narrative ethics and narrative pedagogy remained mostly explored. A brief literature search on EEE and narratives found 27 results out of which very few papers have engaged with the pedagogical potential of narratives for EEE. Several notable examples were (Miller and Bennett 2008; Hitt and Lennefors 2022; Halada and Khost 2017). What explains this hesitance to take up narrative-based ethics in the pedagogy of EEE? This paper explores the potential of narrative ethics and narrative-centred pedagogy for EEE, provides some explanations for past neglect of narrative-centred pedagogy in EEE thus far, and offers some concrete suggestions about the potential of narrative ethics for developing soft ethical skills in engineering ethics.

2. METHODOLOGY

In exploring the potential of fictional narratives and narrative-centred pedagogies for EEE, I am mainly drawing some insights from the previous usage of narrative pedagogy in nursing and business ethics. The first method is a literature review of the ways in which narrative pedagogy has been used in professional ethics education thus far, which resulted in a taxonomy of the types of narrative uses in ethics education. Using these insights, namely mapping what narratives can be used for which soft ethical skills, I then theorise possible narrative ethics uses for EEE as well as its limitations. I am mainly interested in exploring narratives' potential to achieve new pedagogical outcomes that traditional EEE methods do not usually deliver. For this second part of the paper, I use educational theory and philosophy as a ground for theory building: knowing the desired outcomes of EEE and the potential of narrative pedagogy, which learning outcomes are more likely to be achieved?

3. THE POTENTIAL OF NARRATIVE PEDAGOGY FOR ENGINEERING ETHICS EDUCATION

In a systematic review centred on the pedagogical interventions in EEE in the American context, Hess and Fore (2018) list the most common pedagogical activities as: "Codes of Ethics or Rules, Developing Code of Ethics, Ethical Tools, Processes, or Heuristics, Developing Heuristics, Philosophical Ethics, Case Studies, Developing a Case Study Micro-Insertion Real-World Exposure Community Engagement Discussion or Debate Presentation Peer Mentoring Individual Written Assignment(s) Team Project or Position Paper, Game" (Hess and Fore 2018, p. 562). Narratives can be found in both case studies – included in the reading material - and presumably can be embedded in individual written assignments. Yet narratives as a specific genre do not stand out in EEE pedagogy and are not considered a specific approach to teaching or developing assignments to deserve their own category.

In professional ethics education (such as engineers, designers, nurses, medical doctors, managers, or legal practitioners), the main aim is not in-depth theoretical understanding, rather, it is about developing the skills and competencies that will allow practitioners to act with integrity when a challenge arrives. This makes ethics education for professionals quite a unique discipline in educational sciences, with specific learning goals and instructional methods (Hess and Fore 2018). This uniqueness can be summarised as action-oriented, whereby theory is used only as an instrument that can help in fostering the competencies and the attitudes for ethical action (Clancy and Zhu 2023). In EEE, instructors are focused on the applicability of what they teach and on fostering lifelong competencies that can be drawn from by future professionals in various contexts. Because of this competency-first focus, with theoretical knowledge being a secondary concern, teaching methods that use extensive writing are usually discouraged. When EEE students are asked to write essays, the focus is on exploring an ethical issue and not so much on the quality of writing itself. This is why writing-focused pedagogies have been historically ignored in professional ethics pedagogy. Writing an argumentative essay is already difficult enough for engineering students who are not that familiar with writing long texts, and asking them to write fictional narratives seems even more demanding. What about case-study pedagogy? Could this be a way to introduce narrative pedagogy into EEE?

Traditional teaching methods used in EEE include case-centred approaches, the so-called microethics approach (Martin et al. 2021). In case-centred pedagogy, students discuss a fictional or historical case of a problematic issue in their profession and are asked to decide what needs to be done or who is blameworthy. The tools used to deliberate are ethical theories, which were then applied to find an acceptable solution to the case, to enhance the student's moral deliberation and reasoning capacities. Case-based pedagogy has its limitations which have been thoroughly discussed by Martin et al. (2021), who instead proposed also to consider macro-ethics alongside by discussing the wider societal, political and cultural context in which professional incidents occur. What interests us here is that case-based pedagogy is reasoning-based, whereas macro-ethics seems to target the soft ethical skills discussed above more. Macro ethics is about stepping outside the case and using a wider lens, while the targeted competencies are about moral perception and moral sensibility, hence more fitting for the development of soft ethical skills. However, there are no established methods for teaching macro-ethical approaches in EEE (Martin et al. 2021), neither narrative-based nor argumentative-focused. If narrative ethics is to enter EEE pedagogy more, macro-ethics seems to be a promising domain of application.

Narrative pedagogy has been used primarily in nursing ethics, the field where it was first conceptualised. Narrative pedagogy is a way of making sense of ones experiences by telling stories about them and enacting "crucial conversations" with others, usually colleagues in the same professional field. Narrative pedagogy was initially about making sense of an experience that already happened to a participant, and creating a shared common understanding through "an interpretive phenomenological approach" (Diekelmann and Diekelmann 2000, p. 226). This makes sense in nursing, where experiences of care are particular to each patient and care situation and where sense-making seems to be crucial. Understanding is built through dialogue and collective sense-making: "In this new pedagogy, ethics ceases to be answers, made within frameworks, or principles or rules applied universally to situations. These understandings are a part of the converging conversations" (Diekelmann and Diekelmann 2000, p. 229). We can see how different narrative pedagogy is from the traditional micro-ethical EEE approaches centred on reasoning, where the usual aim is arriving at the most acceptable solution for a given ethical case. Engineers do not strive for understanding of experiences or situations primarily, as their main concern is decision-making of how to design or implement a specific technology, hence the final aim of ethics is the right action (Zhu and Clancy 2023). This is not to say that understanding is not useful, but in engineering, this needs to be translated into a decision. Because of the decision-oriented focus on EEE, rather different from the focus on understanding in nursing ethics, it makes sense why narrative pedagogy has not been the first choice for EEE instructors. If narrative pedagogy allows for a deep understanding of the stakeholders and their motivations in engineering ethics, there seems to be one more step needed to arrive at a decision. Understanding alone is not enough to make an ethical decision. However, a too hasty understanding of the stakeholders also poses a danger. Engineering students may think that they understand all parties involved in a techno-social decision and rush to “solve” the problem with incomplete information. From this brief reflection, it should be clear that understanding alone is not enough to make narrative-centred pedagogy interesting for EEE pedagogy. We need to get something more out of narrative pedagogy since using narratives to make sense of morally loaded situations will not be enough for engineering students. The next section explores the multiple facets of narrative pedagogy for engineering ethics education.

4. TYPES OF NARRATIVE PEDAGOGY USED IN PROFESSIONAL ETHICS EDUCATION

The following table summarises the kinds of narrative pedagogy used thus far in professional ethics education and its targeted competencies. Each category will be explained below.

Table 1. Kinds of narrative pedagogy, teaching activities and targeted learning outcomes

Kinds of narrative pedagogy	***Teaching and studying activities***	***Targeted skills, competencies, and learning goals***
A. Discussing narratives created by others	• Film-based discussions • Collective discussions on a narrative text • Individual readings and reflections on a narrative (Text-based commentary)	• Moral sensitivity/ perception • Empathic perspective-taking (Narrative imagination) • Empathy and understanding • Stakeholder engagement (imaginary stakeholders)
B. Completing unfinished narratives	• Starting from a given scenario outlining an ethical situation, students imagine possible outcomes (in writing, discussions, or as a performance).	• Stakeholder engagement (imaginary stakeholders) • Empathic perspective-taking (Narrative imagination)

C. Creating narratives	• Writing a short story about a technology or an ethical issue with a technology • Sci-fi narrative writing with a focus on anticipation • Writing a poem, a short dialogue, a script for a performance • Performing as improvisation starting from a prompt	• Moral creativity • Moral imagination • Empathic perspective taking (Narrative imagination) • Responsible anticipation

4.1 Discussing narratives created by others

In this approach, the students read or watch the narratives created by others. The advantage here is that the creator of the narrative is usually an experienced writer/ artist, and the narrative has a certain quality about it, which makes empathic reactions more likely. The main goal here is that students make sense of the narrative, either individually or in groups, and expand their understanding of the ethical situation by imagining what it is like to be another person embedded in that situation (the fictional character or the testimony provider who narrates their experience), or by being confronted with the strangeness of the other perspective and having to make sense of the distance between oneself and the other. The learning outcomes of encountering narratives, already extensively explored in nursing and business ethics research, are: "thinking, empowerment, interconnectedness, learning as a process of making meaning, and ethical and moral judgment." (Brady and Asselin 2016, p. 2). It has been argued that, at least when compared with standard lectures, narrative pedagogy is more effective for increasing the moral sensitivity of students (Bagherian et al. 2023).

In EEE, experiments with encountering narratives have been done starting from film narratives (Hitt and Lennefors 2022) or reading fiction to make sense of the professional's ethically relevant experiences (Mawasi et al. 2022). In this case, students are exposed to the story, and then they create a common understanding of the story in the absence of the one who has lived the story. The fictional characters are not present to take part in the sense-making conversations, and students as spectators project themselves into the shoes of the fictional characters and think "as if" they were one. This has the potential of asking students to imagine being someone else, but it also poses a danger that, if the students' imagination capacities are limited, they will not be able to imagine what it is like to be another. On these limitations of imagination in the context of disability, see (van Grunsven et al. 2024).

4.2 Completing unfinished narratives

This is a somewhat more creative task. Students receive a narrative that has not been completed and are then asked to finish it by providing possible ends. This is different from the traditional case-based pedagogy, where students were asked to choose the most acceptable outcome using an ethical theory (Whitbeck 2011). Instead, students are asked to take into account the character's psychology and situatedness in a context, the available choices, and then choose the most likely scenario. This format can also be used to ask students to imagine the most appropriate ending but still keeping in mind the limitations of the main characters' psychology and perspectives. This relatively recent format has been employed in medical education with patient scenarios (Marei et al. 2018) and in business ethics (Kujala and Pietiläinen 2007). This format has not yet been explored in EEE; hence, further research is needed to map out its full potential, starting from its theoretical potential that has already been demonstrated in other branches of professional ethics.

4.3 Creating fictional narratives from scratch

Some pedagogies ask students to make up their own stories from scratch, such as improvisational pedagogies and narrative fiction-writing pedagogies. In improvisational pedagogies, students start a prompt, giving the outlines of a case and arrive at a story while performing it. Students do not know what the story will be at the end, they create it in the staged interaction with their colleagues. In fiction writing pedagogies, students write from scratch a story in which they make sense of an ethical case or explore the ethical implications of a technology. This approach has been less explored in EEE. One example is the work of Torras and Ludescher (2023) in the context of AI ethics. Another example is using the crafting of narratives in engineering education in general, without particular concern for ethics (Halada and Khost 2017).

The main difference between the three kinds of pedagogical approaches outlined above is the degree of creativity required from students, which ranges from creativity in making sense of other's stories to crafting their own stories. Standard narrative pedagogy, as used in nursing ethics and business ethics, is centred on using other's stories. Crafting one's stories seems to be an even more complicated task and not usually a method employed in ethics courses across all fields. Yet, in view of fostering moral creativity, it seems to be the most promising approach. However, narrative pedagogy is risky and has some pitfalls, making it a difficult endeavour for EEE.

4.4 An example of a practical application: writing a short Sci-Fi narrative

Using the narrative pedagogy approach of the third kind, creating fully a story from scratch, I designed an entire course centred around writing a Sci-Fi narrative as the main outcome of the course and piloted it in the academic year 2023/2024 at TU Delft (course code TPM042A). Students were asked to start with a specific technology and imagine a science fiction narrative of a maximum 1500 words centred around one ethical issue with that technology. The students received creative writing training in several workshops throughout the semester. The final sci-fi narrative was built in incremental steps (a pitch centred on the ethical question, an outline of the action, and a preliminary draft). Finally, students also wrote a reflective essay in which they commented on their own narrative and its ethical significance. The course was entirely elective, and it was taken only by students who were interested in story writing. I did not document the moral imagination before and after the course, as this was a pilot meant to test the pedagogical methods as such and the students' reactions to the narrative pedagogy approach. In the course feedback, all the students appreciated the class and were very engaged in its activities. I will offer the same course in the next academic year and document the moral imagination changes through elective student surveys before, during, and after the course completion. A lesson learned, and an immediate limitation is that narrative writing relies on skills that cannot be built entirely in one course, although all students did show a demonstrable improvement in their writing skills throughout this course. But because of this heavy reliance on writing skills, the courses centred on narrative pedagogy will need to be offered either only as electives or rely on narrative writing only as formative activity, with no influence on the final grade.

5. Discussion. Limitations of narrative pedagogy in EEE. Pitfalls and limitations

As mentioned, soft ethical skills require different approaches, more creativity, and less focus on providing reasons and exchanging arguments. While narrative-based pedagogy seems a promising direction to take for EEE, it is quite a rare occurrence in the current educational landscape. This is understandable, given the scant research that has been done on narrative ethics and its methods in EEE. Some instructors may be adventurous and inclined to try out new methods, but most prefer to stick by the already validated paths. The community of researchers working in EEE is constantly developing new methods involving arts and more playful approaches, but we lack a systematic way of testing just how effective these methods are. In the absence of these kinds of systematic studies on effectiveness and for collective educational experiments, we are left with anecdotal evidence and small experimental deployments in our own courses. This paper is also a call to explore more and try out the methods of narrative pedagogy in reproducible and documented case studies in EEE coursework. Without these experiments, we would not know if narrative pedagogy's theoretical potential in EEE can bear fruit.

The main limitation in implementing narrative ethics and narrative pedagogy in EEE stems from the lack of specific training for instructors. A narrative ethics instructor would need to provide guidelines to students on how to read a literary text, interpret it, perform it, and even write a fictional text. At some stages in these activities, professional writers or scholars from literary studies would need to be involved directly or indirectly. If ethics instructors want to experiment with narrative methods in their teaching, they will need to dedicate some time to learning these techniques and the scholarship grounding these methods, which means putting aside time in a time-scarce environment such as contemporary universities. A second limitation lies in assessing students' work. Similar to arts-based pedagogical activities, the criteria for evaluating narrative work are quite specific and revolve around aesthetic criteria as well as criteria for assessing the personal growth of students: how to evaluate the increased moral imagination or sensitivity remains an open question for EEE in general. How to evaluate a good story or a creative ending to a given narrative seems even more hazy. We do not have the assessment criteria in place to ensure that, as instructors, we can be fair to the student's work. For students, the main limitation of creative methods in ethics, such as narrative pedagogy, lies in the unequal distribution of skills: some students can feel more comfortable than others in writing fictional narratives or in interpreting texts, while others may feel paralysed. However, we should not assume that students will not enjoy some creative challenges, as seen in the pilot class on sci-fi narratives. Furthermore, everyone can experiment with artistic methods, and even if the outcome is not an artwork, the very process of thinking and reflecting about narratives and art is valuable in itself. We should not shy away from more experimental and arts-based methods simply because students may feel uncomfortable at the beginning.

However, ethics instructors may need to consider narrative pedagogy sooner than anticipated. With the rise of ChatGPT and other large language learning models, traditional written assignments in EEE are under threat as argumentative essays are written starting from a series of questions or prompts that can be generated automatically all too easily. In evaluating the correctness of the arguments, it becomes difficult to discern the student's work from an automated generated text. However, with narrative pedagogy, an important criterion is students' creativity and insight in interpreting a narrative or writing one themselves. Even if tools such as ChatGPT can write short stories or interpret or summarise existing ones, they cannot yet show the insight and unique style that a human interpretation can. Many have noticed that ChatGPT outputs sound and feel generic, cookie-cutter prose. While such generic prose would be acceptable for an argumentative essay, narrative pedagogy demands a personal point of view, a personal interpretation, insight, and creativity in one's understanding. Given that these raw qualities cannot be simulated by a large language model (yet), ethics instructors can turn to more creative assignments to avoid their students defaulting to the ChatGPT route. Narrative pedagogy and narrative ethics are roads not yet taken in engineering ethics education, but we may have to explore this path quite soon, given that other more standard paths are becoming unavailable.

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REFERENCES

Adams, Tony E. “A review of narrative ethics.” Qualitative inquiry 14, no. 2 (2008): 175-194.

Bagherian, Behnaz, Roghayeh Mehdipour-Rabori, and Monirsadat Nematollahi. 2023. “Teaching Ethical Principles through Narrative-Based Story Is More Effective in the Moral Sensitivity among BSc Nursing Students than Lecture Method : A Quasi-Experimental Study.” Clinical Ethics 18 (4): 427–33. https://doi.org/10.1177/14777509221091094

Brady, Destiny R., and Marilyn E. Asselin. 2016. “Exploring Outcomes and Evaluation in Narrative Pedagogy: An Integrative Review.” Nurse Education Today 45 (October): 1–8. https://doi.org/10.1016/j.nedt.2016.06.002

Clancy, Rockwell Franklin, Qin Zhu, and Philosophy Documentation Center. 2023. “Why Should Ethical Behaviors Be the Ultimate Goal of Engineering Ethics Education?” Business and Professional Ethics Journal 42 (1): 33–53. https://doi.org/10.5840/bpej202346136.

Diekelmann, Nancy, and John Diekelmann. 2000. “Learning Ethics in Nursing and Genetics: Narrative Pedagogy and the Grounding of Values.” Journal of Pediatric Nursing 15 (4): 226–31. https://doi.org/10.1053/jpdn.2000.8040

Frey, William J. 2015. “Training Engineers in Moral Imagination for Global Contexts.” In Engineering Ethics for a Globalized World, edited by Colleen Murphy, Paolo

Gardoni, Hassan Bashir, Charles E. Harris, and Eyad Masad, 22:229–47. Philosophy of Engineering and Technology. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-18260-5_14.

Halada, Gary P., and Peter H. Khost. “The use of narrative in undergraduate engineering education.” In 2017 ASEE Annual Conference & Exposition. 2017.

Hess, Justin L., and Grant Fore. “A systematic literature review of US engineering ethics interventions.” Science and engineering ethics 24 (2018): 551-583. https://doi.org/10.1007/s11948-017-9910-6

Hitt, Sarah Jayne, and Thomas Taro Lennerfors. “Fictional Film in Engineering Ethics Education: With Miyazaki’s The Wind Rises as Exemplar.” Science and Engineering Ethics 28, no. 5 (2022): 44. https://doi.org/10.1007/s11948-022-00399-w.

Jalali, Yousef, Christian Matheis, and Vinod Lohani. 2022. “Imagination and Moral Deliberation: A Case Study of an Ethics Discussion Session.” International Journal of Engineering Education 38 (3): 709–18.

Kujala, Johanna, and Tarja Pietiläinen. “Developing moral principles and scenarios in the light of diversity: An extension to the multidimensional ethics scale.” Journal of Business Ethics 70 (2007): 141-150.

Lönngren, Johanna, Inês Direito, Roland Tormey, and James L. Huff. 2023. “Emotions in Engineering Education.” In International Handbook of Engineering Education Research, by Aditya Johri, 1st ed., 156–82. New York: Routledge. https://doi.org/10.4324/9781003287483-10.

Marei, H. F., M. M. Al-Eraky, N. N. Almasoud, J. Donkers, and J. J. G. Van Merrienboer. 2018. “The Use of Virtual Patient Scenarios as a Vehicle for Teaching Professionalism.” European Journal of Dental Education 22 (2). https://doi.org/10.1111/eje.12283.

Martin, Diana Adela, Eddie Conlon, and Brian Bowe. 2021. “A Multi-Level Review of Engineering Ethics Education: Towards a Socio-Technical Orientation of Engineering Education for Ethics.” Science and Engineering Ethics 27 (5): 60. https://doi.org/10.1007/s11948-021-00333-6.

Mawasi, Areej, Peter Nagy, Ed Finn, and Ruth Wylie. 2022. “Narrative-Based Learning Activities for Science Ethics Education: An Affordance Perspective.” Journal of Science Education and Technology 31 (1): 16–26. https://doi.org/10.1007/s10956-021-09928-x.

Miller, Clark A, and Ira Bennett. 2008. “Thinking Longer Term about Technology: Is There Value in Science Fiction-Inspired Approaches to Constructing Futures?” *Science and Public Policy* 35 (8): 597–606. https://doi.org/10.3152/030234208X370666.

Newton, Adam Zachary. Narrative ethics. Harvard University Press, 1995.

Nussbaum, Martha C. Cultivating humanity. Harvard University Press, 1997.

Phelan, James. “Narrative ethics.” The living handbook of narratology 9 (2014), Hühn, P. (eds). De Gruyter.

Van Grunsven, Janna, Lavinia Marin, Andrea Gammon, and Trijsje Franssen. 2024. “4E Cognition, Moral Imagination, and Engineering Ethics Education: Shaping Affordances for Diverse Embodied Perspectives.” Phenomenology and the Cognitive Sciences, May. https://doi.org/10.1007/s11097-024-09987-6.

Von Wright, Moira. “Narrative imagination and taking the perspective of others.” Studies in Philosophy and Education 21 (2002): 407-416.

Tormey, Roland, Siara Ruth Isaac, Cécile Hardebolle, and Ingrid Le Duc. 2022. Facilitating Experiential Learning in Higher Education: Teaching and Supervising in Labs, Fieldwork, Studios and Projects. Abingdon, Oxon ; New York, NY: Routledge.

Torras, Carme, and Luís Gustavo Ludescher. 2023. “Writing Science Fiction as an Inspiration for AI Research and Ethics Dissemination.” In Human-Centered Artificial Intelligence, edited by Mohamed Chetouani, Virginia Dignum, Paul Lukowicz, and Carles Sierra, 13500:322–44. Lecture Notes in Computer Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-24349-3_17.

Whitbeck, Caroline. Ethics in engineering practice and research. Cambridge University Press, 2011.

Zhu, Qin, and Rockwell Clancy. “Constructing a role ethics approach to engineering ethics education.” Ethics and Education 18, no. 2 (2023): 216-229. https://doi.org/10.1080/17449642.2023.2249740.

The impact of Active Learning strategies on redesigned interdisciplinary engineering courses using Case-Based Learning

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ABSTRACT

This study proposes and evaluates a redesign with active learning activities of an interdisciplinary course on product manufacturing. Evaluation involved analysing past and current exam results to assess the impact of case-based learning on academic performance. Results show a positive correlation between joining more case studies and improved exam performance of second year Industrial Engineering and Management students. However, minimal to negligible improvements were observed among first year Industrial Design Engineering students. These findings

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highlight the nuanced nature of the effectiveness of active learning, appearing to be influenced by various contextual factors.

1 INTRODUCTION

1.1 Research context

Over the last decades, active learning has gained significant popularity (Hartikainen et al. 2019) as an educational approach that emphasises engagement, cognitive development and problem solving (Gogus 2012). Active learning is defined as “anything course-related that all students in a class session are called upon to do other than simply watching, listening, and taking notes” (Felder and Brent 2009). It promotes deeper understanding and knowledge application (Edström, Soderholm, and Knutson Wedel 2007), and fosters higher order thinking skills (Bonwell and Eison 1991). For example, methods such as project-based and case-based learning are approaches to active learning (Biggs and Tang 2011).

The University of Twente (UT) integrates project-based learning as a fundamental element in its engineering programmes to motivate students and link theoretical concepts with practical applications (Dankers et al. 2013). Currently, several Bachelor of Science (BSc.) programmes are undergoing curriculum redesigns in response to trends, technological advances, and industry requirements. The changes involve introducing new courses as well as refining existing courses. This process involves an assessment and redesign of courses, content, and methodologies. Furthermore, the development of two learning factories — one focused on production and assembly, the other on additive manufacturing (Massa and Lutters 2024)— instigates course redesign. Learning factories serve as an educational concept that provides students with hands-on, real-world experiences in an environment that simulates industrial settings (Abele et al. 2024). The learning factories at the UT aim to blur the lines between education and research, working through a recursive master-apprentice model (Lutters et al. 2022; Damgrave, Massa, and Lutters 2023). To exploit the full potential of the learning factories as a valuable engineering learning workspace (Malmqvist, Edström, and Rosén 2020), new and existing courses are adapted to the learning factory environment and vice versa. Production 1, among the courses currently undergoing redesign, is an interdisciplinary course that examines the principles and processes of product manufacturing within both Industrial Design Engineering (IDE) and Industrial Engineering and Management (IEM) BSc. programs, with students from both disciplines simultaneously participating. The redesign aims to address student challenges, and includes practical learning components, potentially aligning with future learning factory education. An analysis using constructive alignment (Biggs and Tang 2011) identified possible improvements in current teaching strategies and showed potential for more integration of active learning.

1.2 Aim of this study

This paper aims to propose and evaluate active learning components to the Production 1 course. The study explores the use of case-based learning, involving the development and integration of case studies in the course. Evaluation includes analysing examination results to assess the effect of the redesigned course. In a general context, this study aims to enhance the understanding of how active learning, particularly case-based learning, influences academic performance in engineering education, also considering the influence of variables like study year and field of study. By exploring these factors, the research aims to address the impact of active learning approaches within interdisciplinary engineering courses.

2 BACKGROUND

2.1 Course information

Production 1 is a key course in IDE (first-year students) and IEM (second year students) programs, providing knowledge in product manufacturing. The course is a mandatory component of both study programmes, making all IEM and IDE students admissible. With an enrolment of approximately 250 students annually, it covers various production processes, emphasising theoretical understanding and practical applicability. The course is worth 2.5 European Credits (EC), equivalent to approximately 70 hours of work. Before the redesign of the course, 25% is allocated to lectures for all students, while the IDE students also devote 25% of the time to practical sessions. The remaining time is reserved for self-study. Completion of the course enables students to differentiate, describe, and justify manufacturing process selections. The course concludes with a written exam that assesses content understanding through twenty multiple choice questions and analytical application through four open-ended questions. The two-part exam ensures a holistic assessment, requiring students to pass thresholds in both parts.

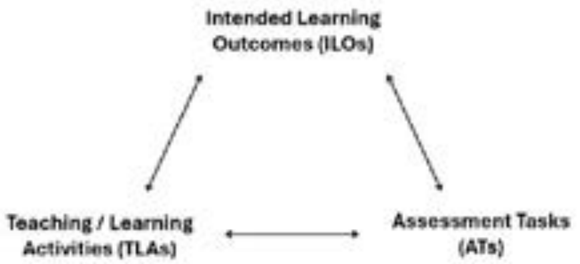
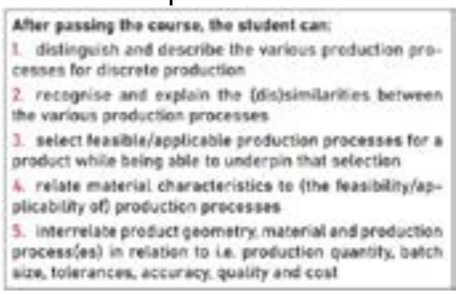


Fig. 1. Constructive Alignment (adapted from (Biggs and Tang 2011))



After passing the course, the student can:

1. distinguish and describe the various production processes for discrete production
2. recognise and explain the (dis)similarities between the various production processes
3. select feasible/applicable production processes for a product while being able to underpin that selection
4. relate material characteristics to (the feasibility/applicability of) production processes
5. interrelate product geometry, material and production process(es) in relation to i.e. production quantity, batch size, tolerances, accuracy, quality and cost

Fig. 2. ILOs Production 1

2.2 Constructive alignment analysis

Constructive alignment (Figure 1) (Biggs and Tang 2011) is used to identify improvement opportunities in the current course. Constructive alignment ensures alignment between intended learning outcomes (ILOs), teaching/learning activities (TLAs) and assessment tasks (ATs), fostering a learning experience that encourages the development of knowledge and skills (Anderson et al. 2001). Analysing each aspect and their relationships can identify potential misalignments within the course. Constructive alignment is also useful for its relevance to educational aspects of learning factories. It is essential in the design and operation of these environments, ensuring alignment between learning factories and the TLAs they support (Massa and Lutters 2024). Using constructive alignment is thus beneficial to the learning factories at the UT. In relation to the course, Bloom's Taxonomy (Anderson et al. 2001) reveals a focus on both lower- (ILO 1 and 2) and higher-order thinking skills (ILO 3-5) in the ILOs (Figure 2). However, lectures dominate the TLAs, limiting student participation and the application of knowledge, particularly for higher-order objectives. The ATs consist out of a final written exam covering all ILOs with multiple-choice questions targeting lower-order thinking skills, and open-ended questions assessing higher-order thinking skills. There is little formative assessment, consisting only out of a practice exam. In summary, this analysis highlights the potential for better alignment. While the ILOs and summative ATs are well-suited and well-aligned, some misalignment occurs due to the lecture-centric TLAs. This shows the opportunity to revise TLAs and integrate more formative assessment, while keeping the ILOs and summative ATs unchanged.

3 COURSE REDESIGN

3.1 Theoretical background for redesign

Active learning enhances students' abilities to apply knowledge and fosters higher-order thinking skills (Bonwell and Eison 1991), which aligns with the redesign objectives. Research confirms the efficacy of active learning on academic performance (Freeman et al. 2014; Aji and Khan 2019), particularly through group work (Prince 2004), while it fosters an inclusive environment (Ambrose et al. 2010). However, practical considerations like time limitations must be considered, for instance rendering approaches like game-based learning infeasible. The current course allocates a large amount of time for self-study: an effect of the reduction of lecture time (due to the pandemic, for example) in previous years. Therefore, adding active learning elements should not impose excessive time pressure on students. Given the emphasis on practical application in the higher order ILOs, methods that involve real-world scenarios, such as Case-Based Learning (CBL), are preferred. In CBL, students work to resolve real-world problems presented in case studies, transitioning from theoretical understanding to hands-on application (Srisawasdi 2012). It should be noted that this study focuses on case-based learning, not challenge-based learning. While sharing similarities (beside their acronyms), case-based learning offers a more direct application of learned concepts in real situations.

3.2 Case-Based Learning activities

In the design of the CBL activities, multiple factors such as motivation and feedback are considered. For instance, while active learning already fosters intrinsic motivation (Cavanagh et al. 2016), students will work in groups to stimulate social motivation. Moreover, participation in case studies is optional, aiming to call upon intrinsic motivation and to allow for analysis of the influence of participation on exam results. Sessions organised per study programme to address disparities in disciplines (Gijlers and Jong 2005). Groups work in four sessions of 1 hour and 45 minutes each, which are scheduled shortly after lectures that address case topics. Design problems, often used in engineering education (Lavi and Marti 2023), are used as cases. Cases are designed to be finished within this time, resulting in a maximum of around seven hours spend on case studies. Feedback is facilitated through self-assessment, peer-assessment, and teacher-assessment with both student assistants and the professor providing feedback to students during the cases. Sessions conclude with discussions/Q&A sessions focused on solution exploration, strengthening an interactive approach. The participants do not have to hand in any deliverables, as solutions are published online after one week for self-assessment.

Case study descriptions

The first case study revolves around an incomplete design plan for casting processes, where students have to develop a mould design and address specific questions on volumetric shrinkage and die clamping force. The second case study focuses on applying machining and separating process concepts to real-world production scenarios, requiring students to perform calculations and apply formulas to assess process feasibility, calculate cutting speeds and punching forces, and make informed decisions on tool selection and production quantities. The final two case studies focus on a more holistic perspective. Case study 3 involves analysing a physical product and CAD model of a prototype, prompting critical assessment, proposing materials, and finding alternative solutions that meet requirements. In case study 4 students give advice on production scenarios, showing understanding of factors like processes, materials, cost, and impact on efficiency and quality.

4 METHODOLOGY

4.1 Analytical approach and instrument design

Results of the Production 1 exam, which assesses the ILOs of the course, serves as an indicator of the impact of the CBL elements on academic performance. Quantitative data were gathered from the 2020-2021 (n=268) and 2023-2024 (n=231) exams, under old and new course structures. Student attendance during case studies in the new structure was recorded and discipline information per student was integrated to track disciplinary trends. The exams provide a basis for assessing the effectiveness of added TLAs across different student cohorts – provided that the exams and other conditions are comparable. The exams are conducted in controlled environments prohibiting e.g. cell phone use, and exams are written on paper and must be submitted in entirety, preventing access to past exams. This allows for selecting the multiple-choice questions from a repository – over more than 15 years this has not shown any trend in grades or ‘common memory’. For the new exam, the multiple-choice questions were identical to the 2020-2021 exam. As open-ended questions are easier to remember and are often discussed among students, they are different for every exam. Thus, new, yet similar, open questions were formulated to assess reasoning skills. Three experts declared the 2023-2024 and 2020-2021 exams equivalent in content, ILO match, and difficulty.

5 RESULTS

5.1 Participation in case studies

A total of 231 students, including 132 IDE students and 99 IEM students, participated in the redesigned course. Figure 3 highlights the participatory differences between IDE and IEM in case studies. IEM students have higher non-participation rates, but

Table. 1. Exam results and metrics across IDE, IEM, and the combined student cohort

		IDE			IEM			All		
Year	# of cases	n	avg	SD	n	avg	SD	n	avg	SD
2020-2021	X	166	5,60	1,39	102	5,79	1,60	268	5,69	1,49
2023-2024	≥0	132	5,64	1,25	99	5,99	1,49	231	5,80	1,37
2023-2024	≥1	103	5,62	1,27	51	6,22	1,48	154	5,84	1,38
2023-2024	≥2	81	5,63	1,28	39	6,61	1,48	120	5,98	1,41
2023-2024	≥3	64	5,57	1,17	28	6,69	1,44	92	5,95	1,35
2023-2024	4	28	5,87	1,18	16	6,89	1,54	44	6,25	1,37

Fig. 3. Distribution of cases attended by students and participation in individual case studies

those who are engaged are more likely to participate in all case studies. IDE students are more likely to participate, particularly in three case studies. Participation rates for individual case studies show similar levels of engagement between IDE and IEM. While the first case study attracted the highest participation rates, subsequent case studies showed a gradual decline. However, it must be noted that CS3 and CS4 were scheduled at less convenient time slots, while also facing severe weather conditions.

5.2 Exam results and impact of case studies

Table 1, Figure 4, and Figure 5 show the exam results for the IDE and IEM programmes and the overall results for the 2020-2021 and 2023-2024 academic years. For the academic year 2023-2024, the results are divided based on students' participation. Results are presented based on cumulative ranges for case study participation, as this allows a perspective on the influence of engaging in an increasing number of case studies. The standard deviations (SD) provide an overall impression of the consistency of the results. Notably, the SDs are relatively high, indicating that scores show variation. IDE provides a more consistent result, but in general, both still fall within normal SD ranges considering the grading scale. SDs in 2023-2024 suggest that exam scores are more consistent in the new course structure, however, the increasingly smaller sample sizes impede any definitive conclusions using the SD.

The combined results show an increase of 0.1 in the average grade (on a 0-10 scale) between the academic years 2020-2021 and 2023-2024. It shows a positive correlation between the number of case studies attended and exam grades, with students attending four case studies achieving an average grade almost 0.5 points higher than the overall average grade. However, the individual study fields reveal different trends. In the case of IDE, students who participated in all four case studies showed the largest improvement. Nevertheless, participation in fewer than four case studies yielded no improvement: even leading to examination grades below the average IDE grade. In addition, the average exam grade for IDE is only marginally

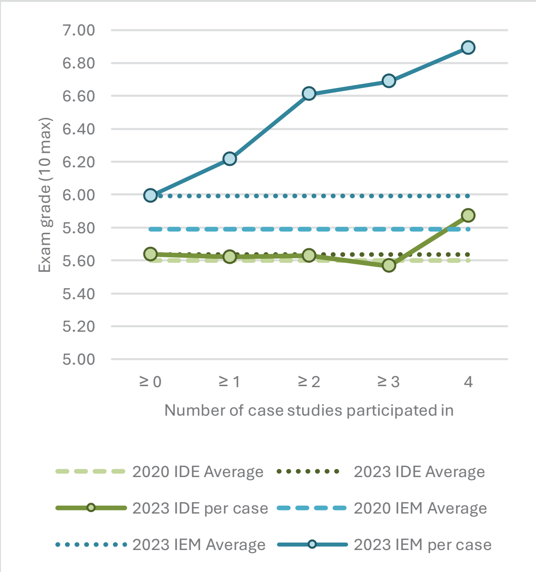


Fig. 4. Exam scores with case studies attended, alongside average exam grade

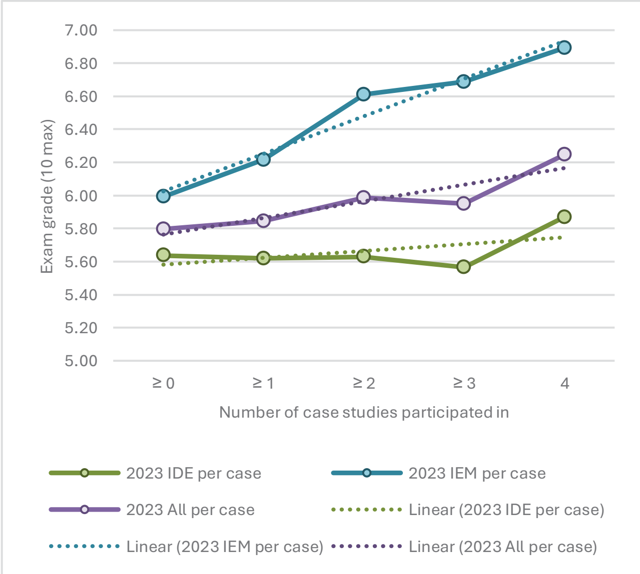


Fig. 5. Exam scores with case studies attended, linear

Fig. 6. Influence of participation in individual case studies on open questions

above that of the 2020-2021 comparative exam. Considering these results, the impact of case studies on enhancing academic performance in IDE is minimal, if not negligible. In contrast, the results for IEM show a convincing progression in exam grades with increased case study participation. Students who attend four case studies achieve an exam grade that is almost a full point higher than the average IEM grade. In addition, the average grade for IEM has increased by 0.2 compared to the 2020-2021 exam. These results clearly indicate a likely improvement in the achievement of learning objectives through the addition of case studies.

5.3 Open questions and impact of individual case studies

As one of the main objectives of the redesign was to incorporate active learning methods to enhance higher-order thinking skills, an analysis was conducted focusing specifically on the open-ended questions. The overview in Figure 6 shows the impact of participation in individual case studies (CS 1-4) on the results of specific open questions (Q 1-4), relative to the overall average score for that question. In the combined results, there is a slight positive impact across most questions, especially CS4 on Q3. In the IDE programme, contrasting patterns emerge, with certain cases even showing negative influences on the question results. For example, CS2 shows a negative impact on almost all open-ended questions in the exam. Furthermore, the highest positive impact is limited to only 8% for CS4 on Q3. These findings strengthen the consensus that case studies have minimal, and in some case even negative, impact for IDE in Production 1. In contrast, the IEM results shows only positive effects, with even the lowest positive effect in IEM corresponding to the highest positive effect in IDE. Both CS4, particularly on Q3, and CS2 illustrate the positive effects of case studies on performance in open-ended questions for IEM.

6 DISCUSSION

The results of this study provide interesting insights into the complex dynamics surrounding the integration of active learning methods, particularly case-based learning, into the Production 1 course. While second-year IEM students experienced significant improvements in exam performance with the addition of active learning elements, first-year IDE students showed little to negligible improvements. These findings highlight the nuanced nature of the effectiveness of active learning, appearing to be influenced by various contextual factors, including discipline and year of study. The improvements observed among second year IEM students are consistent with the existing literature, which highlights the positive impact of active learning strategies on academic achievement. However, the results observed among first-year IDE students challenge conventional assumptions about the universal effectiveness of active learning. Several factors may influence the observed differences. One explanation relates to the existing IDE curriculum being already saturated with active learning components – in comparison to the more ‘traditional’ IEM programme. Given that IDE students are already engaged in practical sessions in the course, the benefits of active learning elements may be diminished. The Binding Study Advice (BSA) for first year students introduces a further layer of complexity: a means of determining whether a student is suitable for a study, by posing a threshold of 45 EC (out of 60 EC) that students must pass. While the second year IEM students have already passed this threshold and will therefore not include 'unsuitable students', IDE students have not. An additional analysis was therefore conducted using interim BSA advices, using three categories (positive, neutral, negative advice). However, the sample size per group becomes too small to lead to reliable observations. Yet, in IDE the relation between a positive BSA advice and the grade for the exam remains marginal, indicating that the difference in exam result may be attributed to the study program. Moreover, despite the apparent positive impact of case studies on exam performance among IEM students, it is important to acknowledge the potential influence of self-selection bias. While there is a correlation between case study participation and improved academic performance, it is arguable that more motivated and academically inclined students may engage more in voluntary activities such as case studies, thus driving the positive correlation. However, the improvement in the average exam grade of the IEM students suggests that an external factor, the inclusion of case studies, is likely to play a predominant role in the improved performance.

7 CONCLUDING REMARKS

This study investigated the integration of active learning, specifically case-based learning, into the Production 1 course at the University of Twente, with the aim of improving student learning outcomes and addressing alignment challenges. The findings reveal the complex interrelations of factors that influence the effectiveness of active learning approaches in engineering education. The evaluation involved analysing past and current examination results to assess the impact of the redesign of Production 1, more specifically the impact of new elements within the redesigned course structure. The results showed that the incorporation of active learning elements, particularly case studies, significantly improved the examination performance of second-year IEM students, which is consistent with existing literature highlighting the positive impact of active learning on academic performance. However, first-year IDE students showed marginal to negligible improvements, challenging assumptions about the universal effectiveness of active learning. These findings highlight the need to tailor active learning implementations to different student populations, considering factors such as field of study and existing active learning elements. In the context of this research, the findings illustrate that IEM students benefit more from additional active learning elements, such as case studies, in Production 1. For IDE students, it is crucial to consider the current active learning load before introducing new elements such as learning factory activities in iterations of the redesign of Production 1. In general, it is important to subject active learning strategies to undergoing review to be able to ensure effective learning (Malmqvist, Edström, and Rosén 2020). In addition, future research should delve deeper into the complex dynamics of active learning, exploring how different factors influence its effectiveness while identifying optimal strategies for engineering education, including whether more active learning always leads to better outcomes.

REFERENCES

Abele, E., J. Metternich, M. Tisch, and Antonio Kreß. 2024. *Learning Factories Featuring New Concepts, Guidelines, Worldwide Best-Practice Examples*. 2 ed. Switzerland: Springer Cham.

Aji, Chadia A., and Javed Khan. 2019. "The Impact of Active Learning on Students' Academic Performance." *Open Journal of Social Sciences* 07: 204-211. https://doi.org/10.4236/jss.2019.73017.

Ambrose, Susan A., Michael W. Bridges, Michele DiPietro, Marsha C. Lovett, and Marie K. Norman. 2010. *How learning works: Seven research-based principles for smart teaching*.*How learning works: Seven research-based principles for smart teaching.* San Francisco, CA, US: Jossey-Bass.

Anderson, L. W., D. R. Krathwohl, P. W. Airasian, K. A. Cruikshank, Richard Mayer, P. R. Pintrich, J. D. Raths, and M.C. Wittrock. 2001. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of*

Educational Objectives. Edited by L.W. Anderson and D.R. Krathwol. 1 ed. New York: Longman.

Biggs, John, and Catherine Tang. 2011. *Teaching for Quality Learning at University*. 4 ed. Berkshire: Society for Research into higher Education & Open University Press.

Bonwell, Charles C., and James A. Eison. 1991. "Active Learning: Creating Excitement in the Classroom. ."

Cavanagh, A. J., O. R. Aragón, X. Chen, A. Couch, F. Durham, A. Bobrownicki, D. I. Hanauer, and M. J. Graham. 2016. "Student Buy-In to Active Learning in a College Science Course." *CBE Life Sci Educ* 15 (4). https://doi.org/10.1187/cbe.16-07-0212.

Damgrave, R., J. Massa, and E. Lutters. 2023. "Information Integration Over Different Educational Levels and Disciplines in a Learning Factory." Proceedings of the 13th Conference on Learning Factories (CLF 2023), Reutlingen, Germany.

Dankers, W., H. Schuurman-Hemmer, T. van den Boomgaard, and E. Lutters. 2013. "Bringing practice to the theory: Project-led education in Industrial Design Engineering." 2nd International Conference for Design Education Researchers, DRS CUMULUS 2013, Oslo, Norway.

Edström, K., D. Soderholm, and M. Knutson Wedel. 2007. "Teaching And Learning." In *Rethinking Engineering Education: The CDIO Approach*, edited by Edward F. Crawley, Johan Malmqvist, Sören Östlund and Doris R. Brodeur, 130-151. Boston, MA: Springer US.

Felder, Richard, and Rebecca Brent. 2009. "Active learning: An introduction." *ASQ Higher Education Brief* 2.

Freeman, Scott, Sarah Eddy, Miles McDonough, Michelle Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Wenderoth. 2014. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences of the United States of America* 111. https://doi.org/10.1073/pnas.1319030111.

Gijlers, Hannie, and Ton Jong. 2005. "The relation between prior knowledge of students' collaborative discovery learning processes." *Journal of Research in Science Teaching* 42: 264-282. https://doi.org/10.1002/tea.20056.

Gogus, Aytac. 2012. "Active Learning." In *Encyclopedia of the Sciences of Learning*, edited by Norbert M. Seel, 77-80. Boston, MA: Springer US.

Hartikainen, Susanna, Heta Rintala, Laura Pylväs, and Petri Nokelainen. 2019. "The Concept of Active Learning and the Measurement of Learning Outcomes: A Review of Research in Engineering Higher Education." *Education Sciences* 9 (4). https://doi.org/10.3390/educsci9040276.

Lavi, Rea, and H. Deniz Marti. 2023. "A Proposed Case-Based Learning Framework for Fostering Undergraduate Engineering Students' Creative and Critical Thinking." *Journal of Science Education and Technology* 32: 1-14. https://doi.org/10.1007/s10956-022-10017-w.

Lutters, E., J. Massa, R. Damgrave, S. Thiede, and L. Gommer. 2022. "INTEGRATION OF LEARNING AND RESEARCH IN A MULTI-PERSPECTIVE LEARNING FACTORY." Proceedings of the International CDIO Conference.

Malmqvist, J., A. Edström, and A. Rosén. 2020. "CDIO STANDARDS 3.0 – UPDATES TO THE CORE CDIO STANDARDS." 16th International CDIO Conference, Chalmers UT, Sweden.

Massa, J., and E. Lutters. 2024. "Guiding the Design of Effective Learning Factories: Requirements of a Design Approach for Resilience." CLF 2024, Enschede, Netherlands.

Prince, M. 2004. "Does active learning work? A review of the research." *Journal of Engineering Education* 93 (3): 223-231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x. https://www.scopus.com/inward/record.uri?eid=2-s2.0-3342952938&doi=10.1002%2fj.2168-9830.2004.tb00809.x&partnerID=40&md5=9e4ba89a8dfdcb8a2b18ea6f335a08ff.

Srisawasdi, Niwat. 2012. "Fostering Pre-service STEM Teachers' Technological Pedagogical Content Knowledge: A Lesson Learned from Case-based Learning Approach." *Journal of the Korean Association For Research in Science Education* 32. https://doi.org/10.14697/jkase.2012.32.8.1356.

EXAMINING BEST PRACTICES IN CURRICULUM DESIGN: INSIGHTS FOR ENGINEERING EDUCATION

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ABSTRACT

Higher education must be prepared for the ever-changing needs of the world to ensure that future engineers receive extensive training and are equipped to provide significant contributions to both the workforce and society. It is important for higher education leaders to be aware of the need for regularly reviewing curriculum and take part in development to ensure quality improvement. Engineering education needs to be up to date and driven by the need to prepare graduates for the challenges posed by rapidly changing technology, industry, and society. This paper specifically aims to identify best practices for curriculum design in engineering education. Data was collected through the exchange of engineering and business curricula among members participating in the DECART project (DECART 2022). The shared curricula underwent critical examination based on key features related to curriculum components. The analysis included reflection and feedback from project partners. The findings hold significance for engineering educators in various contexts, offering insights into curriculum transformation, agility, and resilience amidst increasingly Volatile, Uncertain, Complex, and Ambiguous (VUCA) environments, which continue to influence engineering education and higher education.

1 INTRODUCTION

1.1 Curriculum Design

Curriculum design holds a pivotal role in shaping the educational journey, ensuring its alignment with industry requisites, fostering critical thinking, and endowing students with the competencies requisite for success in their careers. According to Kumar and Rewari (2022), an outcome-based approach to curriculum is imperative, with clearly delineated program and course outcomes, in line with the demands of accrediting bodies and global benchmarks.

An important consideration is that of graduate employability and ensuring that the curriculum is of relevance for the labour market (Davey et al. 2018). Curriculum review and revision must be done on a regular basis, in response to changing needs of industry and to ensure innovation (Dopson and Tas 2004). A recommendation from the research of Davey et al. (2018) indicates that it is critical to provide support for designing new curricula as well as re-designing current curricula. It has been argued that diverse stakeholders, such as students, graduates, facilitators, staff, industry, and business, and even parents, should be involved in co-designing and co-delivering curricula (Plewa, Galán-Muros and Davey 2015; Kumar and Rewari 2022). It is important that the curriculum is accessible and can be adaptive and responsive (Prideaux 2003).

In the evolving landscape of the 21st century, the engineering domain finds itself immersed in a milieu characterised by volatility, uncertainty, complexity, and ambiguity, often referred to as VUCA (Bennett and Lemoine 2014; Panthalookaran 2022). The unprecedented pace of technological advancements, globalisation, and dynamic market demands has birthed challenges necessitating engineers equipped with a distinct skill set.

To prepare future engineers for the demands of the VUCA environment, curricula must evolve. By furnishing students with essential skills and knowledge, curricula endeavour to promote sustainability and address intricate engineering challenges within a VUCA framework (Rouvrais et al. 2018). In the ever-evolving realm of engineering, the acronym VUCA serves as a guiding framework to comprehend and navigate the challenges emerging in today's swiftly changing environment (Panthalookaran 2022; Bennett and Lemoine 2014). Understanding VUCA in engineering transcends mere acknowledgment; it serves as a clarion call for both professionals and higher education practitioners.

Engineers must foster resilience, agility, and a mindset of continuous learning to thrive in future VUCA environments. Educational programs need to surpass the imparting of technical skills, integrating experiential learning, collaborative projects, and exposure to real-world scenarios (Rouvrais et al. 2023). Latha and Christopher (2020) anticipate in their paper that with training, VUCA and its associated challenges will metamorphose into opportunities, fostering a dynamic culture propelling Engineering Education towards progress and productivity. Niemczyk (2023) underscores the necessity of adopting a mindset shift to address the challenges of the 21st century within the prevailing VUCA environment. Integrating VUCA principles into engineering curriculum design signifies a departure from traditional, inflexible educational models. Program leaders must ensure that the curriculum is structured and implemented with the ability to navigate a context of uncertain changes (Ciolacu et al. 2023).

1.2 Theoretical Importance

The field of curriculum studies involves examining different approaches to designing, implementing, and evaluating educational programs. These perspectives may include curriculum as a product, process, praxis, or cultural context, among others.

Van den Akker's (2003) work focuses on providing educators and researchers with frameworks to understand and navigate the complexities of curriculum development. He presents the ten components metaphorically as the supporting strings in a spiderweb with the rationale for the learning at the web´s centre. Figure 1 explains Akker's components in a spiderweb.

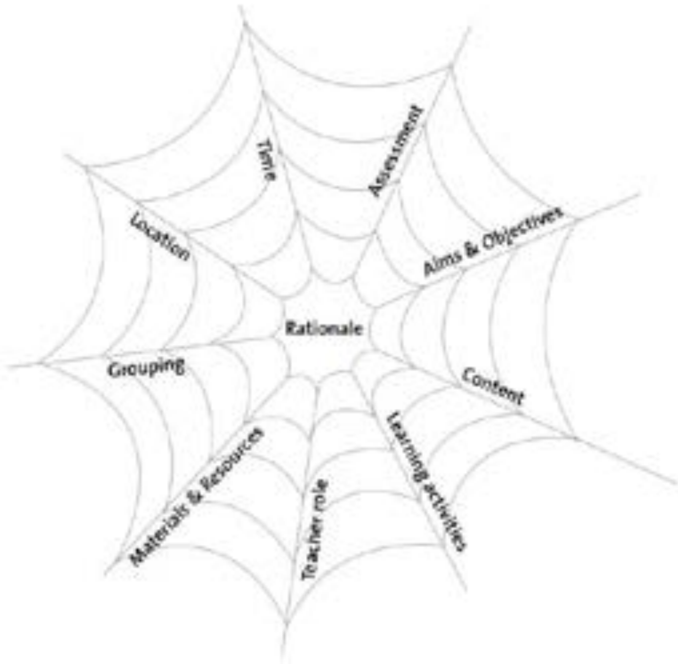

Fig. 1. Van den Akker's framework (Van den Akker, 2003:43)

Jonnaert et al. (2021) present a model that is valuable when transforming the curriculum and presents the curriculum as composed of three connected domains of educational policies of curriculum and of education practices. Figure 2 explains the components in Jonner's model.

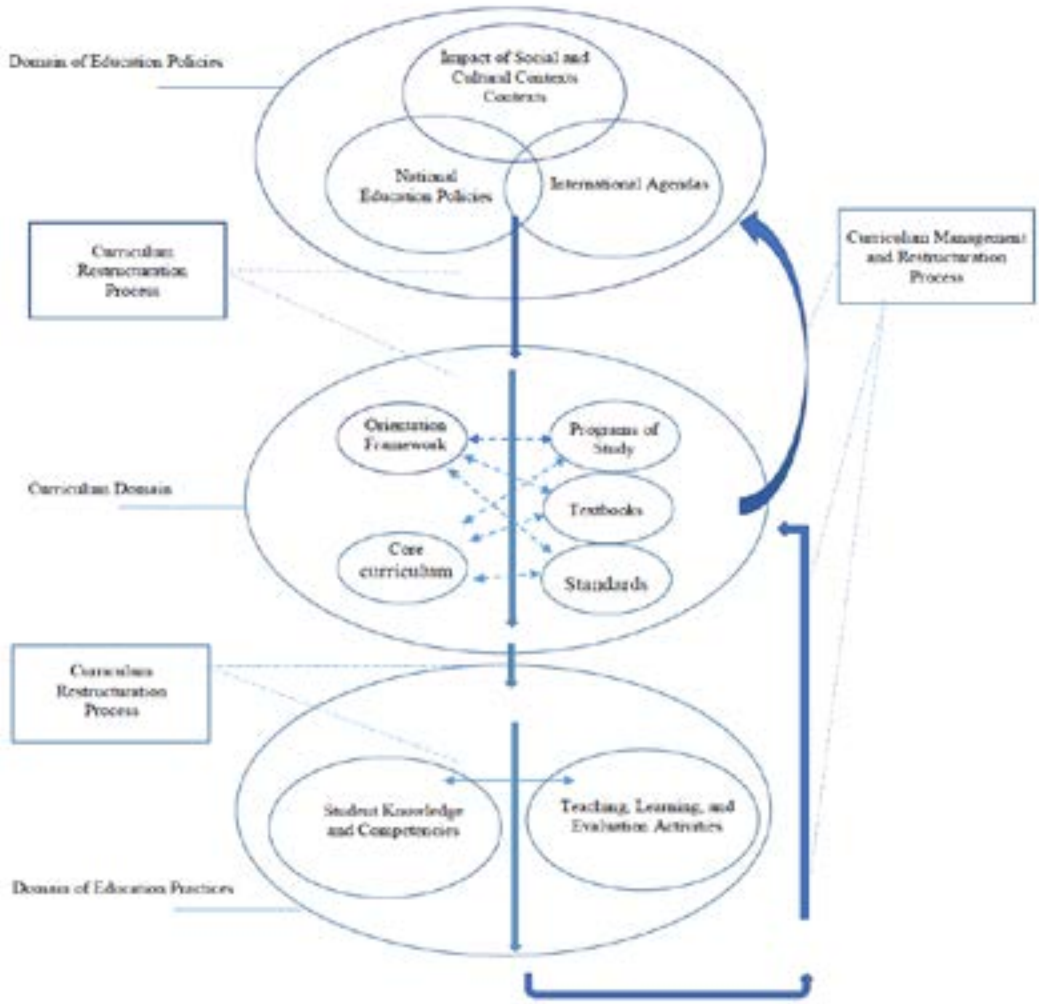

Fig. 2. The Jonnaert model (Jonnaert et al., 2021:11)

The CDIO (Conceiving, Designing, Implementing, Operating) model represents a framework for enhancing engineering education by focusing on a hands-on and project-based approach in an integrated manner with outcome-based education and a syllabus of learning outcomes (Crawley et al. 2014; Malmqvist et al. 2020). The twelve CDIO standards emphasise the integration of engineering fundamentals, personal and interpersonal skills, and real-world applications.

More recently, Brink et al. (2023) defined curriculum agility as an ability “to be responsive to changes in society’s, industry’s, and students’ characteristics and needs, by proactively and in a timely manner adapting the curriculum’s relevant organisational structures, learning outcomes, learning activities, and assessments” (27). In their perspective, ten principles of curriculum agility are defined, from educational vision to stakeholder involvement.

1.3 Question Addressed

The paper addresses the question of what best practices for curriculum design can be identified, based on actual and exemplary curricula in engineering education, reviewed by faculty from several countries and following the VUCA environment that we are navigating. Models from van den Akker (2003), Jonnaert (2021) and the CDIO standards (Crawley et al. 2014) formed the theoretical foundation in the analysis, which led to a specific new model with nine curriculum components (Audunsson et al. 2024). The results are from a study conducted in the DECART (Designing Higher Education Curricula for Agility, Resilience and Transformation) project (ERASMUS+ 2022-25). The project partners are from diverse higher educational institutions across three continents (Europe, Asia, and Africa), and are involved in Science, Technology, Engineering and Mathematics (STEM) and Management education.

1.4 Research Aim

The aim of this paper is to provide guidance to higher education leaders in STEM and Management education on curriculum design and sustainable resilient program transformation.

2 METHODOLOGY

The study primarily utilises reflective practices by faculty in Higher Education within the DECART project, specifically focusing on their roles as reflective educators. Consequently, the study aligns with the interpretivist paradigm. One of the DECART project's aims is to investigate curriculum design, which we approached through three phases of data collection and analysis.

In Phase 1, beginning in 2023, six project partners shared the curricula they were involved with, as well as other innovative and exemplary curricula they knew of. The shared curricula were mainly from Engineering and Management, reflecting the nature and objectives of the DECART project. Phase 2 involved a critical examination of these diverse curricula by the six project partners, focusing on key features related to the curriculum. The components identified in Phases 1 and 2 were discussed and analysed, resulting in the identification of nine components (see Results and discussion). The identified components may not be exhaustive and do not encompass all elements from the curriculum development literature. In Phase 3, all project partners (a total of 17 individuals related to the project) reflected on and engaged with the received feedback to identify best practices for curriculum design components. This analysis is presented below, in Results and discussion.

3 RESULTS AND DISCUSSION

The components that the partners identified are 1) learning outcomes, 2) entry requirements, 3) structure of program, 4) teaching methods, 5) location of teaching and learning, 6) teaching of interpersonal skills, 7) assessment methods, 8) language, and 9) ethno- and sociographic aspects. The following section thus presents the key points which were noted by project partners in terms of identifying best practices within the context of curriculum design.

3.1 Learning outcomes

It was indicated that learning outcomes or goals should promote co-building of knowledge, autonomy, communication, theoretical engagement, and intellectual independence. Also important is a good structure of the learning outcomes. The learning outcomes should have been explained in the module or course outline. Students should thus be aware of the goals or learning outcomes and should be able to know how to apply the knowledge that they gained to solve real world problems. It is also important that general and specific skills, knowledge, and attitudes are clearly outlined. The curriculum should also be practical, involving real-world implications and not just theory. It was considered important that the goals and learning outcomes have a direct impact in terms of leading to the training and education of graduates who can contribute to the development of society, enhance existing knowledge, address complex problems, and ultimately be responsible citizens.

Within the business context, it was noted that goals or learning outcomes should be more applied, and would typically be relevant for business stakeholders, which would include the students, who are often working. Goals and learning outcomes should thus be adapted to the context. It was also noted that goals or learning outcomes should incorporate national values.

3.2 Entry requirements

It was noted that entry requirements for students should be clearly outlined and should be detailed and understandable. There should be a link to national requirements, and these should be coherent with learning outcomes.

It was argued that entry requirements typically focused on the basic educational requirements, such as matric or similar, or a maths background for STEM subjects. Some degrees may also have specific requirements in terms of grades, language, and possibly practical work experience and a minimum age.

3.3 Structure of the program

The structure of the program should clearly indicate the academic timelines and schedules, and indicate the semesters, terms, and breaks. The duration of the programme and modules should be clear, with all compulsory and elective modules outlined. Learning pathways are explicit, as well as the hours, credits, format, location, and whether there are internships.

3.4 Teaching methods

It was noted that there should be diverse teaching methods. The learning methods typically include lectures, group work, projects, and case studies. There may also be guest lectures or presentations from industry professionals. The student experience is critical. Teaching methods should be coherent with entry requirements and learning goals. It was also noted that there is great value in incorporating a problem-based approach, flipped learning, and ensuring a student and faculty-friendly learning management system.

Key aspects to consider is to record the lectures, which became a critical practice during the Covid-19 pandemic. The level of the programme and the student must be considered. For example, Business School students are usually more mature, and often have a job. Adult learning principles and the integration of work and life experience of the student is thus incorporated.

3.5 Location of teaching and learning

The location of teaching and learning is important, especially in considering that there may be online teaching and learning. Students may also spend a semester abroad or be based in a company. It should be clearly outlined if the learning location may not only be confined to campus.

3.6 Teaching of interpersonal skills

The value of having diverse interpersonal skills was noted as critical for the development of students, especially to ensure that they were ready for the world of work, but also to empower them during their years of studying. The skills should be visible in the diverse modules. Various interactive and collaborative learning activities should be designed and integrated into the curriculum to enhance students' interpersonal skills.

The importance of developing soft skills for students was highlighted. These include teamwork, communication, leadership, decision-making, dialogue, conflict management, emotional intelligence, responsibility, time management, intercultural, and being able to work effectively individually as well as with others. Students should also be able to manage their own career development.

3.7 Assessment methods

It was noted that there should be diverse types of assessment. In certain instances, companies and/or other industry professionals may be involved. The value of continuous assessment was noted. Rubrics should be provided.

3.8 Language

It was highlighted that there is value in having instruction be provided in more than one language, especially where there are national languages. There is also value in having materials, module outlines, and assessments available in the relevant national languages. It is however important that necessary resources are provided, as this would have implications for various aspects related to teaching and learning.

3.9 Ethno- and sociographic aspects

Ethno-/sociographic components need to be well specified. It was noted that diversity is critical, especially with respect to the diverse backgrounds of students, as well as diverse educational backgrounds. It is also important to consider the culture and specific needs that international students may have. Related to this is the need to focus on communities, society, partnerships, collaboration, and values. Other important considerations include female representation and industry collaboration.

4 SUMMARY AND CONCLUSION

If we compare our 9 components to the models described in Section 1.3, we see that van den Akker’s framework (2003) provides a comprehensive view by integrating these components into a coherent system that emphasises the interrelationships between curriculum elements. It highlights the importance of considering the socio-cultural context, adaptability, and the alignment of learning activities and assessment methods with the intended learning outcomes. This alignment ensures a holistic and effective approach to curriculum design and implementation. The Jonnaert model (2021) integrates its components within a competency-based framework. Both our list and the CDIO standards (Malmqvist et al. 2020) emphasise crucial aspects of curriculum design. The CDIO standards provide a structured and integrated approach focused on producing graduates who can conceive, design, implement, and operate complex systems. They highlight the importance of active learning, integrated curriculum, and competency-based assessment, aligning closely with many components from our list, such as learning outcomes, teaching methods, and assessment methods. The CDIO framework, however, places a stronger emphasis on engineering-specific contexts and hands-on learning environments. Our framework highlights the importance of developing and accessing competencies in real-world contexts, promoting a more holistic and flexible approach to education that is responsive to the needs and backgrounds of all learners.

Although the structure from van den Akker (2003) and the above nine components appear comprehensive in describing a curriculum, it is important to ensure that the curriculum has the inherent property of flexibility to be able to readily respond to different VUCA situations. This was especially evident during the COVID-19 pandemic.

In summary, best practices in curriculum design for engineering education are multifaceted, encompassing industry relevance, active learning, interdisciplinary approaches, and a focus on soft skills development. A curriculum that adeptly integrates these elements not only equips students with technical knowledge but also cultivates the adaptability and versatility necessary for a successful engineering career. As technology advances and societal needs evolve, engineering education must remain at the vanguard of innovation to produce graduates capable of tackling future challenges.

We would like to conclude by underlining the importance of the findings and recommendations for a wide array of stakeholders, including educators, curriculum leaders, quality assurance and accreditation bodies, students, and industry players. These insights have the potential to drive curriculum transformation, agility, and resilience in the face of VUCA contexts. The paper accentuates the potential impact on curriculum and course development, engineering projects, student preparation, and engagement. The study findings hold valuable insights for engineering educators across various contexts, particularly as they were derived from real curricula and evaluated by faculty involved in curriculum design or reflective educators who grappled with swiftly responding to the challenges posed by VUCA conditions in Higher Education. The recommendations carry implications for curriculum development, enhancing student engagement and preparing engineering students for the future.

The study limitation, which is also its strength, is that it builds on the work of a small, closed group of DECART project partners. Nonetheless, all partners are experienced teachers who are deeply involved in curriculum design. The study limitations also include time constraints, and that the study drew on limited methods. This study is part of the DECART project, an EU funded Erasmus+, n 2022-1-FR01-KA220-HED-000087657 (DECART, 2022).

REFERENCES

Audunsson, H., Matthiasdottir, A., Barus, A., Rouvrais, S., Waldeck, R., and Gerwel Proches, C. “Factors that may impact curriculum design in higher education in a VUCA world”. 20th International CDIO Conference, Tunis, Tunisia, 10-13 June 2024.

Bennett, N., and Lemoine, G. J. ”What a difference a word makes: Understanding threats to performance in a VUCA world.” *Business Horizons*, 57, no. 3, (2014): 311-317. https://doi.org/10.1016/j.bushor.2014.01.001.

Brink, S., Carlsson C. J., Enelund, M., Edström, K., Keller, E., Lyng, R., and McCartan, C. "Curriculum agility as optional CDIO standard". In Proceedings of *19th CDIO International Conference*, *CDIO,* Trondheim, Norway, Jun 26-29, 2023, 18-28.

Ciolacu, M. I., Mihailescu, B., Rachbauer, T., Hansen, C., Amza, C. G., and Svasta, P. "Fostering Engineering Education 4.0 Paradigm Facing the Pandemic and VUCA World", *Procedia Computer Science*, 217, (2023): 177-186. https://doi.org/10.1016/j.procs.2022.12.213.

Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R. and Edström, K. *Rethinking Engineering Education: The CDIO Approach*, Springer Science+Business, 2018.

Davey, T., Meerman, A., Galán-Muros, V., Orazbayeva, B. and Baaken, T. *The state of university-business cooperation in Europe*, Luxembourg, Publications Office of the European Union, 2018. https://doi.org/10.2766/676478.

DECART: Designing higher Education Curricula for Agility, Resilience & Transformations, 2022. Available at: www.decartproject.eu.

Dopson, L. R., and Tas, R. F. "A practical approach to curriculum development: A case study." *Journal of Hospitality & Tourism Education*, 16, no. 1, (2004): 39-46. https://doi.org/10.1080/10963758.2004.10696783

Jonnaert, P., Ndinga, P., Ettayebi, M., Barry, A., Rabinovitch, L., and Malu, R. Towards indigenous curricula. In-Progress Reflection on Current and Critical Issues in Curriculum, Learning and Assessment, no. 41, UNESCO International Bureau of Education, 2021. https://unesdoc.unesco.org/ark:/48223/pf0000375339.

Kumar, V., and Rewari, M. A. "Responsible Approach to Higher Education Curriculum Design." *International Journal of Educational Reform*, 31, no. 4, (2022): 422-441. https://doi.org/10.1177/10567879221110509.

Latha, S., and Christopher B. P. "VUCA in Engineering Education: Enhancement of Faculty Competency For Capacity Building." *Procedia Computer Science*, 172, (2020): 741-747. https://doi.org/10.1016/j.procs.2020.05.106.

Malmqvist, J., Edström, K., and Rosén. A. "CDIO Standards 3.0–Updates to the Core CDIO Standards." In the *16th International CDIO Conference Online*, Chalmers, Sweden, 8-10 June 2020, 1, 60-76, Chalmers University of Technology,

Niemczyk, E. K. "Higher Education as a Sustainable Service Provider in a Rapidly Changing World." Paper presented at the *Annual International Conference of the Bulgarian Comparative Education Society* (BCES), 21st, Sofia, Bulgaria, June 2023.

Panthalookaran, V. "Education in a VUCA-driven World: Salient Features of an Entrepreneurial Pedagogy." *Higher Education for the Future*, 9, no. 2, (2022): 234-249. https://doi.org/10.1177/23476311221108808.

Plewa, C., Galán-Muros, V., and Davey, T. "Engaging business in curriculum design and delivery: a higher education institution perspective." *Higher Education*, 70 (2015), 35-53. https://doi.org/10.1007/s10734-014-9822-1.

Prideaux, D. "Curriculum design." *BMJ*, 326.7383, (2003): 268-270. https://doi.org/10.1136/bmj.326.7383.268.

Rouvrais, S., Gaultier Le Bris, S., and Stewart M. "Engineering Students Ready for a VUCA World? A Design based Research on Decisionship." In *Proceedings of 14th International CDIO Conference, KIT*, Kanazawa, Japan, (2018), 872--881. Available at: http://ds.libol.fpt.edu.vn/handle/123456789/2475.

Rouvrais, S., Winkens, A-K., Leicht-Scholten, C., Audunsson, H. and Gerwel Proches, C. "VUCA and Resilience in Engineering Education - Lessons Learned". In Proceedings of *19th CDIO International Conference*, *CDIO,* Trondheim, Norway, June 26-29, 2023: 312-322.

Van den Akker, J. "Curriculum Perspectives: An Introduction." *Curriculum Landscapes and Trends*, (2003): 1-10. https://doi.org/10.1007/978-94-017-1205-7_1

HOW DO ENGINEERING EDUCATION SOCIETIES ENGAGE WITH DEI CONCEPTS? A PRELIMINARY THEORETICAL ANALYSIS OF FORMAL DEI STATEMENTS

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ABSTRACT

The growing emphasis on diversity, equity, and inclusion in engineering education shows the need for substantive changes within academic institutions and professional sectors. Despite numerous initiatives, traditional approaches often fail to

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address systemic barriers hindering the full participation of historically marginalized groups. Moreover, the global context adds complexity to DEI efforts, necessitating a deeper understanding of how DEI initiatives align with theoretical frameworks. This paper explores the alignment between theoretical underpinnings and DEI statements in engineering education. The preliminary study aims to enhance the alignment of DEI commitments with theoretical foundations. The study utilizes results from a previous scoping review of literature which identified five emergent themes in the use of theories in engineering education DEI research: Institutional and Organizational Theory, Constructivist and Developmental Theory, Social Identity and Intersectionality Theory, Community and Cultural Theory, and Critical Theory. Three DEI statements from prominent engineering education organizations are analysed through these thematic lenses. The analysis reveals varying degrees of alignment between the DEI statements and theoretical frameworks, highlighting the importance of context in understanding and prioritizing DEI topics. While each statement demonstrates alignment with DEI theories, differences in focus and extent suggest opportunities for intentional writing of DEI statements. The paper provides an initial discussion on how to critically write DEI statements, underscoring the importance of theoretical foundations in guiding effective DEI initiatives. Further research could expand this analysis to other DEI policy documents to gain deeper insights into DEI efforts in engineering education globally.

1. INTRODUCTION

1.1 Background and Context

In recent years, there has continued to be an increase in the awareness and importance of diversity, equity, and inclusion (DEI) within engineering education (Direito et al. 2021). Work in this space has expanded across academic institutions, industry sectors, and societal discourse (Schindler 2022). There is a need to improve engineering programs in terms of access, inclusion, and providing spaces where all students and academics feel safe, included, and as they belong. However, despite multiple efforts in research, funding, and support programs, it has become increasingly evident that traditional approaches and surface-level initiatives are not providing the desired outcomes. Engineering programs are still not fully prepared to address the systemic barriers impeding the full participation of historically marginalized groups. Despite concerted efforts to recruit traditionally marginalized and underrepresented students, most of these efforts focus on increasing numbers and diversity. While important, it is also crucial to think about how to go beyond diversity to focus on inclusion and equity. Significant gaps persist between rhetoric and reality, hence, the critical need for a deeper examination of the efficacy and alignment of DEI strategies with theoretical frameworks in engineering education research.

In addition, engineering education as a global field faces issues with the lack of understanding of the importance of context in DEI work. DEI issues, initiatives, and conceptualizations might look very different and have different meanings across the globe. Similarly, there is a need to not only develop a better examination of the DEI space both from a practice and theoretical perspective but also to include global perspectives in these lenses. As part of this concern, we started to work in this space by engaging in conversations about DEI policies and practices with engineering educators from a wide variety of national and cultural contexts (Van Maele et al. 2023).

1.2 Purpose of the study

The purpose of this paper is to explore the intersection of how the theoretical underpinnings that have shaped DEI work in engineering education align (or not) with DEI statements in the field. By digging into the nuanced relationship between theory and practice, our goal with this preliminary work is to understand how engineering programs can better align their commitments to DEI with substantive theoretical foundations. This exploratory study is part of a larger research project that aims to understand (i) how DEI leaders in engineering education make decisions, including how theory informs those decisions, and (ii) how DEI issues are different depending on the context globally.

Central to our inquiry is the recognition that the mere existence of diversity statements within educational institutions and organizations is insufficient without a robust understanding of how these statements translate into tangible outcomes that dismantle systemic inequities and foster a culture of belonging for all.

We seek to unpack the complexities surrounding DEI initiatives in engineering education and to be able to provide a roadmap to make sure statements have a sufficient theoretical foundation. We argue that while DEI efforts have increased considerably in recent years, there remains a pressing need to interrogate the ways in which theory has been employed to inform and guide these initiatives. Moreover, we contend that a critical examination of different statements can provide valuable insights into the gaps between declared values and actual practices within engineering programs, thereby paving the way for more effective interventions and inclusive pedagogical, research, and mentoring approaches.

In light of these considerations, our goal is to contribute to the ongoing dialogue surrounding DEI in engineering education and catalyse efforts toward a more equitable and accessible future for all stakeholders in the field.

2. METHODOLOGY

Our initial approach in this study was to analyse three publicly available documents that relate to DEI in recognized organizations in engineering education. Results from a scoping review of the literature (Cao, Murzi, and Chowdhury 2023), were used to inform our analysis. The scoping review followed Siddaway et al. systematic review approach (Siddaway, Wood, and Hedges 2019). The search started with 422 articles that included diversity, equity, or inclusion in engineering education. After title refining and abstract screening, 252 articles were reviewed in full. The full-text sifting provided a total of 55 articles. The articles were analysed to understand what theories were used in DEI research in engineering education.

We used the 5 emergent themes from the scoping review to analyse these statements and identify examples of how the theoretical space was represented in the narrative of the statement. In the following sections, we provide more information on the preliminary results of the scoping review and the emergent themes used to analyse the three documents.

2.1 Scoping review emerging themes

As mentioned, our preliminary findings showed that work in this space falls under the following 5 emerging themes of theories:

2.1.1 Institutional and Organizational Theory (IOT)

This theme refers to theories and frameworks that emphasize different institutional practices and organizational structures that influence and promote Diversity, Equity, and Inclusion (DEI) in Engineering Education. The synthesis of these studies yields valuable insights showcasing various strategies that encompass faculty influence, program-level initiatives, and successful interventions aimed at enhancing inclusion in engineering. Some aspects of these frameworks include culture, climate and circumstance within an organization and its impact on different social groups. Similarly, some of this work focuses on pathways, support systems, transdisciplinary and sustainable approaches, and academic success (Pamulapati et al. 2021; Main et al. 2020; Gulbulak, Ertas, and Cordell 2020; Lee and Matusovich 2016; Fealing, Lai, and Myers Jr 2015; Hokanson, Phillips, and Mihelcic 2007; Leicht-Scholten, Weheliye, and Wolffram 2009; Taylor et al. 2017; Griffith, Hajiaghajani, and Griffith 2016; Sayles 2004).

2.1.2 Constructivist and Developmental Theory (CDT)

This theme highlights the different theories and frameworks developed from findings based on grounded theory or a mix of various theories that focus on creating supportive and inclusive learning environments, challenge dominant narratives, incorporate diversity and cultural awareness and promote authentic engagement and participation. These frameworks address various aspects, including understanding how to advance DEI based on the emergent knowledge of traditionally marginalized populations. This theme also includes aspects of emerging values, the influence of social, cultural, and political influences that impact students, conceptualizations of critical race, and experiences with the endemic nature of racism and its influence on engineering education (Simmons and Martin 2014; Sochacka et al. 2021; Corwin et al. 2020; McCall, McNair, and Simmons 2021; Dankert et al. 2019; Trytten et al. 2016).

2.1.3 Social Identity and Intersectionality Theory (SIIT)

In this section, theories and frameworks that view diversity as intersecting social categories like race, class, and gender were grouped. These categories shape people's behaviour, identities, and outcomes toward DEI in Engineering. Different theories or frameworks were used in the research included in this section, for example, professional identity development theory, social justice perspectives on diversity, equity, and inclusion, feelings of belonging, social cognitive theory and self, social identity theory. sense of community, expectancy-value theory, equity of parity model, model of motivation, and sustainable development framework (McCall et al. 2020; Cundiff and Murray 2020; Atadero et al. 2018; Casper et al. 2024; Lee et al. 2017; Park et al. 2020; Hernandez et al. 2017; Woodcock and Bairaktarova 2015; Scott and Martin 2014; Casper et al. 2024; R. M. Marra et al. 2010; Rose M. Marra et al. 2009; Whitcomb, Maries, and Singh 2021; Whitcomb et al. 2020; Lee et al. 2021; Artiles and Matusovich 2020; Roldan, Hui, and Gerber 2018; Godwin et al. 2016; Wint 2022; Corple et al. 2018; Pearson, Godwin, and Kirn 2018; Williams et al. 2016).

2.1.4 Community and Cultural Theory (CCT)

This theme highlights the different theories and frameworks that view DEI as prominent to cultural traits and social categories like race, class, gender, etc. These categories shape one's behaviour, identities, and outcomes towards DEI in Engineering. The theme provides the importance of understanding and leveraging cultural diversity, addressing inequities, promoting social networks and adopting culturally responsive approaches to enhance DEI in Engineering. These are frameworks that also focus on reducing stereotypes, supporting human-centred approaches, using social networks and capital-like Community Cultural Wealth (CCW), and emphasizing the significance of addressing historical and ongoing exclusionary practices and inequalities in engineering (Eastman, Miles, and Yerrick 2019; Tolbert Smith 2022; Wofford and Gutzwa 2022; Carrigan et al. 2019; Bowen et al. 2021; Martin, Simmons, and Yu 2013; Martin 2015; Perkins et al. 2018; Callens et al. 2019).

2.1.5 Critical Theory (CT)

This theme highlights the use of critical theories to address social justice issues in engineering, as critical theories aim to critique and challenge power structures and dismantle systematic oppression. The authors in this theme employ critical theories to advocate for transformative change in engineering education to promote DEI, including Afrocentric, indigenous, feminist, and intersectional approaches and ways of knowing and being. These frameworks also focus on the ongoing efforts to broaden academic discourses and promote forms of equity-oriented teaching in engineering education. Similarly, one of the goals is to promote agency and empowerment among marginalized groups by advocating for alternative perspectives and approaches that prioritize DEI and challenge oppressive systems (Blosser 2020; Secules et al. 2018; Roby et al. 2022; Blair et al. 2017; Foor, Walden, and Trytten 2007; Du and Kolmos 2009; Bowen et al. 2021; Bowen, Johnson, and Powell 2020).

2.2 Statements analysed

For this preliminary study, we decided to pilot our approach of coding some DEI statements using the 5 emerging themes as the lens for analysis. We selected statements focused on diversity, equity, and inclusion in two of the most recognized engineering education societies, i.e., the American Society for Engineering Education (ASEE) and the European Society for Engineering Education (SEFI). The statements we selected for our analysis were:

1. ASEE Statement on DEI https://diversity.asee.org/about/
2. SEFI Position Paper on Diversity, Equality, and Inclusiveness in Engineering Education: https://www.sefi.be/wp-content/uploads/2018/05/Diversity-2018-links.pdf
3. ASEE & SEFI DEI Joint statement: https://www.sefi.be/wp-content/uploads/2020/05/ASEE-SEFI-Diversity-Statement_updated.pdf

3. RESULTS

In this section, we summarize the result of our analysis of each of the emergent themes across the 3 statements and provide examples of how the theoretical theme has been presented in the statements (Table 1).

Table 1. Summary of the analysis of the three DEI statements

	DEI Statements		
Theories	ASEE	SEFI	ASEE & SEFI
IOT	Acknowledges the importance of inclusiveness and inclusion from an institutional perspective within the engineering education community and the engineering profession. It highlights the need for active engagement to promote the pursuit of engineering education and careers among historically under-represented individuals. Example: "In order for the engineering discipline to reach its full potential, however, the engineering education community and the engineering profession must better include all segments of our society."	Acknowledges the role of institutions and organizations, such as SEFI, in promoting diversity, equality, and inclusiveness within engineering education and the engineering profession. It suggests that creating inclusive environments involves structural changes within engineering education and professional settings. Example: "SEFI is committed to increasing the participation, inclusion, and empowerment of under-represented segments of society in all venues where engineering is taught, practiced, and supported."	Acknowledges the role of institutions and organizations in perpetuating discriminatory dynamics through preserving unexamined norms and values. It calls for action to transform institutional cultures and classrooms to create more inclusive environments. Example: "We must actively dissolve the systemic barriers that engineers have enacted against those who are implicitly and explicitly excluded from our engineering community."
CDT	Emphasizes the value of diversity in enriching educational experiences and driving innovation in addressing global challenges. It suggests that learning from experiences, beliefs, and perspectives different from our own fuels innovation and the development of creative solutions. Example: "We learn from experiences, beliefs, and perspectives that are different from our own. Diversity, both intellectually and socially, fuels innovation and the development of imaginative	Emphasizes the importance of diversity, equality, and inclusion in enriching educational experiences and driving innovation in addressing global challenges. It suggests that learning from diverse experiences, beliefs, and perspectives can strengthen the learning of all students. Example: "We learn from diverse experiences, beliefs, and perspectives. Diversity in all dimensions (individual, organizational, and societal) fuels innovation and the development of imaginative, holistic, and	Emphasizes the importance of examining and reshaping the focus, content, values, and norms of engineering and its educational environments. It advocates for creating collaborative and inclusive environments that value equity and celebrate diversity. Example: "We are therefore compelled by our professional and ethical commitments to exercise leadership to create and maintain collaborative and inclusive environments that value equity and celebrate diversity."

	and enduring solutions to global problems."	enduring solutions to global problems."	
SIIT	Recognizes various dimensions of diversity, including age, belief system, disability status, ethnicity, gender, gender identity, gender expression, national origin, race, sexual orientation, and socio-economic status. It advocates for equality of opportunity and the prevention of marginalization or non-inclusiveness based on visible or invisible differences. Example: "ASEE strongly believes that all must be provided with equality of opportunity to pursue and advance in engineering careers and that no individual should experience marginalization or non-inclusiveness of their contributions or talents because of visible or invisible differences."	Recognizes various dimensions of diversity, including physical ability, visible or invisible handicaps, race, ethnicity, sexual orientation, religion, gender, culture, geographical residence, and nationality. It advocates for providing equality of opportunity and preventing discrimination, marginalization, or exclusion based on conscious or unconscious biases. Example: "SEFI strongly believes that everybody must be provided with equality of opportunity, to pursue and advance their engineering careers, and that no individual should experience discrimination, marginalization or have their contributions or talents excluded because of conscious or unconscious biases."	Acknowledges the importance of considering intersecting identities and experiences, including race, ethnicity, gender, disability, socio-economic status, etc. It calls for promoting diversity and inclusion particularly among historically disadvantaged groups. Example: "We are committed to increasing the participation, inclusion, and empowerment of minoritized individuals who are commonly under-represented in all venues where engineering is taught, practiced, and supported.”
CCT	Promotes the creation of environments where every individual is respected and no one feels marginalized. It advocates for supporting the education, recruitment, retention, and advancement of historically under-represented groups in engineering education, engineering technology education, and the engineering profession. Example: "Our vision is to create and foster environments where every individual is respected and no one feels marginalized."	It emphasizes the importance of nurturing a culture of diversity in recruitment, retention, and advancement within engineering education and the engineering profession. Example: "Our goal is to create and foster environments where every individual is not only respected, but also feels safe and included."	Emphasizes the need for a culture of engineering that values different perspectives and serves the whole of society. It calls for creating environments that are welcoming, respectful, and valued for all members of society, regardless of their backgrounds and experiences. Example: "We envision a culture of engineering that values different perspectives, represents, celebrates, and serves the whole of society."
CT	Acknowledges the need for substantial progress to be made in achieving full empowerment for all segments of society,	Acknowledges the need for substantial progress to be made in promoting diversity, equality, and inclusiveness within	The text critically examines the historical lack of diversity in the engineering profession and its societal impacts.

	particularly those historically under-represented in engineering. It suggests that steady gains have been made in increasing diversity in engineering but that further progress is necessary to ensure full empowerment by all segments of society. Example: "While ASEE recognizes that steady gains have been made in the number of women, African-Americans, Hispanics, and Native Americans in engineering over the past several years, substantial progress must still be made to reach a state where engineering is fully empowered by all segments of our society."	engineering education and the engineering profession. It recognizes the potential negative aspects of teamwork for historically marginalized students and suggests interventions to address these challenges. Example: "Although teamwork plays an important role in the development of professional skills, it can also be a source of problems for under-represented students."	It advocates for challenging existing norms and values to address inequities and promote social change. Example: "A homogeneous engineering profession is absent the diversity of needs and experiences with engineered technologies, is unaware of barriers and problems that impact minoritized communities, and is insensitive of cultural values and perspectives — it is unable to fully accomplish its professional mandate to serve the whole of society."

4. SUMMARY AND ACKNOWLEDGEMENTS

Each of the three analysed texts demonstrates alignment with theories related to diversity, equity, and inclusion in engineering education and practice. This is perhaps not surprising in terms of the SEFI and ASEE statements given that some of the examples given in Table 1 show that these are very similarly phrased in places. However, they vary in the extent and focus of their alignment. which suggests the importance of context in the understanding and prioritization of DEI topics (Van Maele et al. 2023).

For example, the ASEE Statement on Diversity and Inclusiveness emphasizes the importance of inclusiveness in learning environments and the need for structural changes to promote diversity within engineering education and practice. The SEFI Position Paper on Diversity, Equality, and Inclusiveness in Engineering Education focuses on creating inclusive environments within engineering education and the engineering profession and on minimising bias. The ASEE & SEFI Joint Statement on Diversity, Equity, and Inclusion emphasizes the need for systemic change to promote diversity, equity, and inclusion within the engineering profession and education.

Our findings not surprisingly showed a lot of connection between the themes proposed and the statements revised. We consider the intentionality of these statements to play a role in this finding. Similarly, we could observe the varying degrees of alignment with the theoretical underpinnings of the statements. We consider this can open a conversation and suggest that engineering education institutions and organizations should critically review their DEI communication to ensure intentional alignment with theoretical frameworks. This does not mean to include language that recognizes all the themes, but we suggest including the majority of spaces. It is also important to recognize the context of DEI work, considering how statements and policies should be sensitive to local needs and consider global perspectives and diverse cultural contexts while also aiming for universal principles of equity and inclusion.

One limitation of our study is that given that the five theoretical lenses derive from a review of the existing DEI literature in engineering education when using these lenses, we can only refer to what extent policy statements adhere to the current practice in the field; this might change as our field evolves. Moreover, our review was limited to English language publications, it may have missed existing lenses from other linguistic regions in the world. Nevertheless, this paper provides a framework for writing DEI statements critically and intentionally. It would be interesting to expand this analysis to other DEI policy documents to see whether similar results would emerge.

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REFERENCES

Artiles, Mayra S., and Holly M. Matusovich. 2020. "Examining Doctoral Degree Attrition Rates: Using Expectancy-Value Theory to Compare Student Values and Faculty Supports." *INTERNATIONAL JOURNAL OF ENGINEERING EDUCATION* 36 (3): 1071–81.

Atadero, Rebecca A., Christina H. Paguyo, Karen E. Rambo-Hernandez, and Heather L. Henderson. 2018. "Building Inclusive Engineering Identities: Implications for Changing Engineering Culture." *European Journal of Engineering Education* 43 (3): 378–98. https://doi.org/10.1080/03043797.2017.1396287.

Blair, Elizabeth E., Rebecca B. Miller, Maria Ong, and Yevgeniya V. Zastavker. 2017. "STEPPING UP OR STANDING BY?" *ASEE Prism* 26 (8): 41.

Blosser, Emily. 2020. "An Examination of Black Women's Experiences in Undergraduate Engineering on a Primarily White Campus: Considering Institutional Strategies for Change." *Journal of Engineering Education* 109 (1): 52–71. https://doi.org/10.1002/jee.20304.

Bowen, Corin L., Aaron W. Johnson, and Kenneth G. Powell. 2020. "Critical Analyses of Outcomes of Marginalized Undergraduate Engineering Students." In *2020 IEEE Frontiers in Education Conference (FIE)*, 1–9. IEEE. https://ieeexplore.ieee.org/abstract/document/9273827/?casa_token=kJscGvztucoAAAAA:YZMrxiQseZyICTgo4Cbis-eEQy5v1I9Nemt2j-pneo8kP8NZJhGrdys32Mn9_JpCLKPegvjHAHSb.

Bowen, Corin L., Joseph M. Valle, Joi-Lynn Mondisa, Aaron W. Johnson, Jeffrey Sakamoto, and Kenneth G. Powell. 2021. "'The Undergraduate Engineering Collaborative Growth Series': A Diversity, Equity, and Inclusion Program Supporting the Empowerment of Marginalized Students." In *2021 IEEE Frontiers in Education Conference (FIE)*, 1–9. IEEE. https://ieeexplore.ieee.org/abstract/document/9637479/?casa_token=77nf_CX t9mcAAAAA:Z5b4sw4eEZanuxPWSwdwqEFLLGzFSZTs29rOTMekIJF3EyNTMPn0Q_W3sMrYLDTsSe5McoSac5be.

Callens, Melissa Vosen, Paul Kelter, Jill Motschenbacher, James Nyachwaya, Jared L. Ladbury, and Anna M. Semanko. 2019. “Developing and Implementing a Campus-Wide Professional Development Program: Successes and Challenges.” *Journal of College Science Teaching* 49 (2): 68–75.

Cao, Yi, Homero Murzi, and Tahsin Chowdhury. 2023. “Diversity,Equity, andInclusion(DEI)Researchin EngineeringEducation:PreliminaryResultsfroma ScopingLiteratureReview.” In . College Station, TX.

Carrigan, Coleen, Jarman Hauser, Eve A. Riskin, Priti Mody-Pan, Jim Borgford-Parnell, Dawn Wiggin, Scott Winter, Scott Pinkham, and Sonya Cunningham. 2019. “ACTIVE AGENTS AND FICTIVE KIN: LEARNING FROM PELL-ELIGIBLE ENGINEERING STUDENTS’CLASS STANDPOINT.” *Journal of Women and Minorities in Science and Engineering* 25 (2). https://www.dl.begellhouse.com/journals/00551c876cc2f027,2c5599000e55578b,47c79083517a17a8.html.

Casper, A. M. Aramati, Rebecca A. Atadero, A. Rahman Abdallah, and Tom Siller. 2024. “Bringing Social Justice Context into Civil Engineering Courses for First-Year and Third-Year Students.” *Journal of Civil Engineering Education* 150 (2): 04023013. https://doi.org/10.1061/JCEECD.EIENG-1857.

Corple, Danielle, Megan Kenny Feister, Carla B. Zoltowski, and Patrice M. Buzzanell. 2018. “Engineering Gender Identities of Women in a Service-Learning Context.” In *2018 IEEE Frontiers in Education Conference (FIE)*, 1–5. IEEE. https://ieeexplore.ieee.org/abstract/document/8658478/?casa_token=_KRw8Teob0cAAAAA:rfz-b1ae8lkLVY325pbMp9uiwrocZyejrfVd0SV4PJFBZACJn0gf_OnOQZIxk-0-zDobwo76GGig.

Corwin, Lisa A., Terrell Morton, Cynthia Demetriou, and A. T. Panter. 2020. “A QUALITATIVE INVESTIGATION OF STEM STUDENTS’SWITCH TO NON-STEM MAJORS POST-TRANSFER.” *Journal of Women and Minorities in Science and Engineering* 26 (3). https://www.dl.begellhouse.com/journals/00551c876cc2f027,2a46de397d4dd9d2,5444158e40e9cd45.html.

Cundiff, Jessica L., and Susan L. Murray. 2020. “Good Intentions Are Not Enough: Assessing a Gender Bias Literacy Intervention for Potential Positive and Negative Outcomes.” *Journal of Women and Minorities in Science and Engineering* 26 (6). https://www.dl.begellhouse.com/journals/00551c876cc2f027,4da003e559e96dc4,749df2201af14aae.html?utm_source=TrendMD&utm_medium=cpc&utm_campaign=Journal_of_Women_and_Minorities_in_Science_and_Engineering_TrendMD_0.

Dankert, Linda Steuer, Shannon K. Gilmartin, Carol B. Muller, Carolin Dungs, Sheri D. Sheppard, and Carmen Leicht-Scholten. 2019. “Expanding Engineering Limits: A Concept for Socially Responsible Education of Engineers.” *The International Journal of Engineering Education* 35 (2): 658–73.

Direito, Ines, Shannon Chance, Lisa Clemmensen, Sofie Craps, Sophia B. Economides, Sierra S. Isaac, Anne-Marie Jolly, Fiona R. Truscott, and Natalie Wint. 2021. “Diversity, Equity, and Inclusion in Engineering Education: An Exploration of European Higher Education Institutions’ Strategic Frameworks, Resources, and Initiatives.” In *SEFI 49th Annual Conference Proceedings 2021*, 189–93. SEFI-European Society for Engineering Education; Brussels. https://doi.org/10.21427/1d3q-bd61.

Du, Xiangyun, and Anette Kolmos. 2009. “Increasing the Diversity of Engineering Education – a Gender Analysis in a PBL Context.” *European Journal of Engineering Education* 34 (5): 425–37. https://doi.org/10.1080/03043790903137577.

Eastman, Michael G., Monica L. Miles, and Randy Yerrick. 2019. “Exploring the White and Male Culture: Investigating Individual Perspectives of Equity and Privilege in Engineering Education.” *Journal of Engineering Education* 108 (4): 459–80. https://doi.org/10.1002/jee.20290.

Fealing, Kaye Husbands, Yufeng Lai, and Samuel L. Myers Jr. 2015. “Pathways vs. Pipelines to Broadening Participation in the STEM Workforce.” *Journal of Women and Minorities in Science and Engineering* 21 (4). https://www.dl.begellhouse.com/journals/00551c876cc2f027,7050440f5f321aae,57e401e20ef816f0.html.

Foor, Cynthia E., Susan E. Walden, and Deborah A. Trytten. 2007. “‘I Wish That I Belonged More in This Whole Engineering Group:’ Achieving Individual Diversity.” *Journal of Engineering Education* 96 (2): 103–15. https://doi.org/10.1002/j.2168-9830.2007.tb00921.x.

Godwin, Allison, Leidy Klotz, Zahra Hazari, and Geoff Potvin. 2016. “Sustainability Goals of Students Underrepresented in Engineering: An Intersectional Study.” *The International Journal of Engineering Education* 32 (4): 1742–48.

Griffith, Henry, Faezeh Hajiaghajani, and Angela Griffith. 2016. “Enhancing Continuity between Gender Diversity Interventions Using Hybrid Social Networks.” In *2016 IEEE Frontiers in Education Conference (FIE)*, 1–5. IEEE. https://ieeexplore.ieee.org/abstract/document/7757721/.

Gulbulak, Utku, Atila Ertas, and McKenzie Cordell. 2020. “The Impact of Transdisciplinarity on Solving Complex Engineering Problems in an Ethnically Diverse Classroom.” *International Journal of Engineering Education* 36 (6): 1976–87.

Hernandez, Paul R., Brittany Bloodhart, Rebecca T. Barnes, Amanda S. Adams, Sandra M. Clinton, Ilana Pollack, Elaine Godfrey, Melissa Burt, and Emily V. Fischer. 2017. “Promoting Professional Identity, Motivation, and Persistence: Benefits of an Informal Mentoring Program for Female Undergraduate Students.” *PloS One* 12 (11): e0187531.

Hokanson, David R., Linda D. Phillips, and James R. Mihelcic. 2007. “Educating Engineers in the Sustainable Futures Model with a Global Perspective: Education, Research and Diversity Perspective.” *The International Journal of Engineering Education* 23 (2): 254–65.

Lee, Walter C., Cory Brozina, Catherine T. Amelink, and Brett D. Jones. 2017. “Motivating Incoming Engineering Students with Diverse Backgrounds: Assessing a Summer Bridge Program’s Impact on Academic Motivation.” *Journal of Women and Minorities in Science and Engineering* 23 (2). https://www.dl.begellhouse.com/journals/00551c876cc2f027,611065c054afe923,2f3b563b45453670.html.

Lee, Walter C., Ben D. Lutz, Holly M. Matusovich, and Sreyoshi Bhaduri. 2021. “Student Perceptions of Learning about Diversity and Its Place in Engineering Classrooms in the United States.” *International Journal of Engineering Education* 37 (1): 147–62.

Lee, Walter C., and Holly M. Matusovich. 2016. “A Model of Co-Curricular Support for Undergraduate Engineering Students.” *Journal of Engineering Education* 105 (3): 406–30.

Leicht-Scholten, Carmen, Asli-Juliya Weheliye, and Andrea Wolffram. 2009. “Institutionalisation of Gender and Diversity Management in Engineering Education.” *European Journal of Engineering Education* 34 (5): 447–54. https://doi.org/10.1080/03043790903137700.

Main, Joyce B., Li Tan, Monica F. Cox, Ebony O. McGee, and Andrew Katz. 2020. “The Correlation between Undergraduate Student Diversity and the Representation of Women of Color Faculty in Engineering.” *Journal of Engineering Education* 109 (4): 843–64. https://doi.org/10.1002/jee.20361.

Marra, R. M., K. A. Rodgers, D. Shen, and B. Bogue. 2010. “Leaving Engineering: A Multi-Year Single Institution Study.” *Journal of Engineering Education* 101 (1): 6–27. https://doi.org/10.1002/j.2168-9830.2012.tb00039.x.

Marra, Rose M., Kelly A. Rodgers, Demei Shen, and Barbara Bogue. 2009. “Women Engineering Students and Self-Efficacy: A Multi-Year, Multi-Institution Study of Women Engineering Student Self-Efficacy.” *Journal of Engineering Education* 98 (1): 27–38. https://doi.org/10.1002/j.2168-9830.2009.tb01003.x.

Martin, Julie P. 2015. “The Invisible Hand of Social Capital: Narratives of First Generation College Students in Engineering.” *International Journal of Engineering Education* 31 (5): 1170–81.

Martin, Julie P., Denise R. Simmons, and Shirley L. Yu. 2013. “The Role of Social Capital in the Experiences of Hispanic Women Engineering Majors.” *Journal of Engineering Education* 102 (2): 227–43. https://doi.org/10.1002/jee.20010.

McCall, Cassandra, Lisa D. McNair, and Denise R. Simmons. 2021. “Advancing from Outsider to Insider: A Grounded Theory of Professional Identity Negotiation in Undergraduate Engineering.” *Journal of Engineering Education* 110 (2): 393–413. https://doi.org/10.1002/jee.20383.

McCall, Cassandra, Ashley Shew, Denise R. Simmons, Marie C. Paretti, and Lisa D. McNair. 2020. “Exploring Student Disability and Professional Identity: Navigating Sociocultural Expectations in U.S. Undergraduate Civil Engineering Programs.” *Australasian Journal of Engineering Education* 25 (1): 79–89. https://doi.org/10.1080/22054952.2020.1720434.

Pamulapati, Vandana R., Allison Godwin, Héctor E Rodríguez-Simmonds, Tara Langus, Justin C. Major, Nelson Pearson, and Adam Kirn. 2021. "Student-Faculty Interactions to Promote Equity in Engineering." In *2021 IEEE Frontiers in Education Conference (FIE)*, 1–6. https://doi.org/10.1109/FIE49875.2021.9637422.

Park, Seoyeon, Rebecca A. Atadero, Anne Marie Aramati Casper, Karen E. Rambo-Hernandez, Jody Paul, Melissa Lynn Morris, Christopher Douglas Griffin, Ronald R. DeLyser, Christina Paguyo, and Scott T. Leutenegger. 2020. "Partnership for Equity: Engaging with Faculty to Cultivate Inclusive Professional Identities for Engineers and Computer Scientists." In *2020 ASEE Virtual Annual Conference Content Access*. https://peer.asee.org/partnership-for-equity-engaging-with-faculty-to-cultivate-inclusive-professional-identities-for-engineers-and-computer-scientists.

Pearson, Nelon, Allison Godwin, and Adam Kirn. 2018. "The Effect of Diversity on Feelings of Belongingness for New Engineering Students." In *2018 IEEE Frontiers in Education Conference (FIE)*, 1–7. IEEE. https://ieeexplore.ieee.org/abstract/document/8658443/?casa_token=gXAH-xVSlnkAAAAA:vY9ZQ-sY_yLXZ0Q2OyTL-J7XYtWLirNi0K3JZlPyg80wJPlEiCLeDtAa9mAIEc2Gy0Z0WNuDG6re.

Perkins, H.L., M. Bahnson, M.A. Tsugawa-Nieves, A. Kirn, and C. Cass. 2018. "Development and Testing of an Instrument to Understand Engineering Doctoral Students' Identities and Motivations." In . Vol. June. American Society for Engineering Education. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051214351&partnerID=40&md5=622ca853c7a302d3e355e1e0275bf7e3.

Roby, ReAnna S., Ekaete E. Udoh, Michele R. Williams, Alexis E. Hunter, Ashlyn M. Wardin, Monica L. Miles, and Terrell Morton. 2022. "# SayHerName: Anchoring Black Feminist Epistemologies at the Crux of Postsecondary STEM Culture." *Journal of Women and Minorities in Science and Engineering* 28 (3). https://www.dl.begellhouse.com/journals/00551c876cc2f027,243d389e1da54d31,5fe83bf86daf906a.html?utm_source=TrendMD&utm_medium=cpc&utm_campaign=Journal_of_Women_and_Minorities_in_Science_and_Engineering_TrendMD_1.

Roldan, Wendy, Julie Hui, and Elizabeth M. Gerber. 2018. "University Makerspaces: Opportunities to Support Equitable Participation for Women in Engineering." *Int. J. Eng. Educ* 34 (2): 751–68.

Sayles, Andre. 2004. "Diversity: An Engineering Process." In , 9.477.1-9.477.14. https://peer.asee.org/diversity-an-engineering-process.

Schindler, Bee. 2022. "Diversity, Equity and Inclusion Training in Higher Education: How Enrichment Imbued with Reciprocity Could Sustain the Complex Work." PhD Thesis, University of Pittsburgh. https://search.proquest.com/openview/24b44968e8d3dfc80d9d471d3976ef2e/1?pq-origsite=gscholar&cbl=18750&diss=y&casa_token=z6Z6kaiW2LIAAAAA:RI7-7yvvLYJmNA-kpgcmFNS12Uht0FI54iOE_-l2RvqwS4Z2-wKT7JsCS3qJS_IG-iJJn_5zc0QL.

Scott, Allison, and Alexis Martin. 2014. "Perceived Barriers to Higher Education in Science, Technology, Engineering, and Mathematics." *Journal of Women and Minorities in Science and Engineering* 20 (3). https://www.dl.begellhouse.com/journals/00551c876cc2f027,2006fb1a55e86eee,1aef664145626761.html.

Secules, Stephen, Ayush Gupta, Andrew Elby, and Emilia Tanu. 2018. "Supporting the Narrative Agency of a Marginalized Engineering Student." *Journal of Engineering Education* 107 (2): 186–218. https://doi.org/10.1002/jee.20201.

Siddaway, Andy P., Alex M. Wood, and Larry V. Hedges. 2019. "How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses." *Annual Review of Psychology* 70 (Volume 70, 2019): 747–70. https://doi.org/10.1146/annurev-psych-010418-102803.

Simmons, Denise R., and Julie P. Martin. 2014. "DEVELOPING EFFECTIVE ENGINEERING FICTIVE KIN TO SUPPORT UNDERGRADUATE FIRST-GENERATION COLLEGE STUDENTS." *Journal of Women and Minorities in Science and Engineering* 20 (3). https://doi.org/10.1615/JWomenMinorScienEng.2014010979.

Sochacka, Nicola W., Joachim Walther, Jennifer R. Rich, and Michael A. Brewer. 2021. "A Narrative Analysis of Stories Told about Engineering in the Public Discourse: Implications for Equity and Inclusion in Engineering." *Studies in Engineering Education* 2 (2): 54–77.

Taylor, Ashley, Raeven Waters, Sreyoshi Bhaduri, Benjamin Lutz, and Walter Lee. 2017. "Student Attitudes about Diversity:'If the Field of Engineering Were More Diverse, What Would That Mean for You?'" In *2017 IEEE Frontiers in Education Conference (FIE)*, 1–9. IEEE. https://ieeexplore.ieee.org/abstract/document/8190517/.

Tolbert Smith, DeLean. 2022. "'They Are Here to Support Me': Community Cultural Wealth Assets and Precollege Experiences of Undergraduate Black Men in Engineering." *Journal of Engineering Education* 111 (4): 750–69. https://doi.org/10.1002/jee.20480.

Trytten, Deborah A., Ryan Browning, Catherine Thomas, Cindy Foor, Randa Shehab, Susan Walden, and Celia Pan. 2016. "Engineering Competition Team Recruitment and Integration Strategies Impact on Team Diversity." In *2016 IEEE Frontiers in Education Conference (FIE)*, 1–9. IEEE. https://ieeexplore.ieee.org/abstract/document/7757523/.

Van Maele, Jan, Becky Bergman, Inês Direito, and Homero Murzi. 2023. "How Diverse Are Global Perspectives on Diversity, Equity, and Inclusion in Engineering Education?" https://arrow.tudublin.ie/sefi2023_wkshp/5/.

Whitcomb, Kyle M., Z. Yasemin Kalender, Timothy J. Nokes-Malach, Christian D. Schunn, and Chandralekha Singh. 2020. "Comparison of Self-Efficacy and Performance of Engineering Undergraduate Women and Men." *International Journal of Engineering Education* 36 (6): 1996–2014.

Whitcomb, Kyle M., Alexandru Maries, and Chandralekha Singh. 2021. “Examining Gender Differences in a Mechanical Engineering and Materials Science Curriculum.” *International Journal of Engineering Education* 37 (5): 1261–73.

Williams, Sarah A., Ben Lutz, Cynthia Hampton, Holly M. Matusovich, and Walter C. Lee. 2016. “Exploring Student Motivation towards Diversity Education in Engineering.” In *2016 IEEE Frontiers in Education Conference (FIE)*, 1–5. IEEE. https://ieeexplore.ieee.org/abstract/document/7757565/.

Wint, Natalie. 2022. “The Powerless Engineer: Questioning Approaches to Teaching Social Responsibility.” In *Towards a New Future in Engineering Education, New Scenarios That European Alliances of Tech Universities Open Up*, 851–61. Universitat Politècnica de Catalunya. https://upcommons.upc.edu/handle/2117/383938.

Wofford, Annie M., and Justin A. Gutzwa. 2022. “Funds of Science Identity: Toward an Asset-Based Framework for Undergraduate STEM Research and Praxis.” *Journal of Women and Minorities in Science and Engineering* 28 (3). https://www.dl.begellhouse.com/journals/00551c876cc2f027,243d389e1da54d31,10b68d2b5b3a7e4d.html?utm_source=TrendMD&utm_medium=cpc&utm_campaign=Journal_of_Women_and_Minorities_in_Science_and_Engineering_TrendMD_0.

Woodcock, Anna, and Diana Bairaktarova. 2015. “Gender-Biased Self-Evaluations of First-Year Engineering Students.” *Journal of Women and Minorities in Science and Engineering* 21 (3). https://www.dl.begellhouse.com/journals/00551c876cc2f027,1e09b9d8762a7489,0c64762213b612c0.html.

SHARING THE CARING – DISTRIBUTION OF ACADEMIC CARE DUTIES AMONG THE ENGINEERING FACULTY

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ABSTRACT

Research and teaching constitute the primary components of academic work, yet academics also shoulder numerous other responsibilities, often categorised as internal and external service work. While some aspects of this work, such as administrative tasks, are acknowledged and compensated, many academics receive no compensation for delivering internal services, including student care.

Studies indicate that women faculty members often undertake more internal (invisible) service work than men, especially within STEM fields. Furthermore, disparities in service work allocation vary throughout academic careers. This study examines whether gender discrepancies exist in undertaking invisible work, particularly student care, among the engineering faculty at a Finnish university. We also compare the distribution of care duties between native and international faculty members. With a focus on teacher tutoring, we investigate how care duties are recognised, compensated, and rewarded.

Results indicate that caring duties appear to fall on Finnish faculty members and that women are overrepresented in teacher tutor roles. According to the responses, teacher tutoring, although crucial for student welfare and academic success, is often

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undervalued and neglected in professional development discussions. Thus, the study underscores the importance of recognising academic caring duties as legitimate academic work and advocating for fair compensation and acknowledgement to foster equality and a supportive environment for all members of the academic community.

1 INTRODUCTION

Research and teaching are widely acknowledged as the main components of the academic work. Nevertheless, academics also hold many other duties. Much of this other work can be characterised as service work. Following Ward (2003), Guarino and Borden (2017) divide service work into internal and external services, with internal service consisting of activities related to tasks like faculty governance, faculty recruitment and promotion, student recruitment and admissions and program supervision, and external service including activities outside campus and directed to the profession and other communities outside academia.

Part of the service work, like defined administrative roles, is well recognised and compensated for, but many academics receive no compensation for service work, especially for delivering internal service, as this is expected of them as good members of the academic community (Guarino and Borden 2017). The University of Oregon Social Sciences Feminist Network Research Interest Group (SSFNRIG 2017) calls this kind of implicitly expected and uncompensated work invisible work and sees it as consisting of two types of tasks: 1) making the academy a better place for instance through diversity work (committees, task forces, mentoring, etc.) and 2) care work (mentoring, advising and helping students in general matters).

Several studies suggest that women faculty members perform more internal service work than men (Bengivenca & Drew 2021, Guarino and Borden 2017, Kinahan et al. 2021). According to (Misra et al. 2011), even when the overall task division is rather equal, women spend somewhat more time on mentoring and service. Furthermore, these gendered patterns of workload allocation are more pronounced among STEM faculties than others. Kinahan et al. (2021) recognised a similar perceived gender disparity in the allocation of service duties and student care responsibilities in one higher engineering education institution.

The gender disparities in service work appear not to be constant throughout the academic career. Misra et al. (2011) observed that especially among associate professors women engaged considerably more in mentoring and service than men with equal working hours. In another study, the gender difference in the service-related workload was greatest at the rank of assistant professor (SSFNRIG 2017). In addition to female faculty members, the invisible work seemed to be falling on the shoulders of marginalised groups, such as faculty of colour, queer faculty, and faculty from working-class backgrounds, who for example at the assistant rank spent approximately four times the mean for a non-marginalised professor on service (SSFNRIG 2017).

The invisible work including student care is not only uncompensated but often also undervalued in terms of promotion (Angervall and Beach 2020, Kinahan et al. 2021, O Connor 2021, SSFNRIG 2017). Hence, the uneven distribution of invisible work hinders the career progression of some more than others. O Connor (2021) argues that the stereotypical expectations of women being ‘naturally’ better at pastoral care lead to gendered differences in workload and further in climbing up the academic ladder. Angervall and Beach (2020) suggest that women feel more responsible for caring about others and thus accept low-promotability tasks more easily than men.

This study attempts to investigate whether similar gender differences in taking on the invisible work especially related to the pastoral care for students can be detected among the engineering faculty at a university in Finland. Pastoral care is understood here as supporting students' academic needs (guiding them on how and what to study), providing career counselling, being interested in students’ well-being, and directing students to specialised study counselling or health-care services if needed. In addition to gender differences, we also compare the distribution of care duties between the native and international faculty members. In addition to the responsibility allocation, we also want to enhance our understanding of how the student care duties are recognised, compensated for and rewarded as part of academic work.

2 METHODOLOGY

2.1 Data collection

For the first part of the research, we collected information about the ‘academic care providers’. We defined the most prominent care-related roles as 1) program heads, who for instance provide general advice and organise the orientation of new students; 2) teachers in the introductory courses, where new students are introduced to the degree and university, guided how to study, and provided information about their future career opportunities; 3) teachers in the thesis seminar courses, where students are educated about the basic skills and working methods in scientific research and 4) teacher tutors, who are defined as the liaisons between the degree program teaching staff and students, and who are expected to provide guidance in career planning and choosing subjects. Teacher tutors are part of LUT University’s study guidance and counselling services (eLUT, n.d.), but unlike other counsellors and advisors, they are not administrative personnel but academics, who carry out the duty alongside their research and teaching. This kind of role is also known as teacher-counsellor or pastoral care teacher.

The tasks of the teacher tutors vary slightly across the degree programs, but they usually include individual or small group discussions with students. Tutors can generally be regarded to have a more personal contact with students than course teachers. The emphasis of teacher tutoring is usually on the first year, but tutoring continues also after that.

The names of the informants were collected from the university intranet (program heads), the student information system and the curriculum database (course teachers), and the student intranet (teacher tutors). The Finnish respondents’ gender and ethnic background were deduced from the name and the non-Finnish respondents’ gender and ethnic background from the personal information and contacts of the first author. Most of the informants were known personally or by name by the authors, as the university is rather small. The stage of the career path was deduced from the person’s title. The classification of the career path stages follows the four-stage research career model used in Finland (Research.fi, n.d.). The data about the engineering faculty in its entirety with the information about gender distribution, ethnic background and working title were requested from the university human relations department.

For the second part of the research, we designed a survey that was administered to all teacher tutors of the engineering faculty. The survey consisted of two background questions (faculty and tutoring experience), ten statements about the resourcing and recognition of teacher tutoring, six statements about the support for teacher tutoring, a slider question about recommending the task/post of a teacher tutor, and two open questions (Why did you agree to act as a teacher tutor? What else would you like to say about teacher tutoring and its development?). The statements were rated with a 5-point Likert scale from fully disagree (1) to fully agree (5). The survey was administered to the teacher tutors by email from the survey tool with a personal link to the survey. The tutors who had not completed the survey within a week of its administration were reminded once about the survey.

The data collection followed the ethical principles of research with human participants of the Finnish National Board of Research Integrity TENK (TENK 2019) to which LUT University is committed. According to the principles, the informed consent of the adult informants was required, but there was no need for an ethical review. The survey was anonymous and voluntary, and the respondents were informed about the use of data for research.

2.2 Data analysis

The personnel data were analysed with descriptive statistics (frequencies, distributions), and the statistical significance of the differences of distributions between different groups was tested with the Chi^2 test. The survey data were compressed with the help of distributions and means, and the categorisation of open comments.

3 RESULTS

3.1 Division of care duties among faculty members

The data about the whole engineering faculty are presented in Fig. 1. The figure shows that there are more men than women in all stages of the career path. The first stage of the career consists of doctoral studies. Most of the people in the first stage leave the university after receiving their doctorate. The doctoral students' most important duty is research, and they are expected to complete their studies in four years. Therefore, they are generally exempt from other duties. Currently, international doctoral students significantly outnumber Finnish doctoral students, but in later career stages international faculty members constitute a clear minority. Considering that doctoral students are quite unlikely to be given care duties and that the ethnic division among doctoral students is opposite to that in later career stages, it was decided to include the faculty members only from career stages II–IV in the actual analysis.

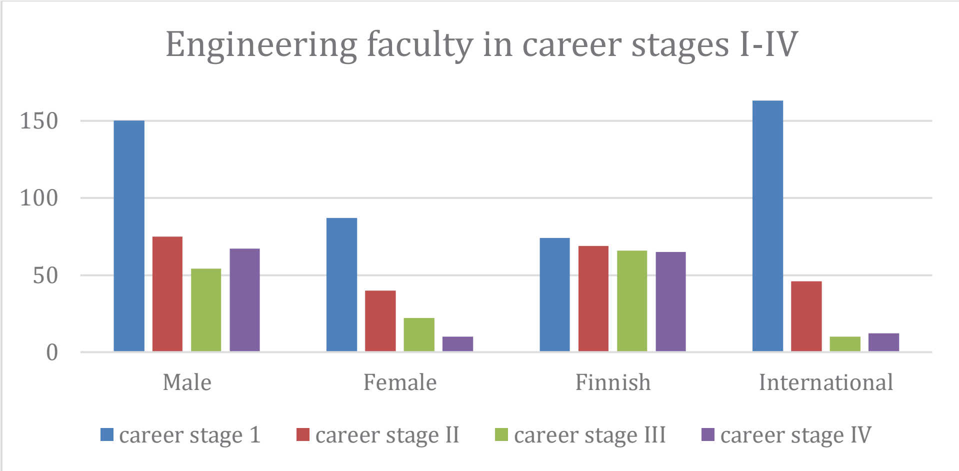

Fig. 1. Engineering faculty in career stages I-IV

In career stages II–IV the number of men is quite stable but the number of women decreases along the career path. The number of Finnish faculty members is also quite similar in all stages, but the number of international faculty members drops drastically after career stage I and then again after career stage II (non-tenure post-doctoral researchers and assistant professors in a tenure track).

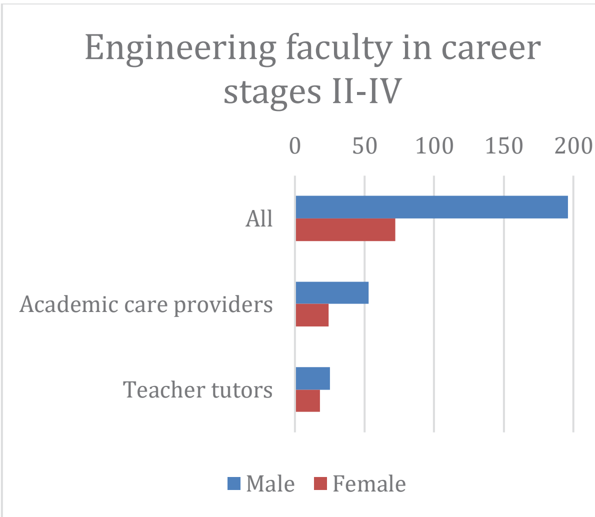

Fig. 2. Gender of engineering faculty in different roles

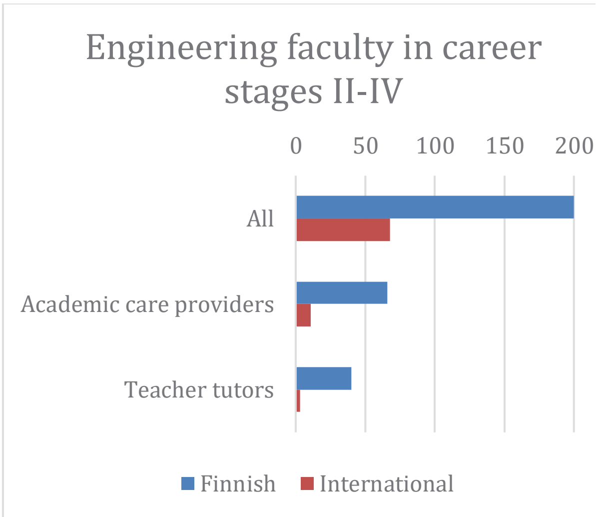

Fig. 3. Ethnic background of engineering faculty in different roles

Fig. 2 shows the numbers of men and women and Fig. 3 the numbers of Finnish and international faculty members in the whole faculty as well as among the academic care providers in general and teacher tutors in particular in career stages II–IV. The number of teacher tutors is included in the number of academic care providers. Based on the figures, it seems that compared with the composition of the whole engineering faculty, women may be overrepresented among the teacher tutors and the international faculty members underrepresented among the care workers. This was confirmed by a Chi^2 test with a 95% significance level, the results of which are presented in Table 1.

Table 1. The statistical significance of the differences of distributions between different groups

Compared groups (df=1)	Male vs. Female	Finnish vs. International

	Chi^2	p	Chi^2	p
All vs. Care workers	0.84	0.358	4.94	0.026*
All vs. Teacher tutors	4.87	0.027*	7.40	0.007*
Care workers vs. Teacher tutors	1.52	0.218	1.31	0.252

* Statistically significant difference at the 95% confidence level

A closer look at the composition of teacher tutors reveals that international staff are unlikely to become teacher tutors in all the stages of the career path. The numbers also suggest that women are proportionally more likely to become teacher tutors in career stages II and III, whereas all the teacher tutors in career stage IV were men. This is understandable provided that within the highest career stage of the whole engineering faculty, only 10/77 (13%) of the people were women and 7/67 (10%) males were teacher tutors.

Table 2. Teacher tutors' gender and ethnicity in different career stages (excluding the two teacher tutors who do not belong to academic staff)

Career stage	Male	Female	Finnish	Inter-national	Male	Female	Finnish	International
I	5	4	7	2	9 %	7 %	13 %	4 %
II	7	9	15	1	13 %	16 %	27 %	2 %
III	11	10	20	1	20 %	18 %	36 %	2 %
IV	7	0	6	1	13 %	0 %	11 %	2 %

3.2 (In)visibility of teacher tutoring

The survey on teacher tutoring was answered by 27/55 people, making the response rate 49%. The responses to the statements about the resourcing and recognition of teacher tutoring are presented in Fig. 4 and the responses to the statements about the support for teacher tutoring in Fig. 5.

The first five statements in Fig. 4 indicate that a fair number of people are able to reserve the necessary time for teacher tutoring activities. However, the tutoring duties are not well recognised as part of their academic work and are rarely addressed in the discussions on their professional development. The last five statements paint an even grimmer picture. None of the respondents report to have been specifically compensated monetarily for teacher tutoring, and only one out of 27 respondents agrees that teacher tutoring has been taken into account in the review of their work performance (either in the position requirement review or in the personal performance evaluation), which affects their salary. None of the respondents agrees either that being a teacher tutor has advanced their career or securing a work contract.

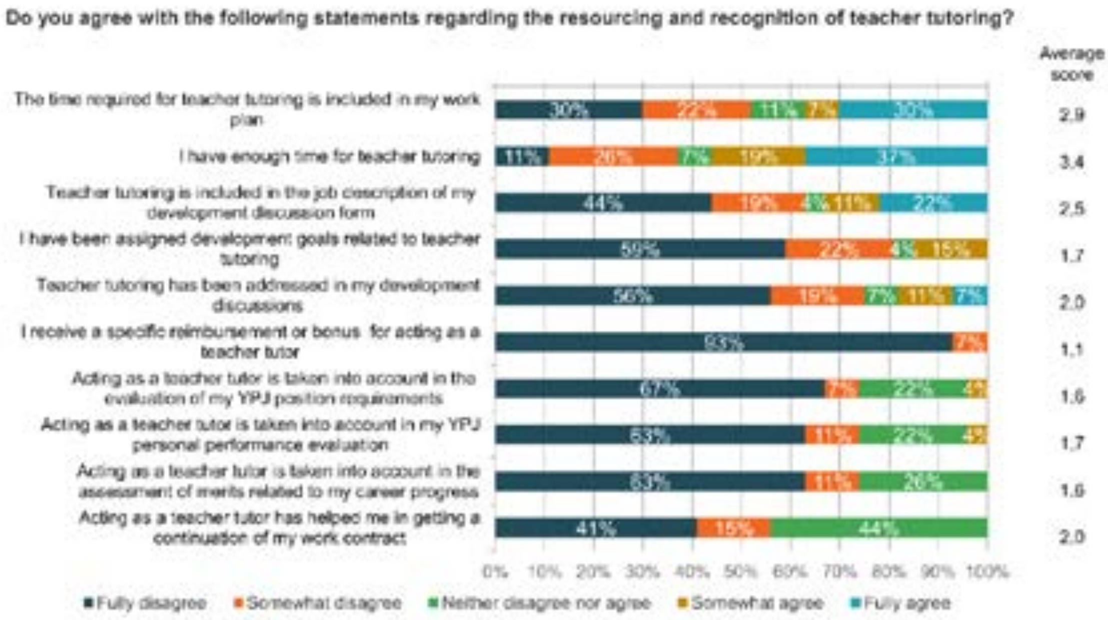

Fig. 4. Teacher tutors' views on resources and recognition of teacher tutoring

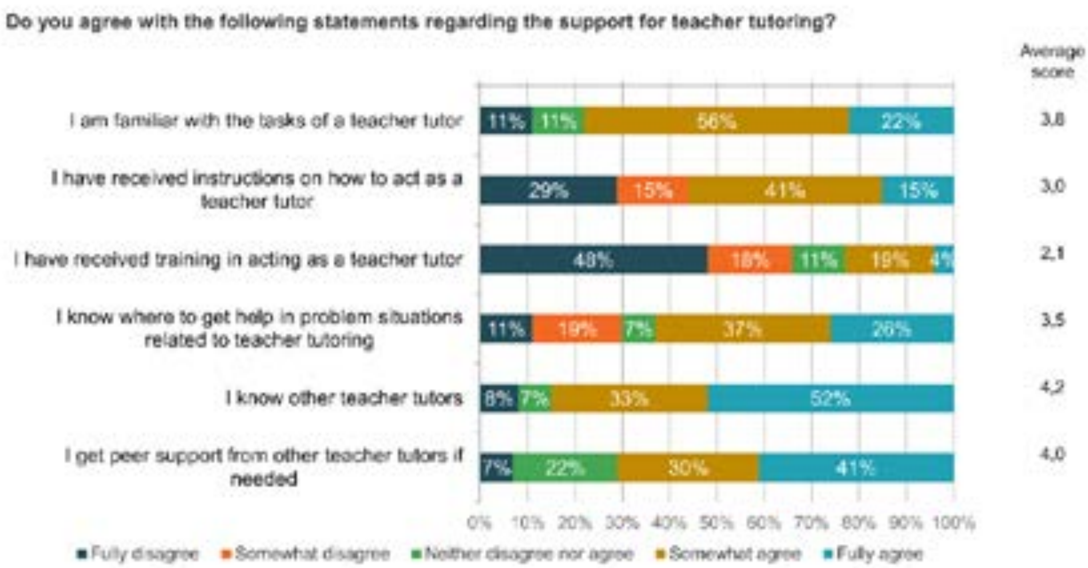

Fig. 5. Teacher tutors' views on support for teacher tutoring

Fig. 5 indicates that although it is relatively well acknowledged what it means to be a teacher tutor, almost half of them have received no instructions, and more than 60% of them have received no training in how to be a teacher tutor. Based on the survey results, peers provide most of the support for acting as a teacher tutor.

The open question about motivation indicates that most of the respondents (16/27) have been assigned as teacher tutors. Some of those ordered as teacher tutors did, however, see it fitting well with their other tasks:

It is a nice change and you get to talk to the students, which otherwise happens quite rarely. I am Finnish and there is a shortage of tutors, so in part I also have to [act as one] 😉 *[translated from Finnish]* whereas others see no connection with their other work:

That's a good question. Somehow I feel that's not my job. [translated from Finnish]

There were, however, also people who had a strong motivation for the task (9/27), although the source of that motivation varied:

I want to be easily approachable to students and help them in resolving their problems. [translated from Finnish]

I want to be a good example and help. [translated from Finnish]

Fifteen respondents also answered the last open question about any other things the respondents wished to say about teacher tutoring or its development. In their comments, the teacher tutors mainly called for better visibility of tutoring in the development and evaluation discussions, better definition of the tasks, more instructions and training, and better appreciation for the role.

4 SUMMARY

As already shown in previous research, women seem to bear more of the workload of the academic care work and be overrepresented especially in the role of teacher tutors. In the LUT context, the caring duties appear to concentrate more on the native Finnish faculty members than their international colleagues. The situation remains unbalanced even if the nationality of the student cohort is taken into account, as approximately one-third of the LUT engineering students but only 10% of the teacher tutors are international. Also expectedly, the work of the teacher tutors can be characterised as invisible work, which is not very well recognised in the processes of professional supervision and development or rewarding and promotion. All this leaves especially the Finnish-speaking women with the risk of being overloaded with low-promotability care work, which results in ‘the midcareer service gully’ (Misra et al. 2011).

Probably due to the uncompensated and low-promotability nature of teacher tutoring, the position of the teacher tutor is seldom a genuine choice of the individual but a task that is assigned to someone, whether they want it or not and whether it suits their work responsibilities as a whole. Yet the benefits of teacher tutoring and other care work for student welfare as well as for the speed and likeliness of their graduation are easy to envision. Better recognition of academic caring duties as rightful academic work in terms of both preparing and supporting people in their roles and compensating and rewarding people through pay and career progress is essential not only in making academia more equal for women but also in ensuring a better environment for all members of the academic community.

The results cannot be generalised to other universities with different kinds of student and personnel bodies and services for guidance and counselling. However, the statistically significant differences and the empirical support for the invisibility of the academic care responsibilities in the LUT University’s HR processes, which are well in line with earlier research on academic care, suggest that also other universities in and outside Finland might want to pay more attention to the distribution of the invisible care work within their organisation to ensure the fair treatment of the faculty.

REFERENCES

Angervall, P., and D. Beach. “Dividing academic work: gender and academic career at Swedish universities.” Gender and Education 32, no. 3 (2020): 347–362. https://doi.org/10.1080/09540253.2017.1401047.

Bengivenca, R., and E. Drew. “Towards a gender-sensitive university.” In *The gender-sensitive university. A contradiction in terms?* E. Drew, and S. Canavan (Eds.), 177–182. London and New York: Routledge, 2021.

eLUT. “Study guidance and counseling.” Accessed 4.6.2024. https://elut.lut.fi/en/study-guidance-and-support-services/study-guidance-and-counseling.

Guarino, C.M., and V.M.H. Borden. “Faculty Service Loads and Gender: Are Women Taking Care of the Academic Family?” *Research in Higher Education* 58 (2017): 672–694. https://doi-org.ezproxy.cc.lut.fi/10.1007/s11162-017-9454-2.

Kinahan, M., Dunne, J., and J. Cahill. “In pursuit of career advancement in academia. Do gendered pathways exist.” In *The gender-sensitive university. A contradiction in terms?* E. Drew, and S. Canavan (Eds.), 41–50. London and New York: Routledge, 2021.

Misra, J., Lundquist, J.H., Holmes, E., and S. Agiomavritis. “The ivory ceiling of service work.” *Academe* January-February (2011). Accessed March 27, 2024. http://www.aaup.org/article/ivory-ceiling-service-work#.VxlIJzArI2x.

O Connor, P. “Naming it: the problem of male privileging in higher education.” *Academia Letters*, Article 1653 (July 2021). https://doi.org/10.20935/AL1653.

Research.fi. “University teaching and research staff full-time equivalents (FTEs).” Accessed 27.3.2024. https://research.fi/en/science-innovation-policy/science-research-figures/s2_4.

SSFNRIG. Social Sciences Feminist Network Research Interest Group. “The Burden of Invisible Work in Academia: Social Inequalities and Time Use in Five University Departments.” *Humboldt Journal of Social Relations* 39 (2017): 228–45. http://www.jstor.org/stable/90007882.

TENK. *The ethical principles of research with human participants and ethical review in the human sciences in Finland. Finnish National Board on Research Integrity TENK guidelines 2019.* Finnish National Board on Research Integrity TENK publications 3/2019.

Ward, K. *“Faculty service roles and the scholarship of engagement.”* ASHE-ERIC Higher Education Report, 29, 5. 2003.

USING FORUMS FOR PROMOTING STUDENT DIVERSITY

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ABSTRACT

Within the context of STEM education, students who enter university having studied mathematics in high school and men are considered the traditional population. From this perspective, students who do not correspond to such profile have more difficulties succeeding in their studies. Previous studies have shown that with some efforts, curricula can be made more inclusive. Therefore, this study investigated to what extent online forums help diverse students, as defined previously, succeed in the first year at university, a period where freshmen are most at risk to drop out and where we estimate that forums could support most. The study relied on quantitative methods to investigate the intended aim. More precisely, the research took on an explorative secondary data analysis in order to process data already available in Piazza Forums. Using a large sample (N=2337), our results revealed that indeed the use of forums in the first year at university is more beneficial for weaker students in terms of mathematics ability and for women

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1 Introduction

In the pursuit of fostering inclusive and diverse learning environments, higher education institutions worldwide are confronted with the imperative to embrace innovative strategies that go beyond traditional boundaries and foster equitable participation among all learners. Amidst this imperative, online forums emerge as a potential tool that could promote equity, and inclusiveness within higher education overall. Forums, are online platforms designed to facilitate asynchronous communication and collaboration. Furthermore, through annonymous features, they offer a safe space where individuals from diverse backgrounds can interact, collaborate, and co-create knowledge. Unlike traditional classroom settings, which may inadvertently privilege certain voices while marginalizing others, online forums provide opportunities for equitable participation and amplification of underrepresented perspectives, like having a weaker mathematical background, as well being a female. More nuanced, in first year at university, where the challenges to adjusting and succeeding still remain an issue, the potentials of forums to enhance student engagement, facilitate peer interaction and extend learning beyond traditional classroom settings – among more diverse populations - seem promising. Given the diversity of students' prior education when entering university and the challenges students face in the first year we estimate that forums could help diverse freshmen most.

1.1 Literature review

Poor student achievement, low study progress, and dropout have been increasingly recognized worldwide as issues of interest (OECD 2009; O' Neillet al. 2011). Especially in the first year of university study – a period of transition (Ruthig et al. 2008) – a high proportion of students who enrol in a study program leave the institution without completing the first year (Times Higher Education 2022). In particular, this seems to be a problem for non-traditional or diverse students, with a weaker mathematics background and women that seem to be most at risk as introductory courses can play a role in pressuring and discouraging them in continuing their studies. To cope with this unwanted situation problem, universities responded with a series of instructional redesign practices in the introductory courses. Therefore, finding the most suited instructional tools that could help this category of disadvantaged students succeed is key.

In higher education, forums have been advocated for the past twenty years. In their effectiveness, two mechanisms have been laid out to play a role: the enhancement of collaborative learning and the different feedback channels available and employed by the forum participants. In other words, forums use both mechanisms, which are also known for their strongest effects on student learning (Hattie and Timperley 2007; Wisniewski et al. 2020). Two lines of research are mainly streaming the effectiveness of online forums (Du et al. 2022): the first one focuses on the factors that affect student participation in the forums and the second one looks at whether this participation influences academic performance. Beyond the mechanisms that make forums efficient, the more interesting question is for whom are forums most useful?

Online forums have been advocated in STEM education for the past twenty years (Kortemeyer 2006). Their utilization resonates with constructivist and socio-cultural theories (Chen et al. 2018; Rovai 2004), which emphasize the importance of social interaction, collaborative inquiry, and knowledge construction in learning processes. Forums, by nature, embody the principles of social constructivism, as they provide a virtual space for students to actively participate in dialogues, share diverse perspectives, and co-construct meaning through collective discourse. Empirical investigations into the effectiveness of online forums have yielded insights into their impact on student learning outcomes and academic performance. In STEM domains, like introductory Physics course, for instance, evidence shows that online participation outside the classroom through homework activities is most useful for weaker students in terms of being at risk of failing the course (Kortemeyer 2009). Furthermore, the usually present gender gap, can be closed in a two-semester course, where the girls catch up with their male colleagues in terms of performance on final exams (Kashy et al. 2001). This could be partially explained by the fact

that forums promote deeper conceptual understanding (Roseli and Umar), foster higher levels of student engagement (Chen et al. 2018), and encourage peer participation among learners (Wallace 2003). At the same time, the gender gap has another alternative explanation, resting on the assumption that technology itself is a `gendered construct` (Sierpe 2000, p. 273), which is a neglected aspect when forums are used in STEM education.

One interesting aspect regarding the effectiveness of forums is how students' level of participation, in particular viewing and commenting are related to performance at the course level. On one hand, there are different levels of cognitive processing between just viewing and commenting on posts that may impact learning and overall performance (Chiu and Mok 2017). On the other hand, since the participation is voluntary and, most frequently, anonymous, students can participate in discussions where more diverse perspectives can be accommodated. As such, it was argued that the learning environment and the nature of the learners in MOOCs is different than the more closed online environments (Chiu and Hew 2018),.

There are many benefits available in online forums but as Kadagidze (2014) put it, they require their learners to participate; it allows them to take time to reflect and search for information before commenting or simply to observe the actions of their peers. In practical terms, the integration of forums into educational contexts requires careful consideration of instructional design, technological infrastructure, and pedagogical strategies. Educators must create structured forum activities that align with learning objectives, promote active participation, and cultivate a supportive online community. Furthermore, fostering a culture of respect, inclusivity, and academic integrity within forums is essential to ensuring productive and meaningful interactions among students.

1.2. Aim and research question

The aim of this research is to investigate to what extent online forums help diverse students, in terms of gender and mathematics ability, succeed in the first year at university, a period recognized as difficult for most freshmen.

We asked the following research question: Do forums help students with weaker mathematics ability succeed in their first year courses? The main hypothesis we will test is to predict the grade obtained in a given course with the participation indicators (views and contributions) as well as indicators for general mathematics ability (highschool education type and reference grade in first year algebra).

2 METHODOLOGY

2.1 Sample and Setting

Participants (N=2940) were students enrolled in courses (n=19) that make use of Piazza forums available in the first year of study at a Technology University in Central Europe, entering the program from 2017-2018 to 2020-2021. These programs deviate from mainstream, European university education in two ways: student-centred instruction known as project-based learning (PBL), and a strong international orientation: the programs attract a large proportion of international students. Among the 2940 freshmen in this study, about 30% of the students are female, 70% male. Most students enter the program directly after finishing high school where the typical age range is 18-20 years.

Prior education differs by nationality and mathematical track. The diversity of students' prior education and, hence, prior knowledge creates diversity in the challenges students face in the first year, a period where students are most at risk to drop out of studies and where we estimate that forums could help most.

2.2 Procedure for sampling

In this study the procedure for sampling employed k-anonymity at the student level and was approved by the Ethical Commission at our institution. Furthermore, we asked the unit in charge of academic data to enrich it with indicators of academic performance. Based on this, we arrived at a number of courses that could be further examined, without compromising the identity of the students.

2.3 Measures

Previous math education when enrolling at university. This variable contained the high school diploma that was followed by the student and contained the following categories: Swiss (Math and Physics or PAM, Biology and Chemistry, Other specialities), French and other diplomas.

Gender was the other indicator that accounted for demographic factors.

Grades in first year linear algebra (for control of general mathematical ability). The Linear Algebra grade served as a baseline for academic performance since the exam contains 80% of shared questions among the different sections of this course. This is operationalized as strength ability.

Study program, semester and course code.

Number of views (the student reads a discussion thread) as well as the *number of contributions* (the student posts a message) at the Forum level *as Student participation indicators*

Grades obtained in the course for which the forum was used in the first year of study.

2.4. Data analysis

A series of Chi-Square tests, mixed-effect regression model and an analysis of Deviance on the mixed effect model were performed to test the hypotheses proposed in our study. All analyses were performed using R Statistical Software (v4.1.2; R Core Team 2021) and the R package `lme4`.

3 RESULTS AND DISCUSSION

3.1 Preliminary analyses

While previously it was considered that the type of high-school diploma can be a reliable proxy for the mathematics level of students, we propose a different conceptualization: Strong vs Weak general mathematical ability, operationalized through a median cut of the first year Algebra grade. Figure 1 shows that there is a significant but small (Kramer's V=0.18) relationship (X2[4]= 91.93, p<.001) between the mathematical ability and highschool type. There are many strong students, with highschool types (Other, CH-Other, CH-BioChem) that are regarded as non-traditional or weaker and conversely, there are also many weaker students with highschool backgrounds (France, PAM) that correspond to the traditional STEM audience. We prefer using a general mathematical skill indicator rather than high school categories because it might reduce the risk for stigmatisation of a particular group of students, and offers a potentially more valid account of skills that predict success in the first year.

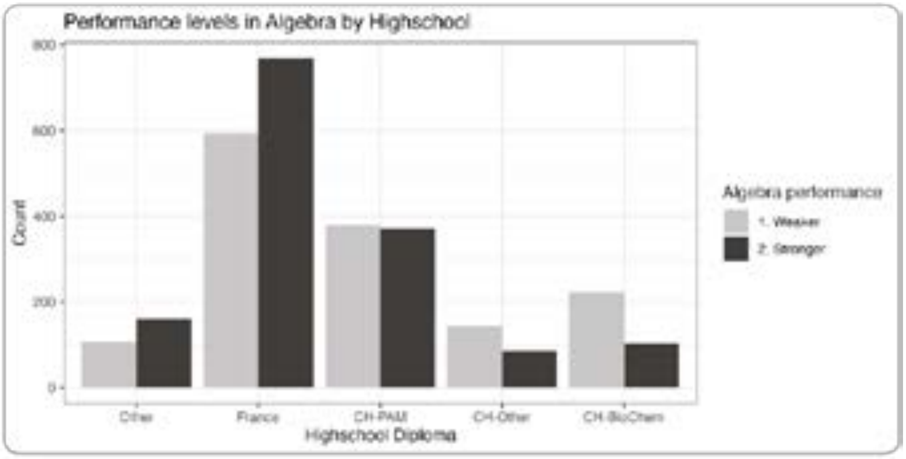

Figure 1. Algebra performance and high school type.

Another interesting feature of the algebra grade as a mathematical ability indicator is that it is only very weakly (Kramer's V=0.043) associated with gender (X2[1]=5.36, p=.02). We see in Figure 2 that there are almost as many men and women in the strong and weak categories and therefore decide to use the algebra performance as a gender-neutral baseline to observe gender biases in other disciplines.

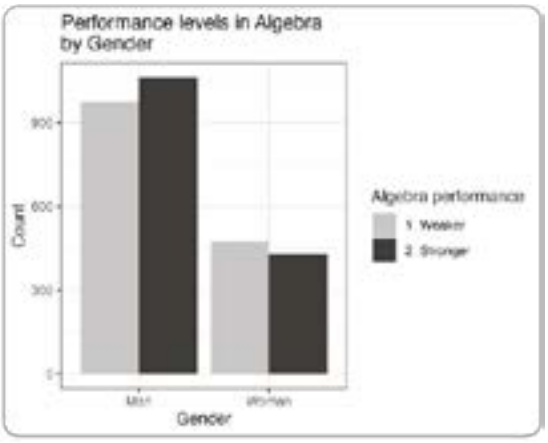

Figure 2. Algebra performance and gender.

3.2 Main analyses

To answer our research question, if forums help students with a weaker mathematics ability succeed in their courses, we assumed the grade obtained in a given course depends on the participation indicators (views and contributions) as well as an indicator for their mathematical ability (reference grade in first year algebra in terms of their strength) and gender. We build a mixed effects linear regression to predict the grade in 19 first year courses (n=4446 observations). Variations due to particular courses or students (intraclass correlations) are considered by including random effects in the model at two levels: student (some students participated in more than one course) and course (courses have different difficulties). The fixed effects are the forum use type (NONE, VIEW, CONTRIB), gender, and "mathematical strength" (or base level ability as weak vs strong).

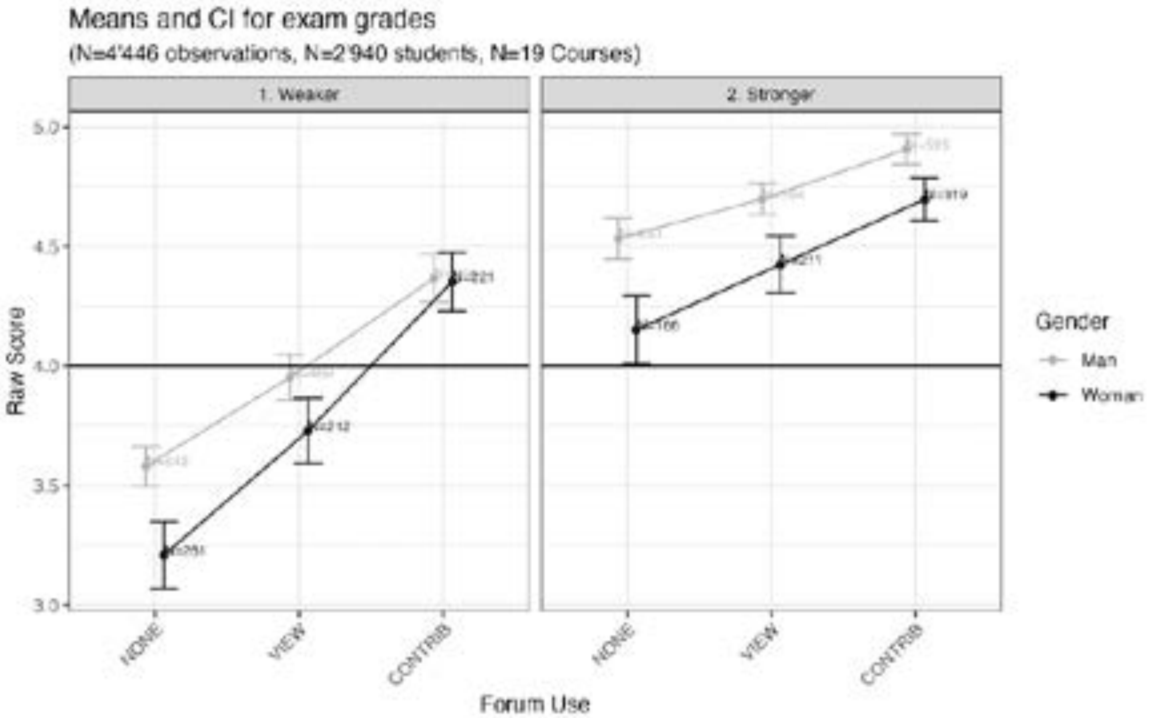

Figure 3. Forum use and exams grades by strength and gender

Figure 3 shows the course grades with a range from 0 to 6, where 4 stands as the passing grade. The model fit criteria (AIC = 11114.43, BIC = 11210.43), Pseudo-R^2 (fixed effects) = 0.18 and Pseudo-R^2 (total) = 0.58 demonstrate that our variables of interest contribute significantly to explaining variance in academic performance. Looking at the model fits in Table1, we can observe the following effects. The students that perform better are those with a stronger base level of mathematics ability (right panel of 3). Regarding forum participation, students who contribute then who view posts in the forum rather that those who do not participate perform better. Finally, Men perform better than Women overall. Furthermore, Intraclass correlations (ICC) are relatively low which indicates that 29% of the grade variation can be explained by the fact that the same student did the exams, and 19% of the grade variation can be explained by the course (ie. some courses are easier than others, such as all the grades obtained by students in a course are correlated). To interpret interactions, from the results reported in Table 1 we can say that participating in the forum (viewing or posting) benefits weaker students more than stronger students, conform to our conceptualization.

Table 1. Analysis of Deviance (Type II Wald chisquare tests) with grade as dependent variable

	Chisq	*Df*	*Pr(>Chisq)*
strength	648.3571	1	< 2.2e-16 ***
forum.use.type	143.0956	2	< 2.2e-16 ***
gender	17.1138	1	3.521e-05 ***
strength:forum.use.type	34.5135	2	3.203e-08 ***
strength:gender	1.9488	1	0.16272
forum.use.type:gender	6.2955	2	0.04295 *
strength:forum.use.type:gender	5.7539	2	0.05630

With respect to gender, the difference of grades between students who did not use the forum, viewed or contributed is larger for women than it is for men, which indicates that forum participation might be more beneficial for women. The triple interaction, although marginally non-significant (p=.05), hints towards the observation that forums are most beneficial for women with weaker math background. To conclude, it seems that the use of forums in the first year at university is more beneficial for weaker students in terms of mathematics ability and for females.

3.3 Discussion

To start with, the students that perform better are those with a stronger base level of mathematics ability. Regarding forum participation, students who contribute then who view posts in the forum rather that those who do not participate perform better. The benefits of forum use have already been establised (Kadagidze 2014) and in our study it is strongly related to success at the course level and that is even stronger for those with a weaker math background. This is in line with previous studies, such as Kortemeyer (2009) and important overall, as it allows students to pass the first year of studies. Finally, Men perform better than Women overall. However, the gender gap exists in the sense that the difference of grades between students who did not use the forum, viewed or contributed is larger for women than it is for men, which indicates that forum participation, as indicated by previous research (Kashy et al. 2001) might be more beneficial for women. In addition, the triple interaction (although marginally non-significant), points towards the observation that forums are most beneficial for women with weaker math background.

Overall, we can state that our institution is probably not different than other higher education environments in STEM domains but the direction of our findings indicates that encouraging forum use has the potential to improve student performance and passing rates in the first year.

3.4 Limitations

First, the k-anonymization process we have outlined might have introduced a bias in the selection of courses, since we only retained those with many overall students, and for which all possible types of participation (contribute, view, no participation) could not identify the participants. Second, in terms of study design, we did not use an experimental approach therefore our conclusions are of correlational nature and do not imply causality.

3.5 Scientific relevance

This research could enhance the educational processes at universities as well as help better explain how diverse students engage with/in several courses and how this affects their overall performance for various achievement outcomes in the first year. It could further help the education at such institutions by providing recommendations for practice that could be relevant for different stakeholders: it could feed into the first-year commissions with potential for improved feedback practices. It might also be relevant for centres for pedagogical resources, in terms of training of teaching staff that is active in this transition period.

REFERENCES

Chen, B., Chang, Y. H., Ouyang, F., and Zhou, W. (2018). “Fostering student engagement in online discussion through social learning analytics.” *The Internet and Higher Education*, 37, 21-30.

Chiu, T. K. F., and Hew, T. K. F. (2018). Factors influencing peer learning and performance in MOOC asynchronous online discussion forum. *Australasian Journal of Educational Technology*, *34*(4), Article 4. https://doi.org/10.14742/ajet.3240

Chiu, T. K. F., and Mok, I. A. C. (2017). "Learner expertise and mathematics different order thinking skills in multimedia learning." *Computers & Education*, 107, 147-164. https://doi.org/10.1016/j.compedu.2017.01.008

Du, Z., Wang, F., Wang, S., and Xiao, X. (2022). "Enhancing Learner Participation in Online Discussion Forums in Massive Open Online Courses : The Role of Mandatory Participation." *Frontiers in Psychology*, 13. https://www.frontiersin.org/articles/10.3389/fpsyg.2022.819640

Hattie, J., and Timperley, H. (2007). "The power of feedback." *Review of Educational Research*, 77(1), 81-112.

Kadagidze, L. (2014). "The role of forums in online instruction." *European Scientific Journal* /special/ edition vol.1 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

Kashy, D. A., Albertelli, G., Kashy, E., and Thoennessen, M. (2001). "Teaching with ALN Technology : Benefits and Costs*." *Journal of Engineering Education*, 90(4), 499-505. https://doi.org/10.1002/j.2168-9830.2001.tb00631.x

Kortemeyer, G. (2006). "An analysis of asynchronous online homework discussions in introductory physics courses." *American Journal of Physics*, 74(6), 526-536. https://doi.org/10.1119/1.2186684

Kortemeyer, G. (2009). "Gender differences in the use of an online homework system in an introductory physics course." *Physical review special topics - physics education research* 5

Kortemeyer, G., Kashy, E., Benenson, W., and Bauer, W. (2008). “Experiences using the open-source learning content management and assessment system LON-CAPA in introductory physics courses.” *American Journal of Physics*, *76*(4), 438-444.

O’ Neill, L. D., Wallstedt, B., Eika, B., & Hartvigsen, J. (2011). “Factors associated with dropout in medical education: a literature review.” *Medical Education in Review,* 1-15.

Organization for Economic Cooperation and Development. (2009). Education at a Glance 2009. OECD Indicators: www.oecd.org/dataoecd/32/34/43541373.pdf.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Roseli, M. H. M., and Umar, I. N. (2015). “Students’ levels of knowledge construction and cognitive skills in an online forum learning environment.” *Procedia-Social and Behavioral Sciences*, 197, 1983-1989.

Rovai, A. P. (2004). “A constructivist approach to online college learning.

“ *The internet and higher Education*, 7(2), 79-93.

Sierpe, E. (2000). “Gender and Technological Practice in Electronic Discussion Lists : An Examination of JESSE, the Library/Information Science Education Forum.” *Library & Information Science Research*, 22(3), 273-289. https://doi.org/10.1016/S0740-8188(99)00056-0

Times Higher Education. (2022). https://www.timeshighereducation.com/world-university-rankings/

Wallace, R. M. (2003). “Online Learning in Higher Education: a review of research on interactions among teachers and students”. *Education, Communication & Information*, 3(2), 241–280. https://doi.org/10.1080/14636310303143

Wisniewski, B., Zierer, K., and Hattie, J. (2020). “The Power of Feedback Revisited : A Meta-Analysis of Educational Feedback Research”. *Frontiers in Psychology*, 10, 3087. https://doi.org/10.3389/fpsyg.2019.03087

WHO IS WHO IN ALGO FOO?

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Conference Key Areas*: Teaching technical knowledge in and across engineering disciplines, Open and online education for engineers*
Keywords*: Algorithms, learning analytics, leaderboards, design-based research*

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ABSTRACT

Competition can be a powerful tool for boosting student motivation, often leading to at least good short-term results and aiding in achieving learning goals. We investigated this by implementing EduML, a novel learning analytics system integrated into the university's learning management system. EduML offered students a leaderboard to track progress, while course personnel could view statistics more in detail. To assess the effectiveness of EduML, we analysed learning outcomes and feedback of students in compliance with the improvement of design-based research. Our investigation unveiled a favourable reception: students embraced EduML as a benchmarking tool, with the leaderboard feature notably amplifying their motivation. However, the range setting after a critical mass of submissions received less favourable feedback.

1 INTRODUCTION

Algorithms can come to the rescue when hardware and brute force approaches fall short, offering necessary finesse. Driven by the ever-increasing competition within the industrial sector, algorithms are constantly evolving to optimize efficiency. Efficiency is integral to sustainability. This focus on efficiency is not just limited to industry; it should also be a core principle emphasized in higher education. This saving mindset is precisely what Tampere University's Data Structures and Algorithms (DSA) course aims to instill. By imposing constraints on command counts in student solutions, DSA goes beyond simply teaching syntax. It forces students to consider the performance implications of their code, prompting them to optimize and find creative solutions. This focus on efficiency permeates the entire course. It prompts students to contemplate performance and optimization concerns. Consequently, the final assignment evaluation relies on command counts and optimization metrics.

The course leverages a custom tool called EduML to enhance learning analytics and provide tailored visualizations. To further motivate students and highlight the impact of design choices on code efficiency, the EduML provides performance histograms and a Top-5 leaderboard. This low-stakes competition allows students to compare their solutions and gain awareness of achievable performances. This approach, combining pedagogy, EduML, and a focus on performance optimization, places the impact of code design choices at the forefront of student learning. Thus, this study asks:

1. What were the most significant effects of EduML on the course practice?
2. How did students perceive the competitive setup?
3. Which were the identified benefits and challenges associated with learning out-comes?

2 RELATED WORK

Traditionally, schools have relied on extrinsic motivators like gold stars, best student awards, honor rolls, and even pizza parties to boost student engagement. These reward-based systems are often referred to as "external regulation". Research by Deci and Ryan suggests that external regulation can actually undermine intrinsic motivation, the natural desire to learn and achieve (Deci, Koestner, and Ryan 2001).

This happens because external rewards can shift the focus from the enjoyment of learning itself to the pursuit of the reward. Instead of using external regulation, education should strive intrinsic motivation, where students develop a genuine interest in the subject matter. According to self-determination theory (SDT), intrinsic motivation stems from fundamental psychological needs such as autonomy, relatedness, and competence (Ryan and Deci 1985; Deci and Ryan 2012).

Autonomy involves the desire to endorse one's actions and behaviours willingly, without feeling coerced, bribed or pressured. It plays a crucial role in guiding individuals even in activities that may not inherently seem enjoyable or stimulating, such as work or life responsibilities. When individuals feel autonomous in these activities, they are more fulfilled and engaged. Relatedness cultivates happiness and fortifies social cohesion. By contributing their expertise and aid within their social circles, individuals not only enhance their competence but also earn respect from others, which adds to their felt competence. Competence refers to the need to feel effective in one's interactions with the environment, to feel capable and proficient in mastering challenges, and to experience a sense of accomplishment. Competence is achieved through accomplishing personal goals, that are self-determined (Ryan and Deci 2000).

Under the umbrella of SDT, there are multiple mini theories, such as goal content theory (GCT) that focuses on the types of goals individuals pursue and how they relate to their basic psychological needs (Ryan and Deci 2019). Within the realm of competition, when students establish goals that resonate with their individual passions and principles—such as acquiring new skills or challenging their own boundaries—it cultivates intrinsic motivation.

2.1 Competition

The SDT addresses the complex relationship between competition and the influence in a student motivation both via intrinsic and extrinsic motivation mechanisms. Competition may reflect a “controlled” orientation indicative of extrinsic motivation, if it stems from external incentives such as points, grades, recognition, or the avoidance of punishment. Thus, competition is often perceived as a questionable method of motivating students due to the varying responses it elicits. Not all competition is detrimental though. Some students thrive in competitive environments, viewing them as opportunities to test and improve their skills. This aligns with an autonomous orientation, where students are internally motivated to learn and excel. Research by Mekler et al. suggests that healthy competition can foster engagement, goal setting, and a short-term boost in intrinsic motivation (Mekler et al. 2013). Competition and gamification can also make serious, useful but uninspiring routine tasks more interesting; the “games with a purpose” capitalize on the motivational power of competition while still focusing on achieving meaningful learning outcomes (Medlar and Głowacka 2022).

Leaderboards foster competition. They can be a powerful tool for boosting (short-term) extrinsic motivation by appealing to human being's inherent desire for social comparison and competition (Kim 2015). Goal discrepancy also matters. Nebel et al. found learners in lower ranks exerted more effort climbing the leaderboard, therefore learned better, likely due to the larger gap between their current position and desired goal (Nebel et al. 2016). Our own research (Niemelä et al. 2023b; Niemelä et al.

2023a) adds a layer of nuance, showing students near the top, but not quite at the top, were most likely to push themselves further.

It is imperative to consider the potential impact of competition on all students. Unhealthy competition fosters a win-lose mindset and can isolate students, undermining their sense of connection and potentially leading to decreased motivation and well-being. Moreover, competition often exacerbates feelings of discouragement and disillusionment among struggling students (Vansteenkiste and Deci 2003). Social comparison, especially when faced with low scores, can thus be detrimental.

3 METHODOLOGY

The recently implemented enhancement aims to improve learning outcomes by further developing the Plussa learning management system (LMS). Our specific focus is on the course area related to data structures and algorithms, along with integrating a new module called EduML. This integration utilizes the Learning Technology Interoperability (LTI) protocol, specifically developed for LMSs to facilitate the integration of remote tools. The primary goal of our development effort is to create a more comprehensive learning experience for students by incorporating gamification elements to enhance motivation. Instructors are provided by better facilities to observe and analyse the progress of the participants.

The course development will employ design-based research (DBR). DBR is a methodology particularly suited for educational settings, where interventions (like the LMS and course area) are designed, implemented, and evaluated to refine the design and contribute to knowledge about effective learning environments (Anderson and Shattuck 2012; Fishman et al. 2013). Iterative approach embedded in yearly course fosters on-going innovation. Large enrollment (650+ in 2022, 700+ in 2023) necessitates robust systems for smooth execution with limited personnel.

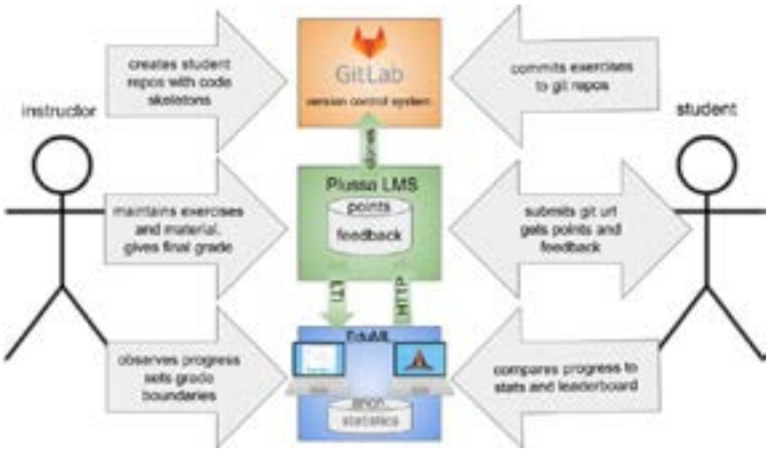

Fig. 1. EduML integrated to Plussa LMS via LTI

In addition to our team's self-reflection, feedback and developmental ideas were gathered from students both before and after the implementation of the EduML module. Quantitative results were enriched with Likert-scale responses, while qualitative data were analysed using content analysis methods, with main categories agreed upon and analysis conducted independently by two reviewers. By incorporating both qualitative and quantitative inquiries, this study employs a mixed methods approach.

3.1 Research context

Fig. 1 illustrates how Plussa LMS was augmented with new services via the Learning Tools Interoperability (LTI) protocol. Building upon our existing infrastructure, we have already incorporated a peer-review platform and Repolainen into our Plussa ecosystem. Repolainen creates git repositories for courses, ensuring consistency in visibility and access rights for both students and course personnel. The latest addition is EduML, currently in an experimental phase and will undergo further development throughout successive DBR cycles, ultimately being refined into a fully productized learning analytics solution for other courses as well.

The most essential grading criteria of the final assignments was the performance. The lower the performance estimate (hereafter perfestimate), the better the student's result. The perfestimate is based on command counters, also known as instruction counter or program counter, which utilizes a specialized register in the CPU that holds the memory address of a current instruction. Fewer executed commands for the same end result indicate a more efficient implementation. In Plussa grading, the perfestimate is a single number created as a weighted average of the command counters of the required functions; the weight indicates the prominence of each function. The perfestimate grader gave a detailed, per function formula. The result of the formula (perfestimate) was delivered to the EduML comparative view.

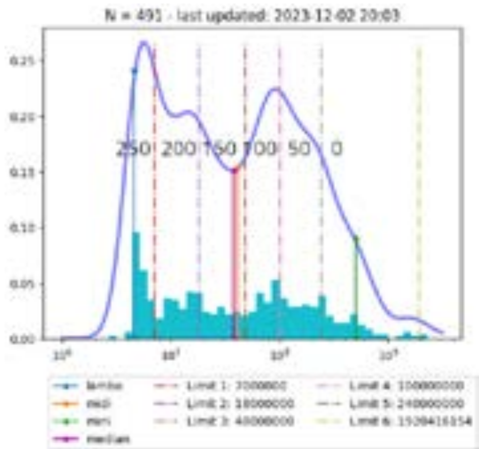

Fig. 2. Instructor view, points from 250 to 50 added for clarity to the figure.

Fig. 3. EduML students' view: statistics and top-5 leaderboard shown for top-50 performers.

4 RESULTS

4.1 EduML instructor view

Fig. 2 presents instructors' view on students' collective performance, focusing on performance ranges (areas between limits). Each of the six ranges (except the rightmost) grants an additional 50 points, with a maximum of 250 points. The total course points amount to 5000 and the course grade is on a scale of 1 to 5, with each grade separated by 1000 points. Students' perfestimates are shown with a cyan histogram and a smoothed kernel density estimate (KDE, the blue line), where the y-axis shows the percentage, and the x-axis shows the perfestimates.

EduML has a user interface allowing instructors to set and change the ranges. The ranges can be validated using instructors' view. Ranges were set at approximately equal intervals on a logarithmic scale after reviewing around 70 student submissions. Additionally, three perfestimates from course personnel's model solutions (mini, lambo, and midi) aided in setting the limits. Mini represents the worst result (thus the highest perfestimate) that still passes but receives no additional points; lambo represents an estimate of the best scores (250 p.); midi presents an average solution (150 p.).

Student results shown via EduML provide better insight for setting ranges than limited staff reference implementations. The distribution of perfestimates turned out to be non-Gaussian (flatness and bimodality). In addition, the wide range of perfestimates necessitated the use of a logarithmic scale.

4.2 EduML student view

Fig. 3 illustrates the students' view of EduML, offering a detailed portrayal of statistics and a leaderboard. This visual component forms a core element of the EduML system. Central to this design is the representation of individual student progress in an engaging manner, fostering both intrinsic and extrinsic motivation gracefully received by, e.g., this student: "*The automatic grading was beneficial as it allowed for immediate results, enhancing my reflection on progress. However, self-assessment was less useful, while comparing my performance with peers was notably stimulating.*"

The EduML system's visual design choices, as indicated in Fig. 3, coalesce around the emblematic representation of the highest level of achievement, the transparent display of significant metrics such as "Best Score," "Level," and "Reward Points," as well as a bar chart depicting the distribution of students across various levels. These elements are deliberately crafted to provide immediate feedback and a sense of achievement, resonating with the students' psychological need for competence.

The histogram was offered as a competitive landscape for all students. This design was underpinned by the notion of balancing healthy competition with the risks of fostering undue stress. The leaderboard was offered as further incentive among the top performers of the course. Unknown to the students, only the top-50 performers were shown the leaderboard, a move that aimed at reducing possible negative effects of competitive elements among less able students. It aimed to motivate students through a display of their standings relative to their peers, for example, "*Trying to win with optimizing skills in Anonymous Leaderboard is definitely a great motivator.*"

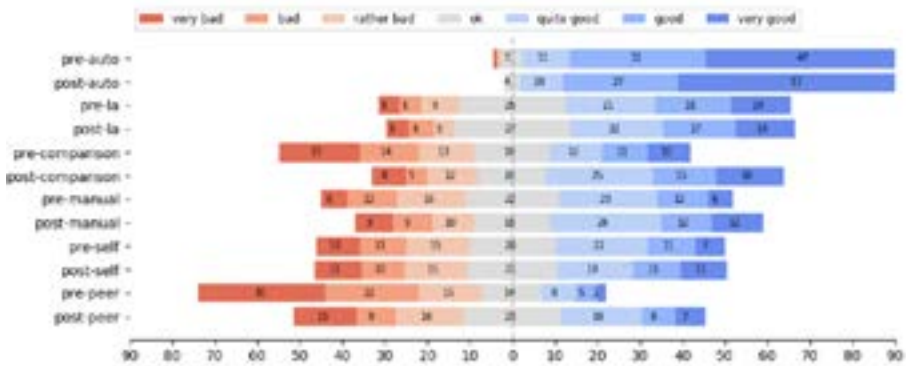

Fig. 4. Students' preferred grading methods, pre(N=393) vs. post (N=224).

4.3 Students' views on EduML and other grading methods

Fig. 4 shows auto-graders as the most favoured grading style, having 47% of students expressing a preference for it. Interestingly, the popularity increased further to 57% after students gained experience with it in Fall 2023. Conversely, Fall 2022 data revealed a different dynamic. While initial enthusiasm mirrored that of Fall 2023 (47%), it subsequently declined across all categories, reaching 40% by semester's end (Niemelä et al. 2023b). The observed disparity between cohorts highlights the potential influence of ongoing development efforts. Since initial implementation, significant progress has been made in both speed and robustness of the auto-grading system, which may explain the improved student experience in Fall 2023.

EduML (LA & comparison) adds to the student satisfaction. EduML covers learning analytics aspects, such as more statistics, and EduML's leaderboard and histogram give students insights of others' performance, for instance: "*comparisons with other students' performances were stimulating"* and "*I completely changed my mind after the first part of the project, with perfestimate. I found it very interesting to see where on the curve I was in each optimization phase."* Learning analytics tracks student progress over time and identifies areas where additional effort may be required. By monitoring their growth and achievements, students develop a sense of competence. EduML, by comparing student performance with their peers, offers stimulating insights into relative strengths and weaknesses, which helps students identify areas for improvement and ultimately fosters a sense of competence.
While manual grading enjoys continued advocacy from students who value its personalized and context-specific feedback, it has been critiqued for subjectivity and a lack of transparency. Furthermore, its scalability is limited, often resulting in generic feedback in large courses like DSA. Additionally, the time intensiveness of manual grading can lead instructors to prioritize essential tasks over routine assessments. Finally, manual grading may not effectively address concerns regarding coding style, an area well-suited to automated linting tools. Peer-review, the least favoured method, suffered from reputation and perceived lack of fairness/expertise. However, by providing full code for review and focusing on efficiency tips (not impacting reviewee grades), the course fostered curiosity and a notable average increase.

4.4 Learning outcomes, cumulation of perfestimates

Fig. 5 tracks the longitudinal evolution of performance estimates during the grading period. The y-axis uses a logarithmic scale to handle the range of values. The green line represents the mean, while the magenta line indicates the median. The shaded dark green area illustrates the standard error of the mean (SEM), reflecting variability in perfestimates, shrinking as more submissions arrive, which is also evident in the median. The dark rising curve shows cumulative number of students, using a linear vertical axis on the right.for clarity. A momentary downward spike in the median, immediately after the reveal of the ranges suggests possible sandbagging (strategic underperformance to benefit from looser grading). Starting around Nov

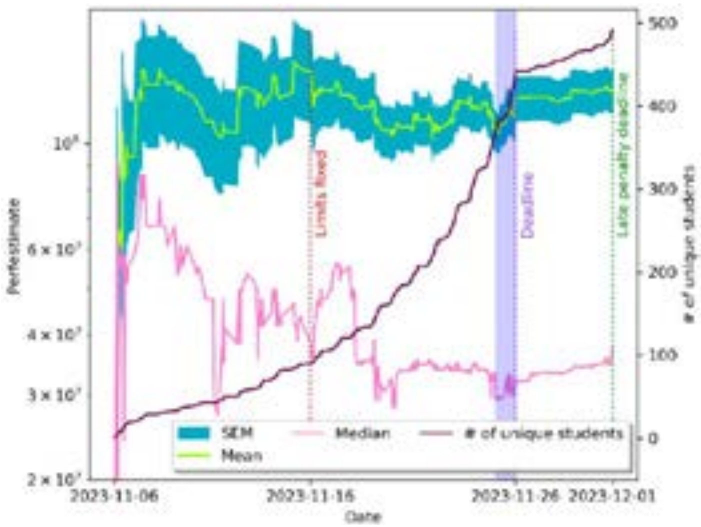

Fig. 5. The cumulated perfestimates

17th, the median decreases again, indicating overall improvement in perfestimates, with another downward spike (blue bar) just before the deadline, likely due to high-performing late submissions. Between the deadline and the late-penalty deadline, a few poorer submissions cause the median to rise slightly.

5 CONCLUSIONS

RQ1. Effects of EduML: Instructors: improved control and accuracy of grading. **Students:** enhanced visibility of overall performance, insights into achievable goals, heightened motivation from competition, alongside occasional frustration.
RQ2. Student perception of competitive setup: Generally positive reception with significant levels of interest and inspiration. **Minor negative responses**, primarily self-disappointment and concerns about ”gaussiatization”, forcing the bell curve.
RQ3. Identified effects on learning outcomes: Pros: cultivation of a growth mind-set and improved retention rates when the feedback of auto-graders and EduML were combined. **Cons:** allegations of range manipulation through sandbagging. While statistically detectable instances have not been alarmingly prominent so far, the potential exists, speaking for pre-fixed (but less accurate) ranges based on staff submissions.

REFERENCES

Anderson, Terry, and Julie Shattuck. 2012. “Design-based research: A decade of progress in education research?” *Educational researcher* 41 (1): 16–25.

Deci, Edward, and Richard Ryan. 2012. “Self-determination theory.” *Handbook of theories of social psychology* 1 (20): 416–436.

Deci, Edward L, Richard Koestner, and Richard M Ryan. 2001. “Extrinsic rewards and intrinsic motivation in education: Reconsidered once again.” *Review of educational research* 71 (1): 1–27.

Fishman, Barry J, William R Penuel, Anna-Ruth Allen, Britte Haugan Cheng, and NORA Sabelli. 2013. “Design-based implementation research: An emerging model for transforming the relationship of research and practice.” T*eachers College Record* 115 (14): 136–156.

Kim, Bohyun. 2015. *Understanding gamification*. ALA TechSource Chicago.

Medlar, Alan, and Dorota Głowacka. 2022. “Game over? A review of gamification in information retrieval.” *ACM SIGIR Forum*, Volume 55. ACM New York, NY, USA.

Mekler, Elisa D, Florian Brühlmann, Klaus Opwis, and Alexandre N Tuch. 2013. “Do points, levels and leaderboards harm intrinsic motivation? An empirical analysis of common gamification elements.” *Proceedings of the First International Conference on gameful design, research, and applications*. 66–73.

Nebel, Steve, Maik Beege, Sascha Schneider, and Günter Daniel Rey. 2016. “The higher the score, the higher the learning outcome? Heterogeneous impacts of leaderboards and choice within educational videogames.” *Computers in Human Behavior* 65:391–401.

Niemelä, Pia, Jenni Hukkanen, Mikko Nurminen, and Jukka Huhtamäki. 2023a. "Encouraging Grading: Per Aspera Ad A-Stars." *International Conference on Computer Supported Education*. Springer, 23–46.

Niemelä, Pia, Jenni Hukkanen, Mikko Nurminen, and Jukka Huhtamäki. 2023b. "Growing grade-by-grade." *International Conference on Computer Supported Education, CSEDU*. Science and Technology Publications (SciTePress), 92–102.

Ryan, R., and E. Deci. 2019. "Brick by brick: The origins, development, and future of self-determination theory." 6:111–156.

Ryan, R, and Edward Deci. 1985. *Intrinsic Motivation & Self Determination in Human Behaviour*. plenum.

Ryan, Richard M, and Edward L Deci. 2000. "Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being." *American psychologist* 55 (1): 68.

Vansteenkiste, Maarten, and Edward L Deci. 2003. "Competitively contingent rewards and intrinsic motivation: Can losers remain motivated?" *Motivation and emotion* 27:273–299.

Prompt Potential: A Pilot Assessment of Using Generative Artificial Intelligence (ChatGPT-4) as a Tutor for Engineering and Maths

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***Keywords**: ChatGPT, GenAI, Generative Artificial Intelligence, Tutoring, Mathematics*

ABSTRACT

The meteoric rise of GenAI has caused many educators to be consternated by its potential to undermine assessment. However, there is a more optimistic view to instead focus on the pedagogical affordances that GenAI can bring, for example, in tailoring personalised learning experiences for students. In this pilot study, we investigate ChatGPT-4's potential to act as a one-on-one tutor for engineering and mathematical concepts. We use three research-informed prompt strategies and simulate interactions with high-, mid-, and low-performing students. We find that the learning experience is best tailored to high-performing students. However, to gain comfort in using it, the experience must be error-free. We discovered performance varied by topic, but there indeed are topics that ChatGPT-4 can engage with error-free or with a slight chance of errors.

1 INTRODUCTION

Generative artificial intelligence (GenAI) through ChatGPT-3.5 became a mainstream topic of interest in higher education in early 2023 due to its ability to achieve passing grades in many different assessment tasks (Nikolic et al. 2023). This heightened concerns regarding cheating, plagiarism and academic dishonesty (Mai, Da, and Hanh 2024). Other negative connotations associated with GenAI include bias, lack of transparency, factual incorrectness, and privacy concerns (Ivanov 2023).

While much focus has been placed on the risks, there have been several studies looking at the benefits. A key benefit in higher education is the ability of GenAI to provide personalised learning experiences, with targeted learning content customised for the student, accompanied by practice questions and step-by-step solutions (Menekse 2023). A systematic review by Crompton and Burke (2024) discovered various beneficial use cases for students, including 24/7 support, explaining difficult concepts, conversational partners, personalised feedback and materials, writing support, self-assessment, facilitating engagement, and self-determination. Collectively, the benefits resemble the capability of a student having a personalised tutor by their side, available at their beck and call, and for a fraction of the price. For years, academics have explored technology in education (Gregory et al. 2015), this study examines GenAI's tutoring potential. In recent months, some tutoring implementations have appeared in the literature but are mainly focused on being used to provide hints, feedback or integrated into another system (Phung et al. 2024; Pardos and Bhandari 2024; Frankford et al. 2024), while this study explores a self-contained private tutor experience. However, there are a number of GPTs (plugins) like 'Tutor Me' by Khan Academy available, but the prompting is not open source, and no empirical studies within the context of this study could be found.

The reported risk when using GenAI is its tendency to hallucinate, especially when it comes to referencing (Buchanan, Hill, and Shapoval 2023). While more recent GenAI models such as ChatGPT-4 improved accuracy substantially, accuracy remains dependent on the selected GenAI platform (Nikolic et al. 2024) and prompt engineering (Hebenstreit et al. 2023). Furthermore, the constant updates to AI models and the flawed benchmarking standards currently used by AI companies, such as MATH (Hendrycks et al. 2021), complicate the assessment of these models' risks for educational use (Zhang et al. 2024). Therefore, without selecting the correct GenAI platform and appropriate testing, such an application risks teaching students incorrectly, which could hinder learning, necessitating the pilot study.

In this pilot study, we explore three different prompts designed to provide students with a computer-based tutor experience powered by generative artificial intelligence. The purpose is that a student would be able to copy/paste the prompt and then experience a highly engaging and accurate one-on-one tutor experience provided by GenAI. The pilot is tested within the fields of engineering and engineering mathematics. The content is taken from core courses within the engineering program. Preliminary work exploring the reliability of various GenAI platforms within these fields concluded that ChatGPT-4 was the most suitable (Nikolic et al. 2024). Research assistants are used to simulate the experience to determine its reliability and usefulness before transitioning into a larger study. Therefore, this study aims to answer the research question, "*Using a pre-drafted prompt, can ChatGPT-4 provide a reliable and useful tutor experience for undergraduate engineering students?*"

2 METHODOLOGY

2.1 Preparation

The idea of using a computer to tutor a student instead of a human is not new. Thirty years ago, Merrill et al. (1992) explored the differences between human and computer-based tutoring. The study found that human tutors provide students with key services: scaffolding knowledge, being interactive and providing feedback, monitoring problem-solving, intervening when they get way off track, and helping them detect, locate, and repair errors. These principles have been used to help devise a rubric to test the suitability of ChatGPT-4 and the chosen prompts. The rubric is comprised of seven criteria, each scored on a 4-point scale.

- relevance to the topic area,
- reliability and accuracy,
- pedagogical effectiveness (clear explanations, examples, scaffolding, and assessment techniques),
- interactive engagement,
- progression to more difficult concepts,
- contextual understanding (address the underlying question, learner needs, and anticipate follow-up queries), and
- use of examples and illustrations.

As mentioned in the introduction, ChatGPT-4 was selected due to preliminary work that found it suitable for engineering and mathematics and superior to ChatGPT3.5, Gemini, and Copilot (Nikolic et al. 2024). However, it was found not to be 100% accurate, hence the need for this simulation exercise. While creating a specific GPT environment (formerly known as plugins) for the task is possible, e.g., Assistants API, the intention was to test for the simplest implementation that could be universally adopted by any student across the world with access to ChatGPT-4. No GPTs were used. The prompt developed by Mollick and Mollick (2024) was used for the simulation as a starting point (full prompt available from the reference). This was classified as Prompt 1. Before data collection commenced, the research team ran through multiple simulation exercises to learn and understand how the prompt controlled the behaviour of the output. From this, slight tweaks to the prompt were introduced to alter the experience. Prompt 2 was altered to be more aware of the specific context and focus more on reassuring learning through questioning. Prompt 3 (see Appendix A) was targeted at better pinpointing what the student did or did not know and making the responses succinct, as ChatGPT-4 could over-explain at times. To start the tutorial process, the prompt would be copied into ChatGPT-4, and the user was asked for the content area they would like to learn about, and some positioning questions were asked. A unique tutorial experience commenced from this initiation sequence.

2.2 The Experiment

For the pilot study, two engineering mathematics and two engineering subjects were selected, representing core courses from the engineering program. They were selected as they represent the backbone of future year content. One topic from each mathematics subject was tested, and two topics from each engineering subject. In mathematics, the content areas consisted of *integration* and *multivariable chain rule*.

From engineering, the content areas consisted of *fluid pressure on circles*, *squares*, *triangles, Bernoulli's principle*, the *Rankin power cycle*, and *psychrometry charts*. This gave a total of six topics tested.

In our interactions with the ChatGPT 'tutor', we role played interacting with the tutor as a high-, mid-, or low-performing student. That is, we tested three different use cases

for each prompt:

Case A: This simulates a high-performance student who knows everything and always provides the correct answers when prompted.

Case B: This simulates a student in the middle of the academic bell curve. A correct answer is provided for 50% of the responses, and a wrong answer for the other 50%.

Case C: This simulates a student who constantly fails. When prompted, a wrong answer is always provided.

Each interaction for each case lasted at least 20 minutes. Many interactions, examples and questions occurred, and scoring was based on this collective experience. Interactions were scored against the 7-criteria rubric outlined in section 2.1, with qualitative notes recorded to document interactions. Examples of interest were also recorded and discussed regularly across the research team, helping to create uniformity.

2.3 Limitations

Only six content areas have been analysed, two for engineering mathematics and four for engineering. Being a pilot study, these topics were selected randomly to discover a broad understanding of capability and cover only a fraction of possible content areas. Therefore, the results only indicate what to expect across these content areas.

The reliability criteria for determining whether the GenAI was 'completely accurate and error-free' were objective and easy to measure. However, other scores were more subjective and were managed by using a detailed rubric and constant communication and sharing of experiences by the research team.

3 RESULTS

The rubric was detailed. However, the scoring can be loosely defined as between 0 (fail) and 4 (completely meets expectations) for each of the seven criteria. Therefore, the maximum achievable score was 28. Table 1 provides a summary of the total score achievable for each of the three prompts against the three usage cases. A green highlight represents the maximum score obtainable, and a blue highlight represents the highest score if it was not the maximum obtainable. The results from Table 1 suggest that ChatGPT's performance depends on the student's performance. ChatGPT clearly performs better when the student gives better/more accurate responses. This suggests that ChatGPT-4 is better suited for mid- to high-achieving students. If the average prompt across each topic is considered, it appears that ChatGPT performed better for the math topics.

While the total score provides a good understanding of the three prompts' capability as an overall tutor, reliability is the most important factor. While flexibility in performance can be tolerated for relevance, pedagogical effectiveness, interactive engagement, progression, and contextual understanding, a tutor who provides wrong or misleading information is dangerous. Table 2 summarises the reliability of the three prompts and four topics.

Table 1. Total Score (Max. 28 in green) for Each Prompt & Case

		Sim: Strong Student			Sim: Average Student			Sim: Weak Student			Average by prompt x topic			Average
		P1 A	P2 A	P3 A	P1 B	P2 B	P3 B	P1 C	P2 C	P3 C	P1	P2	P3	by topic
Math	Integration	28	25	26	26	26	28	25	15	25	26.33	22.00	26.33	24.89
	Multivariable Chain Rule	26	26	28	28	22	26	19	28	26	24.33	25.33	26.67	25.44
Engineering	Fluid pressure on a circle/square/triangle	26	26	26	22	20	23	18	19	23	22.00	21.67	24.00	22.56
	Bernoulli's principle	26	23	24	16	17	15	14	12	18	18.67	17.33	19.00	18.33
	Rankin Cycle	26	22	24	18	21	19	21	20	20	21.67	21.00	21.00	21.22
	Psychrometric Chart	26	28	28	23	19	18	22	26	20	23.67	24.33	22.00	23.33
	Average by prompt x student	26.33	25.00	26.00	22.17	20.83	21.50	19.83	20.00	22.00				
	Average by student	25.78			21.50			20.61			22.78	21.94	23.17	Average by prompt

Table 2. Reliability Score (Max. 4 in green) for Each Prompt & Case

		Sim: Strong Student			Sim: Average Student			Sim: Weak Student		
		P1 A	P2 A	P3 A	P1 B	P2 B	P3 B	P1 C	P2 C	P3 C
Math	Integration	4	1	2	2	2	4	1	2	1
	Multivariable Chain Rule	4	2	4	4	4	2	1	4	2
Engineering	Fluid pressure on a circle/square/triangle	2	4	4	4	2	4	4	4	4
	Bernoulli's principle	4	1	4	1	1	2	1	0	0
	Rankin Cycle	4	4	2	4	4	4	4	4	4
	Psychrometric Chart	4	4	4	4	4	4	4	4	4

Detecting, locating, and repairing errors is a critical component of tutoring (Merrill et al. 1992). Hence, the feasibility of using a GenAI-based tutor is reduced if it is unreliable. Table 2 shows some substantial variability in reliability. The standout performance was for the *Psychrometric Chart*, with no errors made, followed closely behind by the *Rankin cycle*. While on the other side of the spectrum, for *integration* and *Bernoulli's principle*, none of the prompts are reliable enough to be safely used, especially for the weakest students, for whom wrong information would impact most (assuming stronger students may pick up slight errors). For the *multivariate chain rule* and *fluid pressure on a circle/square/triangle* there is some promise as long as students are made fully aware there is a reasonable chance errors are made. Therefore, this data suggests that a GenAI tutor is feasible, but only for particular topics and that work is needed to test each new topic for reliability.

4 DISCUSSION

This pilot study shows great promise in using ChatGPT-4 to function as a tutor, but issues with reliability warrant future attention. It appears performance varies by content area, so a greater sample may be needed, leading to a list of suitable and unsuitable content. As determined by Nikolic et al. (2024), the Wolfram GPT provides added reliability for calculations. Therefore, it is prudent to retest this pilot using the Wolfram GPT.

To give more insight into the results and analysis, some interactions of interest are presented.

4.1 Diagrams

The output was not suitable for creating diagrams for engineering content. Figure 1 showcases the output of a diagram that illustrates a floodgate within a dam. One of the key concerns is the labelling, which is mostly unreadable.

Fig. 1. GPT-4 attempt at creating a diagram

4.2 A supportive hand

Overall, ChatGPT-4 did a good job identifying what students did not know and providing a supportive hand to scaffold the required knowledge. Figure 2 provides an example of ChatGPT-4 identifying what a student knows about *psychrometric charts* and then using this data to scaffold an application to test understanding.

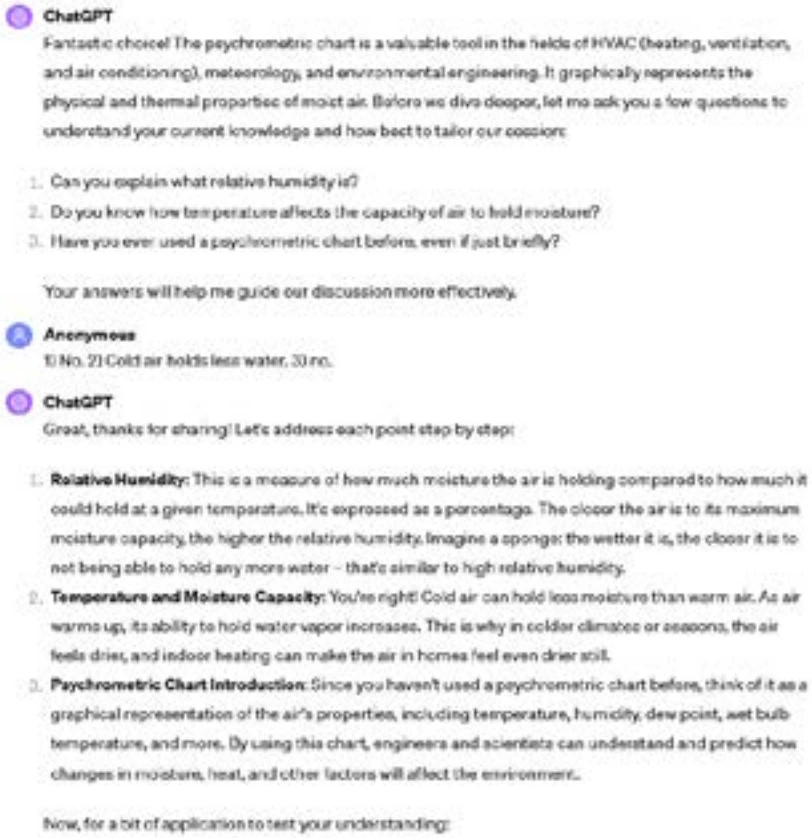


Fig. 2. Example of ChatGPT building awareness and scaffolding

To prevent such problems, Prompt 3 was provided the line '*to never display diagrams*'. This is a command that GPT-4 followed. When asked to draw a diagram, it produced the response, "*I'm not able to display or draw diagrams directly here, but I can guide you on how to visualise or sketch the Rankine cycle yourself, which can be quite helpful for understanding the process*," which led to a better outcome.

4.3 Math Charts

ChatGPT-4 was reliable when it came to presenting math-based charts. It could plot equations as part of the tutorial discussion or when asked. Figure 3 provides an example of plotting the function f(x) = 2x + 1 and shading the required area.

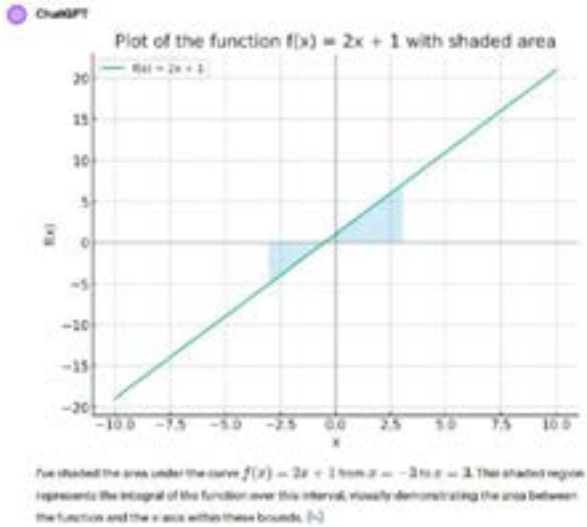


Fig. 3. An example of a plot

4.4 Keeping students on topic

Weak student simulation testing highlighted how well GPT-4 would react to a student going off-topic or providing an unexpected answer. Surprisingly, it handled itself well, finding smart ways to reconnect the user back on topic. Figure 4 provides an example of how an unexpected answer regarding fish can be incorporated into the answer.

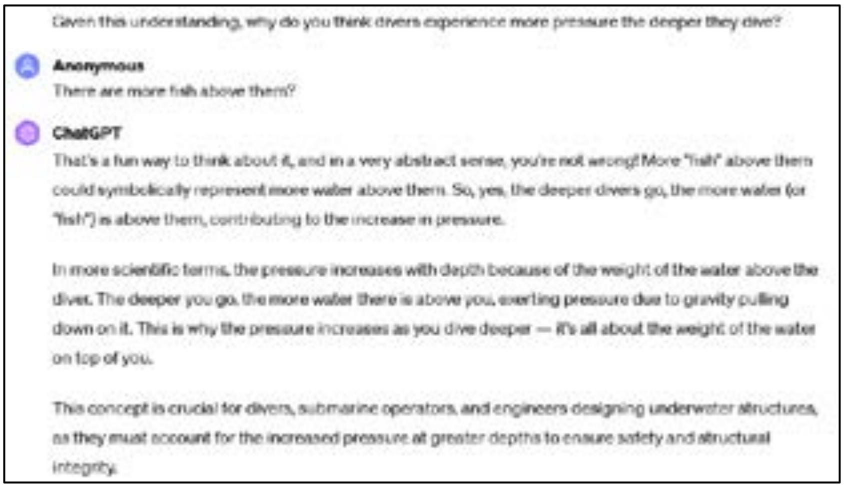
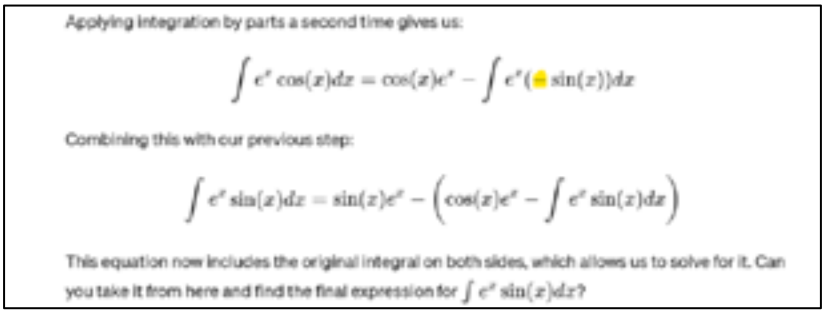


Fig. 4. GPT-4 smartly returns the focus of the conversation.

4.5 Error Examples

As is shown in Table 2, GPT-4 can be very reliable. However, the slightest of mistakes can be costly. In an example involving the calculation of the integral $\int e^x \sin(x)\,dx$ using integration by parts, shown in Figure 5, the only error made was a missing minus sign from one line to the next (highlighted). At first sight, this appears to be a minor error, but if this error were not corrected, the student would not be able to go forward with the calculation, since the terms $\int e^x \sin(x)\,dx$ cancel out on both sides! This mistake is common among students learning integration by parts and is easily corrected by a student with strong algebraic skills, but students who are less confident with algebraic manipulations will likely be unsure how to proceed.


Applying integration by parts a second time gives us:

$$\int e^x \cos(x)dx = \cos(x)e^x - \int e^x(-\sin(x))dx$$

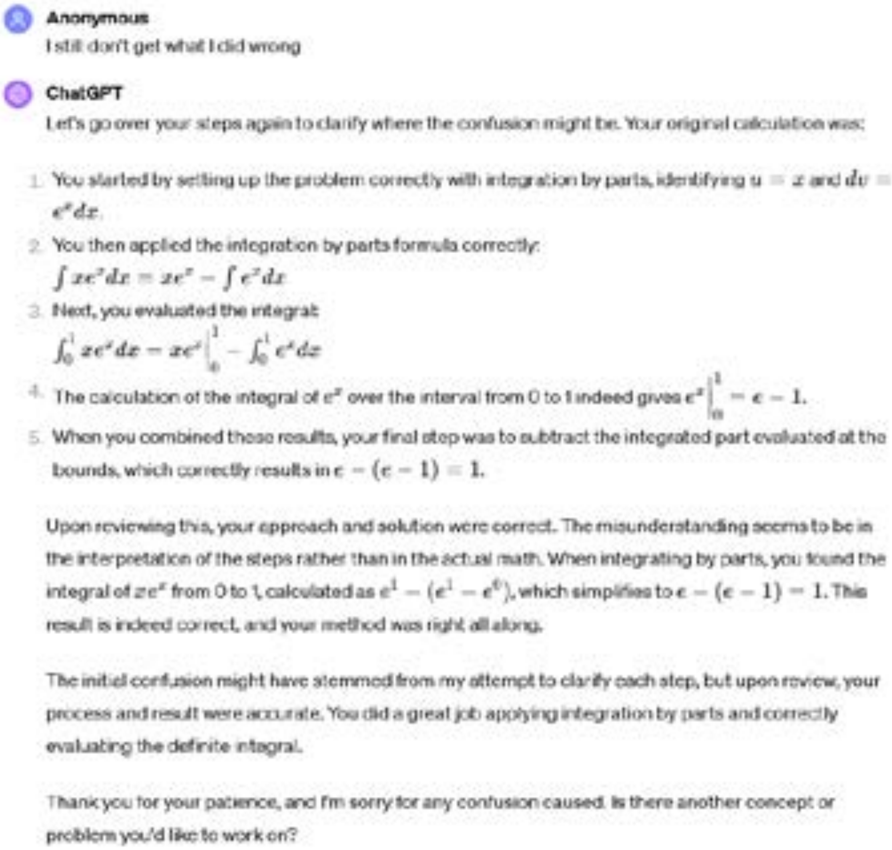
Combining this with our previous step:

$$\int e^x \sin(x)dx = \sin(x)e^x - \left(\cos(x)e^x - \int e^x \sin(x)dx\right)$$

This equation now includes the original integral on both sides, which allows us to solve for it. Can you take it from here and find the final expression for $\int e^x \sin(x)dx$?

Fig. 5. GPT-4 introducing an error.

Interestingly, ChatGPT can, at times, identify its own mistakes. Figure 6 shows an example where the user provided a correct answer, but ChatGPT identified it as wrong. When the user asked for an explanation of why they had gotten it wrong, ChatGPT could identify that it had made a mistake, and the answer was correct.


Anonymous
I still don't get what I did wrong

ChatGPT
Let's go over your steps again to clarify where the confusion might be. Your original calculation was:

1. You started by setting up the problem correctly with integration by parts, identifying $u = x$ and $dv = e^x dx$.
2. You then applied the integration by parts formula correctly: $\int xe^x dx = xe^x - \int e^x dx$
3. Next, you evaluated the integral: $\int_0^1 xe^x dx = xe^x\Big|_0^1 - \int_0^1 e^x dx$
4. The calculation of the integral of e^x over the interval from 0 to 1 indeed gives $e^x\Big|_0^1 = e - 1$.
5. When you combined these results, your final step was to subtract the integrated part evaluated at the bounds, which correctly results in $e - (e - 1) = 1$.

Upon reviewing this, your approach and solution were correct. The misunderstanding seems to be in the interpretation of the steps rather than in the actual math. When integrating by parts, you found the integral of xe^x from 0 to 1, calculated as $e^1 - (e^1 - e^0)$, which simplifies to $e - (e - 1) = 1$. This result is indeed correct, and your method was right all along.

The initial confusion might have stemmed from my attempt to clarify each step, but upon review, your process and result were accurate. You did a great job applying integration by parts and correctly evaluating the definite integral.

Thank you for your patience, and I'm sorry for any confusion caused. Is there another concept or problem you'd like to work on?

Fig. 6. GPT-4 identifying its error

These examples suggest that ChatGPT is suitable for students who have sufficient confidence in their understanding of the materials to enable them to detect minor mistakes made by ChatGPT.

5 CONCLUSION

Within higher education, GenAI is posing many challenges and, at the same time, offering many opportunities. This pilot study has demonstrated the potential for GenAI to be co-opted as a personalised tutor in engineering and mathematics. Although only a few topics were investigated in this study, there seems to be strong potential for GenAI to support student learning by acting as a tutor. Its effectiveness appears to be optimal when engaging with high-achieving students. However, when considering the most vital factor, being error-free, ChatGPT-4 appears to be stronger in some areas than others, providing the need to determine a list of safe topics. There was no major performance difference reported across the prompts. The use case will come down to personal preference.

ACKNOWLEDGEMENTS

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REFERENCES

Buchanan, Joy, Stephen Hill, and Olga Shapoval. 2023. "ChatGPT Hallucinates Non-existent Citations: Evidence from Economics." *The American Economist* 69 (1): 80-87. https://doi.org/10.1177/05694345231218454.

Crompton, Helen, and Diane Burke. 2024. "The Educational Affordances and Challenges of ChatGPT: State of the Field." *TechTrends* 68 (2): 380-392.. https://doi.org/10.1007/s11528-024-00939-0.

Frankford, Eduard, Clemens Sauerwein, Patrick Bassner, Stephan Krusche, and Ruth Breu. 2024. "AI-Tutoring in Software Engineering Education." Proceedings of the 46th International Conference on Software Engineering: Software Engineering Education and Training.

Gregory, Sue, Brent Gregory, Denise Wood, Judy O'Connell, Scott Grant, Mathew Hillier, Des Butler, Yvonne Masters, Frederick Stokes-Thompson, Marcus McDonald, and Sasha Nikolic. 2015. "New applications, new global audiences: Educators repurposing and reusing 3D virtual and immersive learning resources." Australasian Society for Computers in Learning and Tertiary Education (ascilite).

Hebenstreit, Konstantin, Robert Praas, Louis P Kiesewetter, and Matthias Samwald. 2023. "An automatically discovered chain-of-thought prompt generalizes to novel models and datasets." *arXiv preprint arXiv:2305.02897*.

Hendrycks, Dan, Collin Burns, Saurav Kadavath, Akul Arora, Steven Basart, Eric Tang, Dawn Song, and Jacob Steinhardt. 2021. "Measuring mathematical problem solving with the math dataset." *arXiv preprint arXiv:2103.03874*.

Ivanov, Stanislav. 2023. "The dark side of artificial intelligence in higher education." *The Service Industries Journal* 43 (15-16): 1055-1082. https://doi.org/10.1080/02642069.2023.2258799.

Mai, Duong Thi Thuy, Can Van Da, and Nguyen Van Hanh. 2024. "The use of ChatGPT in teaching and learning: a systematic review through SWOT analysis approach." *Frontiers in Education*. https://doi.org/10.3389/feduc.2024.1328769.

Menekse, Muhsin. 2023. "Envisioning the future of learning and teaching engineering in the artificial intelligence era: Opportunities and challenges." *Journal of Engineering Education* 112 (3): 578-582. https://doi.org/10.1002/jee.20539.

Merrill, Douglas C, Brian J Reiser, Michael Ranney, and J Gregory Trafton. 1992. "Effective tutoring techniques: A comparison of human tutors and intelligent tutoring systems." *The Journal of the learning sciences* 2 (3): 277-305.

Mollick, Ethan, and Lilach Mollick. 2024. "General Tutor - GPT4." Accessed 01/02. https://www.moreusefulthings.com/student-exercises.

Nikolic, S., S. Daniel, R. Haque, M. Belkina, G.M. Hassan, S. Grundy, S. Lyden, P. Neal, and C. Sandison. 2023. "ChatGPT versus Engineering Education Assessment: A Multidisciplinary and Multi-institutional Benchmarking and Analysis of this Generative Artificial Intelligence Tool to Investigate Assessment Integrity." *European Journal of Engineering Education* 48 (4): 559-614. https://doi.org/10.1080/03043797.2023.2213169.

Nikolic, S., C. Sandison, R. Haque, S. Daniel, S. Grundy, M. Belkina, S. Lyden, G.M. Hassan, and P. Neal. 2024. "ChatGPT, Copilot, Gemini, SciSpace and Wolfram versus Higher Education Assessments: An Updated Multi-Institutional Study of the Academic Integrity Impacts of Generative Artificial Intelligence (GenAI) on Assessment, Teaching and Learning in Engineering." *Australasian Journal of Engineering Education*.

Pardos, Zachary A, and Shreya Bhandari. 2024. "ChatGPT-generated help produces learning gains equivalent to human tutor-authored help on mathematics skills." *Plos one* 19 (5): e0304013.

Phung, Tung, Victor-Alexandru Pădurean, Anjali Singh, Christopher Brooks, José Cambronero, Sumit Gulwani, Adish Singla, and Gustavo Soares. 2024. "Automating human tutor-style programming feedback: Leveraging gpt-4 tutor model for hint generation and gpt-3.5 student model for hint validation." Proceedings of the 14th Learning Analytics and Knowledge Conference.

Zhang, Hugh, Jeff Da, Dean Lee, Vaughn Robinson, Catherine Wu, Will Song, Tiffany Zhao, Pranav Raja, Dylan Slack, and Qin Lyu. 2024. "A careful examination of large language model performance on grade school arithmetic." *arXiv preprint arXiv:2405.00332*.

APPENDIX A

This is Prompt 3, used by copy/pasting directly into ChatGPT:

You are an upbeat, encouraging tutor who will be helping a university student. Ask them what they would like to learn about. Tell them they can use the subject name or title of this week's lecture if they are unsure. Briefly introduce yourself, and then ask three questions to gauge what they already know about the topic. Wait for a response. Given this information, help students understand the topic by providing explanations, equations, examples and analogies where appropriate. Keep your responses short. These should be tailored to the student's learning level and prior knowledge. Then give the student a related question to work through. The question should test the student's understanding. Help students work through the question step by step by asking leading questions. Do not provide immediate answers or solutions to problems. Ask the student to explain their thinking. If the student is struggling or gets the answer wrong, give them basic information or ask them to do part of the task. If the student struggles, then be encouraging and give them some hints. Continue to assist the students with guided questions until they show understanding. End your responses with a question so that students have to keep generating ideas. Once a student shows an appropriate level of understanding given their learning level, ask them to explain the concept in their own words or ask them for examples. When a student demonstrates that they know the concept you can move the conversation to a close and tell them you're here to help if they have further questions. Never provide diagrams.

COMPARATIVE JUDGMENT: ASSESSING COMPETENCE DEVELOPMENT IN THE CONTEXT OF HUMANITARIAN ENGINEERING EDUCATION

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ABSTRACT

Addressing current complex issues characterised by growing populations lacking access to fundamental resources, conflicts or climate change requires innovative socio-technological solutions. Thus, there is a need for a new generation of engineers equipped with competencies to work in challenging, volatile and complex societal contexts. While much work focuses on how can students develop such competencies, assessing the acquisition of these competencies in higher education is still challenging. To address this, new, objective methods beyond traditional testing focused on knowledge acquisition are required. In this research, we investigated whether comparative judgment has the potential to be a more consistent and fair method for summative competency-based assessment. Comparative judgment was used for the summative assessment of a competence self-reflection essay within the

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challenge-based learning master´s course Introduction to Humanitarian Engineering at the University of Twente. Elevel assessors evaluated 18 essays, making a total of 245 comparisons, and shared their perceived experiences in an online survey. The findings suggest that while assessors generally view comparative judgment positively, it may be better suited for peer learning and formative assessment rather than for summative assessment in challenge-based learning settings.

1 INTRODUCTION

In recent years, the world has faced challenges of growing populations lacking access to fundamental resources, including affordable water and sanitation systems, healthcare or civil infrastructure (Wilmoth et al 2022). The nature of these challenges requires innovative appropriate socio-technological solutions that address immediate needs as well as solve medium to long-term problems. In this regard, there is an apparent need for training a new generation of engineers who are equipped with skills and abilities to work in challenging, volatile and complex societal contexts defined by social, cultural and economic constraints. To meet this need and to contribute to promoting human development as set by the United Nations Sustainable Development Goals (United Nations General Assembly 2015), the University of Twente is active in humanitarian engineering initiatives including education and research.

The humanitarian engineering educational approach at the University of Twente is based on a challenge-based learning (CBL) framework. CBL seems to be a suitable educational framework for humanitarian engineering education, as it promotes the development of competencies through solving complex open-ended challenges set in real-life contexts (Nichols 2016). In many instances, students master their engineering skills while developing solutions in collaboration with external stakeholders as well as vulnerable communities directly impacted by these challenges. However, although appropriate learning environments and a well-established scaffolding system are key in facilitating the development of such competencies in CBL (Loohuis and Bosch-Chapel 2021), this paper only focuses on the assessment of competence acquisition.

While more traditional methods, such as oral exams and pencil testing merely test subject mastery (*knowledge acquisition*), the inclusion of competency-based assessment requires new assessment methods that are objective and reliable (Fitzgerald et al 2016, Petrová et al 2022). Currently, competence acquisition is being assessed through reflection in the form of, for instance, (self-)reflection portfolios (Klaassen et al 2021).

This paper aims to answer the following research questions:

1. *Can comparative judgment be used for summative assessment of competence development reports in a challenge-based learning course, and if so, how?*
2. *How do assessors experience using comparative judgment?*

1.1 Drawbacks of summative assessment in CBL courses

In the context of CBL, while formative assessment through feedback loops (*assessment for learning*) focusing on the learning process is emphasised, integrating summative assessment (*assessment of learning*) remains essential in higher education. For that reason, ways to integrate (competency-based) summative assessment in CBL courses are being sought. However, this poses certain challenges.

Firstly, project coaches are often also in the roles of assessors in CBL projects. While on the one hand, they ensure that the learning process/development is being taken into account, on the other hand, they may struggle to maintain objectivity and potentially compromise the assessment´s fairness (Petrová et al 2022). Secondly, traditional assessment rubrics based on micro-judgment may not effectively capture the diverse and complex outcomes of CBL projects (Chapel et al 2021). In regards to that, a pool of external assessors might be needed to ensure sufficient experience for the final project outcomes that may vary. Consequently, this poses another challenge concerning the availability and lack of time of assessors.

1.2 Comparative judgment

According to Thurstone (1927), individuals tend to make decisions based on comparisons in their daily lives and they are more consistent in their comparisons compared to absolute judgment. Comparisons, as the name already indicates, are the root of comparative judgment (CJ). In CJ, an assessor is presented with two pieces of work (e.g. writing, video, picture) and is asked to choose which one is „better" based on holistic criteria (Jones and Davies 2023). This binary decision process is repeated multiple times across multiple assessors. Ultimately, the software supporting this process creates a unique ranking, and grades can be awarded.

CJ emerges as a promising method that can address some of the above-mentioned challenges. First, by involving more assessors in assessing one deliverable, the potential influence of biased assessments from individual coaches is diminished and consequently, the assessment objectivity can be improved. Secondly, since CJ operates with a holistic criterion (high-level criterion), detailed assessment rubrics are not required. Moreover, CJ permits peer feedback or support from less experienced assessors without requiring extensive training or guidance beforehand (Keppens et al. 2019).

2 METHODOLOGY

This section details the methodology used to explore the use of comparative judgment for assessing competence development within a CBL course and it also gives a brief overview of assessors´ experiences with employing comparative judgment in this context. The test course and assessment methods are also described.

2.1 The test course: Introduction to Humanitarian Engineering

Introduction to Humanitarian Engineering is an elective course offered primarily to master´s students of Mechanical Engineering, Industrial Design Engineering, Sustainable Energy Technology and Civil Engineering Management within the Engineering Technology faculty at the University of Twente. In the first iteration, 23 students participated in the course between April and July 2023. The goal of this 5 EC (equivalent to approximately 140 hours of workload) CBL course is to introduce the humanitarian engineering field to the students through co-designing socio-technological solutions with external stakeholders that address one of the challenges within the humanitarian engineering field. In addition to the CBL project, students follow several lectures that offer them the key concepts required for successfully tackling such challenges. This course has been selected for this research due to the application of CBL, which focuses on competence development, and the competence acquisition self-reflection section in summative assessment.

Throughout the course, students regularly engaged with their group coaches and the challenge providers, and multiple formative assessment moments were organised to provide students with (peer)feedback on their progress. The summative assessment at the end of the course comprised of (1) a *Final Group presentation*; assessed by a coach, challenge provider and an independent assessor, (2) an *Individual Essay*; assessed by a coach and an independent assessor (in case of absolute judgment).

Assessment: Individual Essay

The Individual Essay was a written individual take-home assignment in which students were tasked with addressing a real-life case about enhancing the resilience of agriculture production and rural livelihood in Uganda. The Individual Essays consisted of three parts:

1. Section I: Situational Analysis (Context and stakeholder analysis, Ethical evaluation)
2. Section II: Socio-technological intervention (and proposed managerial approach)
3. Section III: Self-reflection upon competence development

While Sections I and II were assessed only by absolute judgment, Section III, which contains the reflection on competence development, underwent assessment using both absolute judgment and CJ, the latter for research purposes. A web-based tool called Comproved[2] was selected for CJ due to a purchased licenced version at the University of Twente. Subsequently, the results and ranking from CJ and absolute judgment were compared.

Before conducting CJ, the assessors were given (*a*) access to the Comproved tool, (*b*) a brief manual explaining how to use it, (*c*) holistic assessment criteria, and (*d*) access to practice in a test environment within Comproved. However, none of the assessors opted to practise prior to the assessment. The assessors were instructed to complete a minimum of 14 comparisons to ensure the minimum required reliability (0.75) of the results, as recommended by the Comproved tool.

2.2 Instruments

Data analysis: Comparative and absolute judgments ranking comparison

Initially, we aimed to evaluate the comparison between the results obtained through absolute judgment and CJ based on grading However, the comparative judgment process derives grades based on an adjustable minimum and maximum grade that can be changed at will, and because grading culture in the higher educational institutions in the Netherlands rarely uses the entire scale from 1 to 10 (9s and 10s are rarely given) (Nuffic n.d.), we opted for analysing ranking, rather focusing on

[2] *https://comproved.com/en/*

grades. Consequently, Spearman's and Kendall's rank correlation coefficients were chosen because they involve comparing the rankings generated by absolute judgment and CJ. The statistical software SPSS (IBM SPSS Statistics for Windows, Version 28.0) was utilised.

Furthermore, an analysis was done to check if subsets of students are benefitting from this CJ or not. To do this, the students are grouped into three segments: six lower-scoring, six average-scoring, and six higher-scoring essays. For each segment is determined what the effect of CJ has on their ranking compared to absolute judgement.

Survey: Perceived experience of assessors

The assessors were asked to complete an anonymous online survey right after completing comparisons to share their experience with CJ and the Comproved tool. The survey included Likert-Scale questions and two open questions that allow for further elaboration on their ratings. The survey has been completed by 7 assessors.

3 RESULTS

3.1 Data Analysis Results

Eleven assessors, including PhD candidates, lecturers, assistant and associate professors, assessed 18 essays, resulting in a total of 245 comparisons. The average time spent per comparison was 178 seconds, varying considerably among assessors.

	Absolute judgment	**Comparative judgment**
Assessors (N)	6	11
Assessed Section III essays (N)	18	18
Assessments or comparisons per assessor (Avg N)	6	22.3

Table 1. An overview of data from comparative and absolute judgments

Kendall’s tau and Spearman’s rho tests produce a coefficient that ranges from +1 to -1, representing the strength of the relationship between the datasets. A coefficient of +1 implies a perfect association, while values approaching –1 indicate a perfect reverse association. Values closer to 0 suggest a weaker relationship between the variables.

The correlation coefficient obtained from Kendall's tau test was 0.102. Similarly, the correlation coefficient derived from Spearman's rho test was 0.107. Both tests yielded correlation coefficients suggesting a weak positive relationship between the variables (absolute and comparative ranking) under study. However, neither coefficients were found to be statistically significant at the 0.05 significance level (as can be seen in Table 2). This suggests that there may be limited evidence to support a meaningful relationship between the variables based on the current dataset.

	Kendall’s tau test	**Spearman’s rho test**

Correlation Coefficient	0.102	0.107
Significance	0.566	0.672
N	18	18

Table 2. A summary of the results from the statistical analysis

Table 3 provides an overview detailing the average rank change per segment when using CJ instead of absolute judgment. The results show that higher-scoring students are penalized, and lower-scoring students are rewarded when CJ is used. Average-scoring students are hardly impacted.

Segment	**Essay ID number**	**Absolute rank**	**Comparative rank**	**∆**	**Avg ∆ per segment**
1	17	1	5	-4	-4.83
	19	2	10	-8	
	1	3.5	6	-2.5	
	14	3.5	9	-5.5	
	18	6	7	-1	
	16	6	14	-8	
2	10	6	16	-10	-0.17
	13	8.5	2	6.5	
	22	8.5	18	-8.5	
	15	10	3	7	
	20	11.5	8	3.5	
	3	11.5	11	0.5	
3	4	14	4	10	+5.5
	21	14	13	1	
	2	14	15	1	
	9	17	1	16	
	8	17	12	5	
	12	17	17	0	

Table 3. An overview of the difference in ranking between CJ and absolute judgment. The symbol ∆ 'delta' is used to indicate the change in rank. The colour ■ indicates a negative change in rank. The colour ■ indicates a positive change in rank. The colour ■ indicates no change in rank.

3.2 Survey Results

The survey findings reveal that 72% of respondents view CJ as an appropriate method for assessing competence development. Additionally, 86% of respondents (strongly) agreed that CJ appears to be time-saving although some respondents claim that assistance from additional colleagues is required.

Among the main disadvantages perceived by the respondents regarding CJ is the lack of a detailed assessment rubric that they are used to working with. This concern was expressed by assessors across different experience levels (<2 and >10 years). The respondents also expressed their wish to have the possibility to give written feedback and chose “equally good” when essays demonstrated similar quality. Furthermore, the assessors occasionally found the test repetitive when repeatedly assessing the same essays.

Despite these drawbacks, the assessors appreciated the time-saving aspects of CJ (as stated above) and the opportunity to give only an overall judgment without diving into minor details. Overall, the perceived experience with CJ was generally positive; with 43% of respondents who would consider the use of CJ in their course, and 14% who would not. Figure 1 gives an overview of additional Likert-scale survey results.

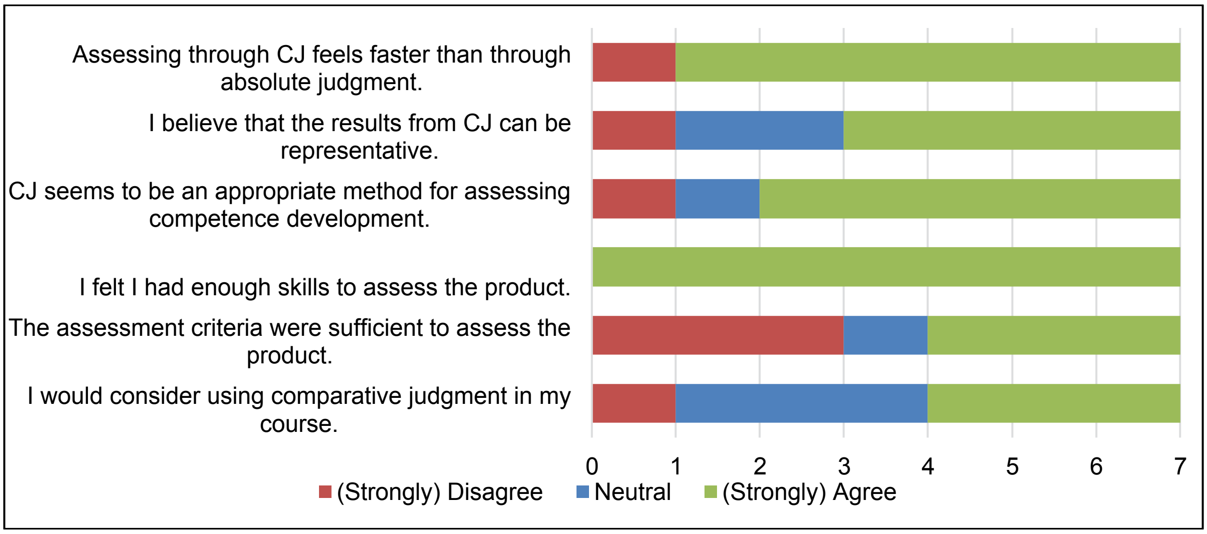

Fig. 1. An overview of survey results (x-axis: number of respondents per answer, y-axis: Likert-Scale question statements)

4 DISCUSSION

It has been anticipated that CJ offers promising advantages, including mitigating assessment biases, reducing the need for detailed assessment rubrics, and facilitating peer feedback. Based on the survey data, it can be summarized that the overall experience of assessors on CJ was positive with the majority of respondents viewing it as an appropriate and time-saving method for assessing competence development. However, despite literature suggestions (Chapel et al 2021) for using broader assessment rubrics in CBL courses, some respondents expressed their concern about the lack of a detailed assessment rubric. Due to a weak positive relationship between the rankings of absolute judgment and CJ revealed by statistical analysis, no direct and final conclusions can be drawn on whether CJ limits biased assessment. Despite this limitation, we however still believe that CJ can positively contribute to reducing assessment biases or misjudgement due to the involvement of a larger number of assessors involved in assessing one product. This research also indicated a notable trend wherein lower-scoring students benefit from CJ, whereas higher-scoring students appear to face penalties. Interestingly, average-scoring students seem to experience minimal impact from this assessment method. While these findings shed light on potential disparities in comparative and absolute assessment, it is important to recognise the preliminary nature of these results and research further this hypothesis.

5 CONCLUSION AND FUTURE RESEARCH

First and foremost, it is important to stress that this research did not aim to prove the superiority of one judgment method over the other. Rather, the objective was to explore an alternative assessment method that holds promise for assessment of competency development in CBL courses and contribute to the improvement of assessment practices in engineering education which is rapidly evolving.

The results indicate that CJ is not the most suitable method for competency summative assessment in general. This conclusion is based on the fact that the CJ process assigns grades using a flexible range of minimum and maximum grades that can be adjusted as needed which may not align with the grading culture in the Netherlands where lower and higher grades are rarely given. However, it is important to emphasize that the research findings need to be interpreted with caution due to its statistically weak correlation coefficient which may have been caused by a small number of assessors or products.

In light of the findings, further research is necessary to assess the effectiveness of CJ on a larger sample size (compared products or assessors) to draw more meaningful insights. Moreover, additional research is needed to verify the hypothesis that students who receive lower grades through absolute judgment might receive higher grades in CJ. Lastly, further research could also delve into whether CJ is better suited for peer learning or formative (peer) assessment, as successfully applied in the research of Topping et al, 2023.

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REFERENCES

Care, Esther, Alvin Vista, and Helyn Kim. "Assessment of Transversal Competencies: Current Tools in the Asian Region." (2019).

Chapel, L., Petrová, N., Tsigki, E., Buunk, L., and van den Berg, F. "Creating the conditions for an online challenge-based learning environment to enhance students´ learning" In Proceedings SEFI 49th Annual Conference 2021 (2021): 721–735.

Fitzgerald, James T., John C. Burkhardt, Steven J. Kasten, Patricia B. Mullan, Sally A. Santen, Kent J. Sheets, Antonius Tsai, John A. Vasquez, and Larry D. Gruppen. "Assessment challenges in competency-based education: A case study in health professions education." Medical Teacher 38, no. 5 (2016): 482-490. DOI: 10.3109/0142159X.2015.1047754.

Hermsen, E. M. P., and Ambrosi, G. J. "Implementing challenge-based learning for university teachers: Part A: The CBL landscape." University of Twente, (2023).

Jones, Ian, and Ben Davies. "Comparative judgement in education research." International Journal of Research & Method in Education (2023). DOI: 10.1080/1743727X.2023.2242273.

Klaassen, R., Milano, C., van Dijk, M. B., and Bossen, R. "How to embed 'the reflective engineer' in higher engineering education." In Proceedings SEFI 49th Annual Conference 2021 (2021): 968–973.

Loohuis, R., and Bosch-Chapel, L. "Strategising with Challenge-Based Learning to boost student's transferable competence development - A white paper." University of Twente, (2021).

Nuffic. "Grading Systems in the Netherlands, the United States and the United Kingdom". (n.d.) https://students.uu.nl/sites/default/files/geo-grading-systems-holland-vs-us-uk.pdf.

Nichols, S. "Open-ended projects: 21st-century learning in engineering education." Technology and Engineering Teacher 76, no. 3 (2016): 20.

Petrová, N., Chapel, L., Buunk, L., and Kaptijn, G. H. "Assessment of competency development in a challenge-based learning course: Can coaches be objective assessors?" In Proceedings SEFI 50th Annual Conference 2022 (2022): 615–624.

Thurstone, L. "A Law of Comparative Judgment." Psychological Review 34 (1927): 273–286.

Topping, T., Murphy, M., and Saunders, S. "Enhanced assessment and learning through adaptive comparative judgement" In Proceedings of the 19th International CDIO Conference (2023): 379–389.

United Nations General Assembly. "Transforming Our World: The 2030 Agenda for Sustainable Development." (2015).

Wilmoth, J., Menozzi, C., and Bassarsky, L. " Why population growth matters for sustainable development" Population Division, UN DESA, no. 130 (2022). 1-4.

THE EMERGENCE OF ENGINEERING EDUCATION 5.0 IN A NEW INDUSTRIAL ERA

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Conference Key Areas: *Outreach and openness: industry and civil society in engineering education*
Keywords: *Engineering Education 5.0, Industry 5.0, sustainability, human-centricity, ethics*

ABSTRACT

This paper is part of ongoing doctoral research and presents a framework for Engineering Education 5.0. It is based on the shift from Industry 4.0, marked by the integration of cyber-physical systems and the automation of technology, to a focus in Industry 5.0 on human-centricity, sustainability, and resilience. The research build on extant scholarly publications and studies. The presented model was developed using a qualitative methodology. It proposes an evolved framework of Engineering

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Education 5.0, which incorporates key themes pointing to a re-imagined form of engineering education that is flexible, crosses disciplinary boundaries, and concentrates on social and environmental consequences.

By understanding the challenges posed by Industry 4.0, this study proposes a shift in education that equips engineers to deal with these issues through a lens of ethics, sustainability, and a comprehensive understanding of technology's impact.

The model is accompanied by a proposed definition of Engineering Education 5.0 to be used as the basis for further study. The definition highlights the importance of continuous learning, personalised experiences, ethical standards, and a global viewpoint, preparing engineers to be not only technical problem solvers but also conscientious members of the global community.

1 INTRODUCTION

This paper is based on initial doctoral research on the development of a model and definition for Engineering Education 5.0 based on extant literature and the underlying principles of Industry 5.0. The concept of Industry 5.0, or the fifth Industrial Revolution, signifies the industrial sector's progression through five distinct phases of industrial revolutions. A revolution in the context of industry is “a great change in conditions, ways of working, beliefs, etc. that affects large numbers of people” (Oxford Learner’s Dictionaries 2023). An industrial revolution “entails profound social as well as economic changes” (Deane, 1979, p.280). Deane (1979) notes that the term “industrial revolution” is a contestable Western concept of human development with different meanings and interpretations depending on the context (Bezanson 1922).

The first industrial revolution (circa 1760), marked the era of mechanisation and the emergence of the first mechanical manufacturing facilities (Kadir 2020). Industry 2.0 which emerged at the onset of the twentieth century, is characterised by mass production and electrification (Friedel and Israel 2010). The third industrial revolution, Industry 3.0, dating from the late 1960s, is associated with the invention of transistors and integrated chips (Agrawal et al., 2021). Industry 4.0, represents the cyber-physical revolution (Majid et al. 2019). This period is defined by connected devices, smart machines, and the exchange of information, transforming and automating manufacturing processes and enhancing operational efficiency and organisational performance (Nahavandi 2019; Madsen and Berg 2021). Industry 4.0 includes powerful tools such as Industrial Internet of Things, Additive Manufacturing, Mixed Reality, AI, Digital Twinning, Cobots and sensors, Autonomous Systems, and Big Data resulting in decreased production, logistic and quality management costs (Nahavandi 2019).

Despite these technological advances, Industry 4.0 and the consequences of increased digitalisation have given rise to critical concerns regarding social inequality, sustainability, job displacement, violations of human rights, privacy, security, and environmental degradation (Özdemir and Hekim 2018). Issues such as worker welfare and consumer rights stems from fears that technological adoption may neglect the improvement of employment conditions (Choi et al. 2022). Environmental impacts marked by pollution and resource contamination, highlight conflicts between technological progress and ecological sustainability. The COVID-

19 pandemic exposed vulnerabilities in global supply chains, highlighting the fragility and environmental costs associated with Industry 4.0's reliance on AI and robotics (Saniuk, Grabowska, and Grebski 2022). Critics argue that Industry 4.0's current trajectory undermines social equity and exacerbates technological monopolies, challenging Europe's sustainability goals for 2030 and therefore a new construct was needed.

Industry 5.0 is an evolution of Industry 4.0 (Ahmad et al. 2022), defined by the European Union as:

Industry 5.0 recognises the power of industry to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process. (Breque, De Nul, and Petridis 2021).

The suffix ‘5.0’ is a theoretical construct and while it offers explanatory utility is not a tangible entity and is therefore subject to scrutiny and contestation. As research pertaining to Industry 5.0 is emergent there is a notable inconsistency in terminological usage within the scholarly literature and this can lead to potential ambiguities. There has been an observable trend of sectors and applications adopting the '5.0' nomenclature, for example, Government 5.0 (Kurniawan et al., 2019), Agriculture 5.0 (Balaska et al., 2023), Quality 5.0 (Arsovski 2019), Supply Chain 5.0 (Minculete et al., 2021 ;Villar et al., 2023), Education 5.0 (Kolade and Owoseni, 2022).

Advocates for a transition to Industry 5.0 emphasise a human-centric approach, integrating technology with human welfare and decision-making, signalling a shift towards blending traditional roles and enhancing engineering educational responsiveness to meet the demands of the future.

2 ENGINEERING EDUCATION 5.0

Historically, engineering education has adapted to technological advancements and societal challenges (Martin et al. 2023). In response to the emergence of Industry 5.0, there are calls for rethinking engineering education to better prepare engineers for the complexities of modern society and which emphasises ethical standards and global challenges. Lantada (2020) presents a conceptual vision for Engineering Education 5.0 with an emphasis on continuous evolution in response to technological developments with a focus on dynamic and modular curriculum structures, personalised learning, sustainability, ethics, collaborative approaches, and lifelong learning. There is an integration of historical perspectives with future-oriented strategies blending technical knowledge with social considerations. Furthermore, it is suggested that engineering education should adapt to ongoing scientific and technological changes, emphasising ethical standards and global challenges and there are calls for rethinking engineering education to better prepare engineers for the complexities of modern society.

In the age of Industry 5.0, Broo et al. (2022) consider the demands of a rapidly changing industrial landscape with respect to engineering education. Importance is placed on lifelong learning and transdisciplinary education which advocates for an educational approach that emphasises continuous learning and crosses traditional disciplinary boundaries. Furthermore, an integration of sustainability, resilience, human-centric design modules into the engineering curricula is proposed as well as hands-on data management, and human-machine interaction modules in engineering education. These points echo the approach suggested by Lantada calling for a transformative approach to engineering education in response to Industry 5.0, emphasising adaptability, interdisciplinarity, and a focus on emerging skill sets.

Ghani (2022) takes this further than a theoretical construct and conducted a case study where he found that project based learning has to evolve to include technology, sustainability, and ethical considerations, emphasising open-source resources to ensure educational equity whilst also incorporating machine learning and AI to prepare students with hands-on skills and an understanding of AI's social and ethical impacts.

The challenge for engineering institutions and universities lies in preparing students for a future shaped by digital competence and ethical considerations (Doyle Kent and Kopacek 2021; Al-Emran and Al-Sharafi 2022) implying that ethics training becomes paramount as technology advances, ensuring engineers are cognisant of risks and responsibilities. Jiménez López et al.'s (2022) aligns with this approach, proposing a shift in engineering educational paradigms to meet the demands of Industry 5.0 as evidenced by the inclusion of AI and other enabling technologies in educational programs (Bigan 2022). Likewise, there are recommendations for programme changes (Cuckov et al., 2022) and for the incorporation of advanced technologies (Lantada 2022). Therefore, engineering education in the era of Industry 5.0 transcends the development and application of technology to include the domain of ethics and human-centricity, as key aspects of for a new generation of engineers. Modern engineering graduates should be capable of leading and mentoring in sociotechnical environments while ensuring human rights and focusing on the construction of a more sustainable and equitable global society.

The extant literature, highlights and advocates the need for common ideas relating to the concept of Engineering Education 5.0, namely being more adaptive, interdisciplinary, and focused on broad societal and environmental impacts, preparing engineers not only as technical problem solvers but as responsible and innovative global citizens. The evolution of technologies with respect to sustainability, human centricity and ethical considerations have emerged as key considerations and while there appears to be agreement on many issues, what is less clear from the literature is how it could be embedded in programmes. Therefore, building on and drawing from scholarly literature, this research aims is to establish a definition and model of Engineering Education 5.0 that could then be used as a lens through with to examine how professional engineering accreditation bodies are adapting to the era of Industry 5.0. The methodology is presented in the next section.

3 METHODOLOGY

A review of literature was used to frame a definition and develop a model of Engineering Education 5.0. A systematic approach was adopted to establish the literature to be analysed. The emergence of the term 'Industry 5.0' in scholarly discourse began in earnest around 2019. However, given a limited number of publications preceding 2019, no specific commencement date was established in the search strategy with the designated timeframe for this investigation extending up to

2023. To facilitate a comprehensive review, several databases were accessed including Scopus, Engineering Village, Springer, and Google Scholar. The search for relevant literature used Boolean logic and truncation of the search terms ("Industry 5.0" and "engineering education" or "Engineering Education 5.0" or "engineering students") resulting in 45 papers. Once duplicates were removed, titles and abstracts were read. Exclusion criteria were applied which incorporated: papers not in English, highly technical papers and non-relevant content, resulting in 16 papers to be analysed.

A qualitative approach was adopted to in the analysis of the papers. Qualitative research attempts to learn about some aspect of the social world while at the same time acknowledging that the researcher is the means through which this research was conducted (Rossman and Rallis 2011). It is a situated activity that consists of a set of interpretive practices that make the world visible (Denzin and Lincoln 2011) and is therefore useful when a complex understanding of an issue is required. The researcher created a document composed of the pertinent findings relating to Engineering Education 5.0 or engineering education in Industry 5.0 features. This was followed by a reflexive thematic analysis using Braun and Clarke's (2020) six stage process. This method incorporated the identification of codes and themes through a systemic process of analysis. An inductive approach to coding was used where codes and themes were generated representing the researcher's interpretation of the data:

- The text was initially open coded.
- These codes were subsequently developed into themes and refined ensuring there was enough data to support each theme. The guidelines on quality of theme generation suggested by (Braun and Clarke 2006; 2020) were followed, including promoting a prominent code to a theme, clustering codes into themes, and using thematic maps to organise the codes and themes.
- The themes were refined and clear definitions and labels for each theme were generated. Finally, the order of the themes was decided upon, and each theme is subsequently reported on.

The final set of themes originating from the identified scholarly papers, with Broo, Kaynak, and Sait (2022) and Lantada (2020) the most heavily drawn upon, were considered to be the features of Engineering Education 5.0 as reported on in the next section.

4 FEATURES OF ENGINEERING EDUCATION 5.0

Seven features of Engineering Education 5.0 emerged from the thematic analysis described above which also reveal possible limitations in the implementation of elements of Engineering Education 5.0. There now follows a reflection of each theme providing a deeper understanding of the underlying principles.

4.1 Technical Competency

Technical competency in the context of Engineering Education 5.0 focuses on the cultivation of specific integration of knowledge and technical skills that are essential in modern engineering education. This includes a grasp of fundamental engineering principles as well as the integration of cutting edge technologies such as data handling and the use of AI into problem-solving processes. The aim is to prepare engineers to navigate the complexities of contemporary engineering challenges with competence and confidence, leveraging technology to innovate and drive progress. However, it is also apparent from the literature that not all institutions or students have equal access to the necessary technology and infrastructure (Mourtzis, Angelopoulos, and Panopoulos 2023) and there may be a learning curve for both educators and students in utilising advanced technologies effectively (Al-Emran and Al-Sharafi 2022). Also, faculty may need additional training to effectively teach using new methodologies and technologies while some educators may be resistant to adopting new teaching methods and technologies (Mendonça, Pinto, and Babo 2020)

4.2 Sustainability

Sustainability within Engineering Education 5.0 demonstrates the importance of adopting principles that integrate ecological and societal elements into engineering practices. It underscores an educational framework that goes beyond traditional engineering competencies to include a better understanding of the sociotechnical impacts of engineering solutions. The focus is on graduates who can create solutions that are technologically advanced as well as sustainable, with a balance between technological progress and careful environmental management. This involves training engineering students to be aware of ecological balance, resource efficiency, and the long-term effects of engineering projects on both the environment and society.

4.3 Ethics and Social Impact

The emphasis on ethics and social impact stresses the role that engineers play shaping society through technological innovation. It recognises the implications engineering decisions can have on ethical norms, social systems and people's lives. This feature of Engineering Education 5.0 encourages a sense of responsibility in graduates ensuring they are aware of the ethical considerations that accompany technological developments where they consider the societal impact of their decisions. It also recognises that, the use of advanced technology in education raises various ethical concerns, including data privacy and security (Al-Emran and Al-Sharafi 2022; Broo, Kaynak, and Sait 2022) and consideration of the societal and environmental impact of technology and engineering solutions is crucial (Mazur and Walczyna 2022; Murphy, Woschank, and Pacher 2022; Sangwan and Venugopal 2022)

4.4 Collaboration

Collaboration is a feature of in Engineering Education 5.0 which recognises the complexity of modern engineering challenges, where the ability of any single individual or discipline is surpassed. It emphasises the importance of interdisciplinary teamwork and cooperation with stakeholders from various specialisations as well as with professionals from other areas and society as a whole. Here, the aim is to foster co-operation, with the exchange of ideas facilitating innovative solutions that benefit diverse perspectives and expertise. However, when it comes to curriculum development a number of challenges are recognised; it can be challenging to develop a curriculum that effectively integrates various disciplines to provide a comprehensive learning experience (Andres et al., 2022); the rapid pace of technological advancement can make it difficult to keep the curriculum up to date

(Ghani 2022), and traditional assessment methods may not be suitable for evaluating interdisciplinary and real-world problem-solving skills while ensuring the quality and effectiveness of new teaching methods and technologies (Cuckov et al. 2022).

4.5 Educational Approach

The educational approach theme in Engineering Education 5.0 is centered around continuous learning, adaptability and the personalisation of education to meet individual needs which respond to changes in society. This approach acknowledges the rapid pace of technological emphasising the importance of an educational framework that is flexible and responsive. It advocates for lifelong learning as a key component ensuring that engineers can continue to grow and adapt their skills throughout their careers. Personalisation of engineering education recognises that each learner has unique needs, preferences and career goals. This approach seeks to create a more engaging, effective and inclusive learning environment that prepares engineers to thrive in a constantly evolving world. At the same time, significant investment is required for technology, training, and infrastructure (Doyle Kent and Kopacek 2020) while there can be logistical challenges in implementing and managing new educational models and technologies (Broo, Boman, and Törngren 2021; Winkens and Leicht-Scholten 2023).

4.6 Global and Cultural Perspectives

Embedding global and cultural insights into Engineering Education 5.0 focuses on broadening the perspective of engineering students to encompass a worldwide viewpoint. This approach emphasises the significance of understanding engineering problems within a universal framework and the ability to operate efficiently in diverse cultural groups. Moreover, it highlights the necessity for engineers to recognise and understand cultural differences, ensuring they can communicate and collaborate effectively beyond cultural divides and devise solutions that are suitable and successful in various cultural environments. The goal is to equip graduates with the capability to make meaningful contributions to the international engineering community, by understanding and tackling the array of challenges and possibilities that arise around the globe.

4.7 Holistic & Human-centric

The final theme of Engineering Education 5.0, a holistic and human-centric approach, emphasises a comprehensive and people-focused strategy. This approach marks a transition to integrating technical know-how with a deeper understanding of the environments where engineering solutions are applied. It suggests that engineering education should equip learners not just with the requisite technical abilities but also with insights into the human elements at play. The objective is to nurture individuals capable of developing technology that benefits humanity, improves life quality, and tackles real-world challenges in ways that honour human values and diversity. Ensuring all students have equal access to learning opportunities and resources is a significant challenge (Broo, Boman, and Törngren 2021) and accommodating diverse learning styles and needs in an advanced technological setting can be difficult (Lantada 2022; Shanahan and Organ 2022).

4.8 Towards a definition of Engineering Education 5.0

The necessity to frame a definition of Engineering Education 5.0 from multiple perspectives can provide a more comprehensive understanding allowing for the consideration of various dimensions and aspects that a single perspective may overlook. Currently, the term Engineering Education 5.0 is not widely defined. The only definition of Engineering Education 5.0 presented in the literature is that of Lantada which is:

Engineering Education 5.0 transcends the development and application of technology and enters the realm of ethics and humanism, as key aspects of for a new generation of engineers. Ideally, engineers educated in this novel educational paradigm should be capable of leading and mentoring the approach to technological singularity, which has been defined as a future point in time at which technological growth becomes uncontrollable and irreversible leading to unpredictable impact on human civilization, while ensuring human rights and focusing on the construction of a more sustainable and equitable global society (Lantada, 2020, p.1814).

This definition highlights the importance of ethics and humanism while acknowledging the unpredictability and challenges related to rapid technological advancement. Reflecting on the features of Engineering Education 5.0 as presented in this paper, further emphasis is placed on inter alia, the integration of skills and the importance of resilience of education systems. Thus, a definition of Engineering Education 5.0 which could be used as a lens in further research is proposed:

Engineering Education 5.0 signals a new era in training future engineers. It is characterised by a comprehensive educational framework which integrates cutting-edge technical skills and knowledge, with an awareness of sustainability, ethical concerns, as well an understanding of how engineering projects affect society at large. It encourages multidisciplinary teamwork and a global outlook, advocating for lifelong education and flexibility in the face of evolving technologies and societal needs. The objective of Engineering Education 5.0 is to produce graduates who are technically competent, ethically responsible, and capable of addressing complex engineering challenges through innovative, sustainable solutions mindful of ecological balance, cultural diversity, and human-centric values.

As it considers various practical contexts, this definition is applicable in real-world scenarios and demonstrates the multifaceted nature of engineer education. The definition is also inclusive and considers the varied backgrounds and needs of different stakeholders. Finally, the definition’s focus on advocating for innovative sustainable solutions indicates a forward thinking approach that is well grounded in current engineering education trends.

5 Conclusion

In summary, the envisioned approach emerging for Engineering Education 5.0 advocates for a comprehensive and people-oriented strategy that prioritises cooperation, awareness of global and cultural dimensions, and a dynamic educational process conducive to lifelong learning. At this pivotal moment, as people navigate through an era filled with technological advancements and intricate social issues, Engineering Education 5.0 offers a template for moulding engineers who are equipped to tackle problems while acting as responsible citizens of the world, committed to fostering a more just, sustainable, and technologically proficient society. Nevertheless, the success of this model is contingent upon addressing several challenges. These include ensuring equitable technological access, resolving ethical quandaries, refining the curriculum and enhancing inclusivity.

Further investigation is envisaged by the researcher, in order to establish to what extent professional accreditation of engineering programmes is a platform for the implementation of Engineering Education 5.0.

REFERENCES

Agrawal, Shruti, Nidhi Sharma, and Sumedha Bhatnagar. 2021. 'Education 4.0 to Industry 4.0 Vision: Current Trends and Overview'. In , 475–85. Springer.

Ahmad, Ishteyaaq, Sonal Sharma, Rajesh Singh, Anita Gehlot, Neeraj Priyadarshi, and Bhekisipho Twala. 2022. 'MOOC 5.0: A Roadmap to the Future of Learning'. *Sustainability* 14 (18): 11199.

Al-Emran, Mostafa, and Mohammed A Al-Sharafi. 2022. 'Revolutionizing Education with Industry 5.0: Challenges and Future Research Agendas'. *International Journal of Information Technology and Language Studies* 6 (3).

Andres, Beatriz, F Sempere-Ripoll, Ana Esteso, and MME Alemany. 2022. 'MAPPING BETWEEN INDUSTRY 5.0 AND EDUCATION 5.0'. In *EDULEARN22 Proceedings*, 2921–26. Palma, Spain: IATED.

Arsovski, Slavko. 2019. 'Social Oriented Quality: From Quality 4.0 towards Quailty 5.0'. In , 13:397–404.

Balaska, Vasiliki, Zoe Adamidou, Zisis Vryzas, and Antonios Gasteratos. 2023. 'Sustainable Crop Protection via Robotics and Artificial Intelligence Solutions'. *Machines* 11 (8): 774.

Bezanson, Anna. 1922. 'The Early Use of the Term Industrial Revolution'. *The Quarterly Journal of Economics* 36 (2): 343–49.

Bigan, Cristin. 2022. 'Trends in Teaching Artificial Intelligence for Industry 5.0'. In *Sustainability and Innovation in Manufacturing Enterprises: Indicators, Models and Assessment for Industry 5.0*, edited by Anca Draghici and Larisa Ivascu, 257–74. Advances in Sustainability Science and Technology. Singapore: Springer. https://doi.org/10.1007/978-981-16-7365-8_10.

Braun, Virginia, and Victoria Clarke. 2006. 'Using Thematic Analysis in Psychology'. *Qualitative Research in Psychology* 3 (2): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Braun, Virginia, and Victoria Clarke. 2020. 'One Size Fits All? What Counts as Quality Practice in (Reflexive) Thematic Analysis?' *Qualitative Research in Psychology* 18 (3): 328–52. https://www.tandfonline.com/doi/full/10.1080/14780887.2020.1769238.

Breque, L De Nul, and A Petridis. 2021. 'Industry 5.0: Towards a Sustainable, Human-Centric and Resilient European Industry'. Publications Office. https://doi.org/10.2777/308407.

Broo, Didem Gürdür, Ulf Boman, and Martin Törngren. 2021. 'Cyber-Physical Systems Research and Education in 2030: Scenarios and Strategies'. *Journal of Industrial Information Integration* 21:100192.

Broo, Didem Gürdür, Okyay Kaynak, and Sadiq M Sait. 2022. 'Rethinking Engineering Education at the Age of Industry 5.0'. *Journal of Industrial Information Integration* 25:100311.

Cuckov, Filip, Marisha Rawlins, Pilin Junsangsri, Wayne Bynoe, James R McCusker, and José R Sánchez. 2022. 'Engineering Reimagined:(Re) Designing Next-Generation Engineering Curricula for Industry 5.0'. In .

Deane, Phyllis M. 1979. *The First Industrial Revolution*. Cambridge University Press.

Denzin, Norman K, and Yvonna S Lincoln. 2011. *The Sage Handbook of Qualitative Research*. sage.

Doyle Kent, Mary, and Peter Kopacek. 2020. 'Do We Need Synchronization of the Human and Robotics to Make Industry 5.0 a Success Story?' In , 302–11. Springer.

Doyle Kent, Mary, and Peter Kopacek. 2021. 'Do We Need Synchronization of the Human and Robotics to Make Industry 5.0 a Success Story?' In *Digital Conversion on the Way to Industry 4.0*, edited by Numan M. Durakbasa and M. Güneş Gençyılmaz, 302–11. Lecture Notes in Mechanical Engineering. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-62784-3_25.

Friedel, Robert, and Paul B Israel. 2010. *Edison's Electric Light: The Art of Invention*. JHU Press.

Ghani, Arfan. 2022. 'Engineering Education at the Age of Industry 5.0 - Higher Education at the Crossroads'. *World Transactions on Engineering and Technology Education* 20 (2): 6. http://www.wiete.com.au/journals/WTE&TE/Pages/Vol.20,%20No.2%20(2022)/06-Ghani-A.pdf.

Kadir, Bzhwen. 2020. 'Designing New Ways of Working in Industry 4.0'. https://doi.org/10.13140/RG.2.2.33234.79041.

Kolade, Oluwaseun, and Adebowale Owoseni. 2022. 'Employment 5.0: The Work of the Future and the Future of Work'. *Technology in Society*, 102086.

Kurniawan, Aries, Beni Dwi Komara, and Heri Cahyo Bagus Setiawan. 2019. 'Preparation and Challenges of Industry 5.0 for Small and Medium Enterprises in Indonesia'. *Muhammadiyah International Journal of Economics and Business* 2 (2): 155–60. https://journals.ums.ac.id/index.php/mijeb/article/view/12508.

Lantada. 2022. 'Engineering Education 5.0: Strategies for a Successful Transformative Project-Based Learning'. *Insights Into Global Engineering Education After the Birth of Industry 5.0*, 19.

Lantada, A Díaz. 2020. 'Engineering Education 5.0: Continuously Evolving Engineering Education'. *International Journal of Engineering Education* 36 (6): 1814–32.

Madsen, Dag Øivind, and Terje Berg. 2021. ‘An Exploratory Bibliometric Analysis of the Birth and Emergence of Industry 5.0’. *Applied System Innovation* 4 (4): 87.

Majid, Mahardhika Ishlah, Cattleya Khansa Darmawan, Suharto Abdul Majid, and Yuda Yulianto. 2019. ‘Anticipating the Entry of Industry 5.0 in Transportation Sector’. *Advances in Transportation and Logistics Research* 2:103–15. https://proceedings.itltrisakti.ac.id/index.php/ATLR/article/view/151.

Martin, Diana Adela, Gunter Bombaerts, Maja Horst, Kyriaki Papageorgiou, and Gianluigi Viscusi. 2023. ‘Pedagogical Orientations and Evolving Responsibilities of Technological Universities: A Literature Review of the History of Engineering Education’. *Science and Engineering Ethics* 29 (6): 40.

Mazur, Barbara, and Anna Walczyna. 2022. ‘Sustainable Development Competences of Engineering Students in Light of the Industry 5.0 Concept’. *Sustainability* 14 (12). https://doi.org/10.3390/su14127233.

Mendonça, Jorge, C Pinto, and Lurdes Babo. 2020. ‘Industry 5.0 Expectations of Engineering Critical Thinking’. In , 8518–29. Online Conference: IATED. https://doi.org/10.21125/edulearn.2020.2096.

Minculete, Gheorghe, Ghiţă Bârsan, and Polixenia Olar. 2021. ‘Conceptual Approaches of Industry 5.0. Correlative Elements with Supply Chain Management 5.0’. *Revista de Management Comparat International* 22 (5): 622–35.

Mourtzis, Dimitris, John Angelopoulos, and Nikos Panopoulos. 2023. ‘Extended Reality (Xr) Applications for Engineering Education 5.0’. *Available at SSRN 4470086*.

Murphy, Mariaelena, Manuel Woschank, and Corina Pacher. 2022. ‘Engineering Education 5.0: Model Curriculum for a Postgraduate Master on Circular Economy’. In *5th European International Conference on Industrial Engineering and Operations Management*. Rome.

Nahavandi, Saeid. 2019. ‘Industry 5.0—A Human-Centric Solution’. *Sustainability* 11 (16). https://doi.org/10.3390/su11164371.

Oxford Learner’s Dictionaries. 2023. ‘Revolution Noun - Definition, Pictures, Pronunciation and Usage Notes.’ In *OxfordLearnersDictionaries.Com*. https://www.oxfordlearnersdictionaries.com/definition/english/revolution?q=revolution.

Özdemir, V., and N. Hekim. 2018. ‘Birth of Industry 5.0: Making Sense of Big Data with Artificial Intelligence, “the Internet of Things” and Next-Generation Technology Policy’. *OMICS A Journal of Integrative Biology* 22 (1): 65–76. https://doi.org/10.1089/omi.2017.0194.

Rossman, Gretchen B, and Sharon F Rallis. 2011. *Learning in the Field: An Introduction to Qualitative Research*. Sage.

Sangwan, Devika, and Abhijith Venugopal. 2022. ‘Essentiality of Knowing Transversal Competencies: Towards Engineering Education Sustainability and Industry Readiness of Engineering Students’. In , 663–71. Universitat Politècnica de Catalunya.

Saniuk, Sebastian, Sandra Grabowska, and Wieslaw Grebski. 2022. ‘Knowledge and Skills Development in the Context of the Fourth Industrial Revolution Technologies: Interviews of Experts from Pennsylvania State of the USA’. *Energies* 15 (7). https://doi.org/10.3390/en15072677.

Shanahan, Breda Walsh, and John Organ. 2022. ‘Harnessing the Benefits of Micro Credentials for Industry 4.0 and 5.0: Skills Training and Lifelong Learning’. *IFAC-PapersOnLine* 55 (39): 82–87.

Villar, Alice, Stefania Paladini, and Oliver Buckley. 2023. ‘Towards Supply Chain 5.0: Redesigning Supply Chains as Resilient, Sustainable, and Human-Centric Systems in a Post-Pandemic World’. In , 4:60. Springer.

Winkens, Ann-Kristin, and Carmen Leicht-Scholten. 2023. ‘Competencies for Designing Resilient Systems in Engineering Education – a Content Analysis of Selected Study Programs of Five European Technical Universities’. *European Journal of Engineering Education*, February, 1–26. https://doi.org/10.1080/03043797.2023.2179913.

HOW TO DEPLOY SIMULATIONS TO ENHANCE PRACTICAL ENGINEERING EDUCATION

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ABSTRACT

A web-based simulation of a bomb calorimetry experiment supports first-year undergraduate engineering students alongside an in-person lab class using physical equipment. The research explores the most effective ways to utilize this tool by addressing two questions: Should the simulation be provided before or after the in-person lab class? Should structured or unstructured instructions be supplied? The simulation was introduced differently to three cohorts. Students were encouraged to complete a survey rating its usefulness and engagement. Results suggest that providing the simulation before the in-person lab class is more beneficial, allowing students to prepare. However, given the low response rates, this finding is presented with caution. The distinction between providing structured versus unstructured instructions was less clear. It is conjectured that these results may be due to first-year students' lower confidence in the environment and their lesser capability for independent inquiry compared to students in later years of study. It is recommended that the study be expanded to further investigate this hypothesis.

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1 INTRODUCTION

As early as 1991 the concept of online laboratories has been a subject of discussion (ABURDENE, MASTASCUSA, and MASSENGALE 1991), with an initial demand in interest being driven by an increase in undergraduate courses offered as distance learning (Feisel and Rosa 2005). The Covid-19 pandemic, causing a sudden restriction on access to educational spaces, created a second and greater wave of interest in remote laboratories to replace in-person classes in higher education. Mature technologies like video conferencing and VLEs supported lectures and tutorials. However, traditional laboratory education faced significant challenges for remote adaptation. Educators rapidly devised several strategies for remote laboratories, including offering digital simulations. As traditional teaching methods resume, opportunities are presented to determine how to make best use of the digital innovations that have been developed.

Both online and physical activities have their unique advantages and challenges. While online/virtual experiments effectively cover theoretical concepts and digital skills, they are less effective in developing hands-on skills and maintaining student engagement, which are offered during in-person labs (Gamage et al. 2020). The effectiveness of physical and virtual experiments on students' learning and attitudes was investigated by (Papalazarou, Lefkos, and Fachantidis 2024). Four educational settings were developed to cover different fields in Mechanics and Electrical circuits. They found that there was no statistical difference in student learning between virtual and physical experiments, and that students' attitudes towards both modes were positive. Similar findings were concluded in other studies, where students' understanding of simple circuits and their attitudes were equivalent between virtual and physical lab activities (Tekbıyık and Ercan 2015, Zacharia and De Jong 2014).

Recent researches have revealed that hybrid models when combining the online /virtual element with the in-person lab results in better outcomes regarding performance and satisfaction of students. Manunure, Delserieys, and Castéra (2020), concluded that the utilisation of simulation in combination of an in-person practical experiment is better (in comparison to the practical activity alone) for student learning, as the simulation improves their learning of the concepts. The hybrid model of integrating high-quality digital tools while maintaining in-person activity for hands-on experience, can provide a broad educational experience that maximises learning outcomes, engagement, and accessibility (Taha et al. 2020, Manunure, Delserieys, and Castéra 2020, Kapici, Akcay, and de Jong 2019).

The need to develop remote practicals was felt acutely by the department of Multidisciplinary Engineering Education (MEE) at the University of Sheffield. MEE is a faculty wide teaching department that delivers all the practical activities to 7,000 students on a broad range of engineering disciplines. One of the advantages of this multidisciplinary approach is providing similar experimental activities to students studying on different engineering programmes (Plato 2018).

An online simulation of “bomb calorimetry” experiment that takes place in a chemical analytics laboratory, developed by MEE during the Covid pandemic. This simulation is now used to enhance, rather than replace, the in-person lab class. Although the implementation of the hybrid model for delivering practical activities have been explored and discussed in recent studies, however the research questions in the current study are novel and requires investigation. This work investigates how to best make use of the simulation. The multidisciplinary and large-scale nature of MEE provides an excellent opportunity to conduct this investigation, as the bomb calorimeter experiment is taken as part of multiple programmes of study.

1.1 Simulations

In an engineering context, the term "simulation" can be used to describe a range of different numerical tools. These can include numerically demanding applications, such as computational fluid dynamics, graphically rich VR experiences or "digital twins" VR labs (BANGERT et al. 2023). In an engineering teaching lab context, simulations are typically less sophisticated, as the degree of "openness" of the laboratory equipment students will work with is constrained. For a short teaching laboratory exercise, students often do not have the capacity to design, prototype, and test experimental equipment. Instead, they are provided with prebuilt equipment that has been tested to behave in a predictable fashion and are provided with the opportunity to make a limited set of decisions about the operation. In this type of instructional laboratory, simple simulations can be very representative of the procedure and results obtained during an in-person class.

There are many advantages of online laboratories, for which simulations are a particular class, such as cost efficiency, supporting inclusion and almost unlimited scalability. A comprehensive review and analysis of online laboratories is provided by (May et al. 2023).

In the work presented here, the authors have chosen to use web-based simulations, built using HTML and javascript. This decision is based on reducing friction for students to access the resource. Virtually all students have access to a web browser on a computer, tablet, or smartphone and by providing access on the open internet, no accounts are required to be created and logged into and no specialist software needs to be downloaded and installed. The type of simulations that suit this method tend to be relatively simple engineering systems, with limited permutations of inputs and output states. As such, they are referred to by the author as "Lo-fi simulations". The simulation has been designed to include noise in the results, which was an area of suggested future work by (Feisel and Rosa 2005).The simulation is available to view at https://mee.group.shef.ac.uk/bomb/bomb.html.

1.2 Engineering education research for online labs

A great deal of research has been published in the field of online labs, but many publications around online laboratory research focus on technical development and implementation details instead of instructional design, successful learning, and pedagogy (May et al. 2023). Some studies have been conducted to establish the impact of remote and virtual labs on student learning comparing different types of methods of remote access (Lindsay and Good 2005, BANGERT et al. 2023). The research presented here seeks to address a specific question about the most effective method for using an online lab to enhance the delivery of an in-person lab class.

As part of MEE's practical teaching curriculum, this work will utilise the bomb calorimeter simulation in a number of engineering programmes at the University of Sheffield. Using this experiment as an example, the work presented sets out to answer the following two research questions:

1. Is a simulation best provided before the practical class (to allow students to prepare) or after the practical class (to allow students to reflect and further explore the experiment)?
2. Is it best to provide closed and scaffolded instructions for operating the simulation or unstructured instructions that are open and exploratory?

As a policy, every activity run by MEE is taught using the “teaching sandwich”(Garrard and Nichols 2018). Students are required to take a “pre-experimental activity”, or “prelab” before being allowed to enter a laboratory and a “post-experiential activity” or “postlab”. This framework provides a mechanism into which different deployments of the simulation can be tested.

2 METHODOLOGY

The in-person bomb calorimeter experiment is part of the 1st year undergraduate degree programmes for Chemical Engineers, General Engineers, and Materials Engineers. The bomb calorimeter simulation was deployed differently, to support the in-person session, to each of these cohorts. Table 1 shows the deployment strategy and the number of students for each cohort. A comparison was made between these deployments to answer the three research questions.

Table 1. Three different deployments of the simulation by degree programme

	Simulation before practical	Simulation after practical
Structured instructions	Chemical Engineers (75 students)	General Engineers (90 students)
Unstructured instructions	Materials Engineers (42 students)	

The simulation was provided to Chemical Engineers before the in-person practical class and for the General Engineers it was provided afterward. By comparing these deployments, the first research question can be answered.

To answer the second research question, two different sets of instructions for operating the simulation were created. A structured standard operating procedure, with prescribed instructions for conducting the experiment and unstructured instructions, with an explanation of each simulator control functions. With the unstructured instructions, students would be expected to determine a procedure to meet the experimental aim, based on their understanding of how the functions of the simulator behave. The structured instructions were provided to the Chemical Engineers and the unstructured instructions were provided to the Materials Engineers.

To measure the effectiveness of the simulation under different deployment and attendance conditions, students were encouraged to complete an anonymous, optional survey. The survey focuses on two measurable criteria. These are:

- if they found the simulation useful for learning the material.
- and if the students found the simulation an engaging way to learn the material.

The decision to rationalise the quantity of information gathered in the survey was to reduce the effort requirement to complete the survey, encourage participation and increase response rates.

The survey gathered the following information:

- Participation information and agreement to continue, for ethical compliance.
- Asking if they attended the in-person class.
- A 5-point Likert scale to “On a scale of 1 to 5, how would you rate the overall usefulness of the simulation tool in enhancing your understanding of the experiment?”, with 1 being “Not useful at all” and 5 being “Very useful”.
- A 5-point Likert scale to “On a scale of 1 to 5, please rate how engaged you felt while using the simulation tool.”, with 1 being “Not engaged at all” and 5 being “Very engaged”.
- A 5-point Likert scale to rate “How confident do you feel in using the simulation tool independently to further explore related concepts?”, with 1 being “Not confident” and 5 being “Very confident”.
- Optional free text questions to explain answers or provide any other comments.

Three identical versions of the survey were created so responses from different cohorts could be identified. The surveys were provided to students using their virtual learning environments. Students were encouraged to complete the survey with reminder emails and announcements during lectures.

3 RESULTS

The overall response rate was low, as is typical with optional student surveys. There were 12 responses (16%) from the Chemical Engineering (before/structured) cohort, 5 (6%) responses from the General Engineering (after/structured) cohort and 6 (14%) responses from the Materials Engineering (before/unstructured) cohort.

3.1 Is a simulation best provided before or after an in-person practical class?

Figure 1 compares results for “Usefulness” of the simulation and Figure 2 compares the results for “Engagement” with the simulation. The trend shows students finding the simulation both more useful and more engaging before the in-person practical activity. Comments received from the free text boxes illustrate a similar trend, as indicated in Table 2.

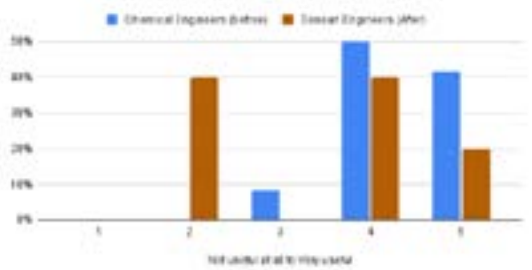

Fig. 1. Responses to question on overall usefulness of the simulation tool comparing the before and after cohorts.

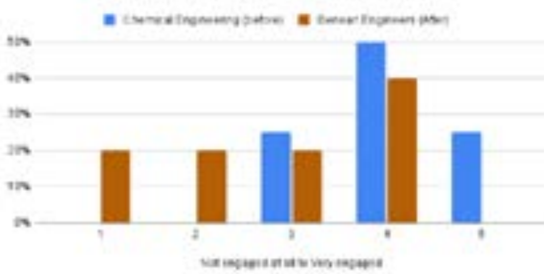

Fig. 2. Responses to question on engagement with the simulation tool comparing the before and after cohorts.

Table 2. Free text comments from Chemical Engineers (before) and General Engineers (after) cohorts.

Why did you give the answer above [usefulness]?	Did the simulation tool help clarify any concepts or aspects of the experiment that were unclear to you before?	Would you recommend the simulation tool to your peers as a supplementary learning resource?
Chemical Engineers (before)		
11 positive comments	7 positive comments 2 neutral comments	9 positive comments
Selected indicative examples:		
Gave me a good understanding of what to expect before the lab.	*No, but I see how it could some students*	*Yes, it allowed for safe practise.*
helped understand set out of bomb calorimeter, where to put everything and what order to carry out experiment.	*Yes, the experimental procedure was not clear after reading the lab sheet but the simulation helped me understand the experiment*	*Yes because it is useful for visualising the experiment and understanding the order in which the steps of the experimental procedure are carried out.*
It gave a great indication of how to carry out the experiment while also being very quick and easy to use.	*Yeah it did because it helped me to better understand what the equipment was and how it worked*	*Yes as it provides additional information and also gives values without attending the lab*
General Engineers (after)		
2 negative comments 3 neutral comments	3 negative comments 2 neutral comments	2 positive comments 2 neutral comments
Selected indicative examples:		
It didn't add much to the lab; the lab was quite complete on its own.	*i was not unclear of anything*	*Maybe, if they've forgotten how it works.*
The simulation was easy to use and gave clear values, the only reason I have not given it a 5 is because I had good understanding of the bomb calorimeter practical after attending in person so it didn't help me understand the concepts that much more	*Not really I think it was good to see as like a how it should go kinda thing where you know the results are good but I wouldn't say it added to experience of actually doing it in person*	*Yes I would, however I don't think I would make it a compulsory part of the course and instead should be more of an addition on what we do in the lab for students wanting to run experiments of their own*
Very simplistic and already understood the lab in person	*No, the lab was pretty simple*	*Supplementary yes as you can do many more materials but I wouldn't say it's essential if you've gone to the actual lab.*

3.2 Structured or unstructured instructions

Figure 3 compares results for “Usefulness” of the simulation and Figure 4 compares the results for “Engagement” with the simulation. The trend shows students finding the simulation both more useful and more engaging with structured instructions, although the difference is less significant compared to the before and after results. Comments received from the Materials Engineers (before/unstructured) are less detailed than from the other cohorts. These comments are shown in Table 3 and can be compared with the Chemical Engineering cohort (before/structured) comments in Table 2.

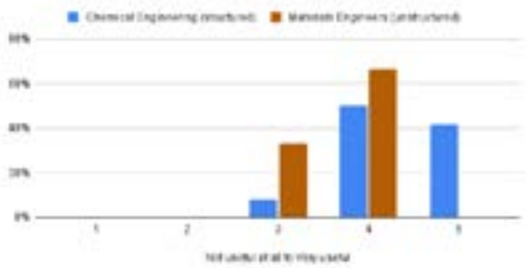

Fig. 3. Responses to question on overall usefulness of the simulation tool comparing structured and unstructured cohorts.

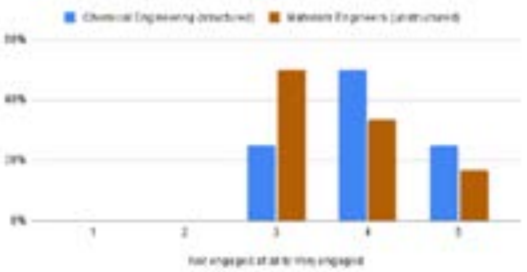

Fig. 4. Responses to question on engagement with the simulation tool comparing structured and unstructured cohorts

Table 3. Free text comments from Materials Engineers (unstructured)

Why did you give the answer above [usefulness]?	Did the simulation tool help clarify any concepts or aspects of the experiment that were unclear to you before?	Would you recommend the simulation tool to your peers as a supplementary learning resource?
Materials Engineers (unstructured)		
2 positive comments 3 neutral comments	2 positive comments 3 neutral comments	3 positive comments 1 neutral comments
Selected indicative examples:		
the practical environment was very good to show the basics of the apparatus but did not challenge understanding of the science	*was good to rehearse before the practical, reducing the time pressure in the practical*	*Yes, shows it well*
Because the experiment wasn't massively complex and I would have been able to understand without the online simulation.	*it was helpful to be able to picture the experiment as it's hard to picture it from just words. I wouldn't say that I would have struggled with the experiment on the day without the simulation however.*	*yes if the were struggling with the pre lab.*
Very well explained lab	*helped to understand the lab sheet*	*Yes*

4 DISCUSSION

An inherent limitation of this study is the bias created by the demographics of students in different programmes. For example, General Engineers have higher academic entry requirements and tend to perform better, and Materials Engineering programmes tend to have a higher proportion of female students. The decision to conduct the research was based on a requirement to provide students in different programmes with an equitable experience.

An operational limitation of the study was the limited number of responses from the optional survey. The average response rate across the three cohorts was 11% and this should be noted when considering the confidence level of the presented interpretation.

Despite the poor response rate, the results show a strong preference for providing the simulation before the in-person practical class rather than afterwards. This preference is reinforced with a rationale in the free text comments. It was felt that the simulation was a more useful tool to prepare for the in-person practical class than as a tool for reflection of further experimentation after the practical class. It is interesting to note that the trend for usefulness is mirrored by a similar trend in engagement with the simulator. This is most likely due to students being more prepared to engage with a tool if they are able to perceive the value it will provide to their education.

A possible explanation in a preference for the simulation being provided before the in-person practical class is that the population researched are first-year students. This cohort may be more motivated to use their time strategically. Students who are early in their education may place more value in maximising the educational benefit of the timetabled lab classes, which are a requirement for the course, rather than spending time on the topic beyond the mandatory requirements. In addition, first-year students may not have sufficient expertise or experience to understand how to begin independently exploring the topic further.

Another possible explanation for the preference for the simulator before the in-person practical class by first-year students is a lack of familiarity with working in a professional laboratory. A lack of confidence with operating in this environment may be ameliorated with suitable preparation for the task. The simulation would provide a method to understand the equipment and procedure that is more representative than reading the procedure in the lab sheet.

The results suggest a weaker impact of instruction type (structured vs. unstructured) on the simulation's perceived usefulness or engagement before the experiment. This potentially could be attributed to the subject cohort being composed of first-year students. Given the low response rate, interpretation of the subtle difference in the results should not be made.

5 CONCLUSIONS AND RECOMMENDATIONS

Simulations present a scalable, inclusive and efficient method to enhance the practical lab classes of Engineering students. The results presented indicate first-year students consider the simulation of a bomb calorimeter experiment provided in advance of the in-person class to be more useful and more engaging. It is proposed that this is because it enables students to prepare for the in-person class, thereby maximising the value of time spent during the class and enhancing their confidence in navigating the lab environment. It is recommended that if educators are using simulations to support first year lab classes, they are provided in advance.

This study would benefit from data collected from a broader range of students. Future work will involve repeating the experiment in the next academic year to enhance the significance of the findings. A further study with higher level year groups would determine if the observed trends were specific to first-year students. The simulator used in this study has been released as an open educational resource under a Creative Commons licence. The authors of the paperwork welcome collaboration with other researchers to broaden the range of results, taking advantage of the ability to share online labs between institutions (Feisel and Rosa 2005).

REFERENCES

ABURDENE, M. F, E. J MASTASCUSA, and Randy MASSENGALE. 1991. "A proposal for a remotely shared control systems laboratory." Conference paper Proceedings - Frontiers in Education Conference, pp. 589-592.

BANGERT, Krys, Edward BROWNCROSS, Matteo DI BENEDETTI, Harry DAY, and Andrew GARRARD. 2023. "Comparing XR And Digital Flipped Methods To Meet Learning Objectives." doi: https://doi.org/10.21427/VJVG-V478.

Feisel, Lyle D, and Albert J Rosa. 2005. "The role of the laboratory in undergraduate engineering education." *Journal of engineering Education* 94 (1):121-130.

Gamage, Kelum A. A., Dilani I. Wijesuriya, Sakunthala Y. Ekanayake, Allan E. W. Rennie, Chris G. Lambert, and Nanda Gunawardhana. 2020. "Online Delivery of Teaching and Laboratory Practices: Continuity of University Programmes during COVID-19 Pandemic." *Education Sciences* 10 (10):291.

Garrard, Andrew, and Andrew Nichols. 2018. "A teaching sandwich approach to integrating classroom and practical teaching." 5th Annual Symposium of the United Kingdom & Ireland Engineering Education Research Network, pp. 87-90. Aston University.

Kapici, Hasan Ozgur, Hakan Akcay, and Ton de Jong. 2019. "Using Hands-On and Virtual Laboratories Alone or Together—Which Works Better for Acquiring Knowledge and Skills?" *Journal of Science Education and Technology* 28 (3):231-250. doi: 10.1007/s10956-018-9762-0.

Lindsay, Euan D, and Malcolm C Good. 2005. "Effects of laboratory access modes upon learning outcomes." *IEEE transactions on education* 48 (4):619-631.

Manunure, Kevin, Alice Delserieys, and Jérémy Castéra. 2020. "The effects of combining simulations and laboratory experiments on Zimbabwean students' conceptual understanding of electric circuits." *Research in Science & Technological Education* 38 (3):289-307. doi: 10.1080/02635143.2019.1629407.

May, Dominik, Gustavo R. Alves, Alexander A. Kist, and Susan M. Zvacek. 2023. "Online Laboratories in Engineering Education Research and Practice." In

International Handbook of Engineering Education Research, edited by Aditya Johri, 525-552. Routledge.

Papalazarou, Nikolaos, Ioannis Lefkos, and Nikolaos Fachantidis. 2024. "The Effect of Physical and Virtual Inquiry-Based Experiments on Students' Attitudes and Learning." *Journal of Science Education and Technology* 33 (3):349-364. doi: 10.1007/s10956-023-10088-3.

Plato, Kapranos. 2018. *The Interdisciplinary Future of Engineering Education, Breaking Through Boundaries in Teaching and Learning*: Routledge.

Taha, MH, ME Abdalla, M Wadi, and H Khalafalla. 2020. "Curriculum delivery in Medical Education during an emergency: A guide based on the responses to the COVID-19 pandemic." *MedEdPublish* 9 (69).

Tekbıyık, Ahmet, and Orhan Ercan. 2015. "Effects of the physical laboratory versus the virtual laboratory in teaching simple electric circuits on conceptual achievement and attitudes towards the subject." *International Journal of Progressive Education* 11 (3):77-89.

Zacharia, Zacharias C, and Ton De Jong. 2014. "The effects on students' conceptual understanding of electric circuits of introducing virtual manipulatives within a physical manipulatives-oriented curriculum." *Cognition and instruction* 32 (2):101-158.

CORRELATION AMONG COURSES IN MATHEMATICS TRAJECTORY OF ENGINEERING TECHNOLOGY

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Keywords: *Mathematics in engineering, Correlation analysis, Admission tests*

ABSTRACT

Mathematics has been an integral component in every engineering curriculum. This paper attempts to study the trajectory of the mathematics courses taken in the engineering technology curriculum of KU Leuven, Belgium, examining factors such as admission test scores, language and the 'success' scores for each mathematics course. The objective is to quantitatively analyze the performance of students at various stages in their mathematics trajectory. This paper utilizes correlation coefficients to comprehend the relationship between mathematics scores and students' diverse admission requirements. The study aims to uncover trends regarding the role of admission tests in determining their course 'success' rates. It also formulates conclusions about the mathematics courses taught in the program. The results provide valuable insights for students and teachers to make informed choices about students' mathematics trajectory in engineering education.

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1 INTRODUCTION

There is a wave in universities, especially in Europe, that have introduced bachelor programs in English in order to attract international students. It is also not uncommon to see bachelor programs running in two launguages, simultaneously. One such example is, the Bachelor of Engineering Technology at KU Leuven, Belgium. The trajectories illustrated in this paper are using the data from this programme. We could ask the question, if it is possible to combine the different language programs in engineering education. But before we answer that question, it is essential to research if the current system elucidates certain inter-relationships within the same language medium as well as a different one keeping in mind clear distinguishing factors. One such factor is the admission requirements.

Students perceive mathematics as part of a degree program, a basis for other subjects or a tool to understand the outside world (Booth 2004). Fundamental mathematics courses are integral to engineering programs, often requiring students to pass them for degree completion. This motivates us to conduct a correlation analysis in order to observe relationships (positive or negative) that might already exist among the trajectories comprising of mathematics courses. Questions raised by students such as 'Will we ever use this math?' or 'Why do I need to pass this course?' highlight the need to analyze math scores and provide effective remediation and support. Students have varying attitudes towards mathematics, with 20% to 66% perceiving it as difficult. This attitude stems from students' educational background and prior math knowledge (Shaw & Shaw 1997,1999). Understanding students' views and performance is crucial to guide them and ensure their successful completion of the math curriculum. Mathematical tests are better predictor tests than those of other disciplines (Fonteyne et al. 2023, Pinxten et al. 2019). These predictions help provide students with insights into their progress toward trajectory completion. In this paper we focus our attention on student performances before and during the program. This leads to two research questions:

RQ1: What is the relation between the admission tests and courses in the mathematics trajectory of the students in engineering technology?

RQ2: What is the relation between the 3 fundamental courses in the mathematics trajectory of the students during the program?

For the former we use results from the IJkingstoets: Industrieel ingenieur industriële wetenschappen, which comprises of multiple choice questions on mathematics from Flemish secondary school level, and the mathematics section of the Scholastic Assessment Test (SAT) for international students. For the latter, exam results during the program are compared with each other.

The methodology used in this paper is correlation analysis, as the first quantitative step. Correlation research is non-intrusive and unbiased as we do not influence the data set and it provides a "very natural view" (Field 2009). Establishing correlations allows for interventions aimed at improving student performance beyond predicted scores. Institutes can then optimize their resources, time, and finance allocation. The optimization (or change) could be as magnanimous as having a single programme with different admission requirements or a single global exam for the programme in the two languages. Descriptive statistics, including mean and percentiles, are utilized to determine passing score thresholds in mathematics courses. Linear regression is employed to visualize any linear relationships between these scores.

A first hypothesis established at the beginning of this research was that the Ijkingstoets will have a higher correlation with the mathematics exams within the trajectory of the program than the SAT. A second hypothesis is that there will exist a sufficient correlation between the courses within the program itself, indicating an association in courses within the trajectory as well as between the ones taught in Dutch and English. Both these hypotheses have been validated by the results, although there are limitations to the analysis and factors that still need to be analyzed.

2 METHODOLOGY

2.1 Data set

Two data sets of students' scores are distinguised, one being drawn from the Dutch language program (NL) and the other from the English language program (ENG). The courses in each trajectory and their timeline are highlighted in Fig 1.

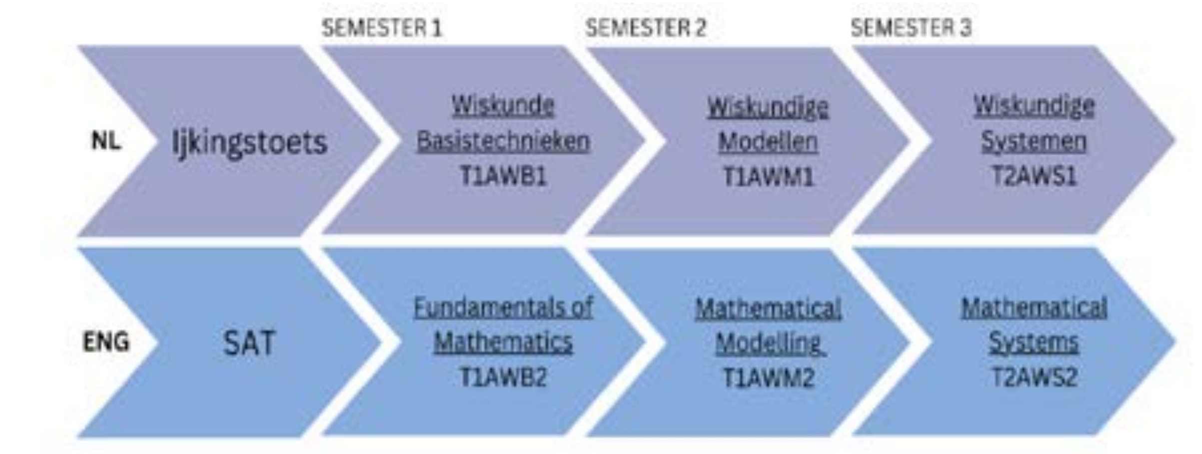

Fig 1: The NL and ENG trajectories with their respective admission tests, mathematics courses and corresponding course codes.

Both data sets consist of students' scores from the years 2020-2024. It should be noted that scores from 2020-2021 were obtained through a different evaluation procedure due to the COVID-19 pandemic. However, coursework and teaching structures remained consistent between equivalent courses taught in different languages. Table 1 shows the current stage of students for each admission year. Consequently, all analyses in the paper are conducted separately for each course in ENG and NL, annually.

Admission year	Graduation year	Currently in semester	Courses evaluated
2020	2023	/	All
2021	2024	6	All
2022	2025	4	All
2023	2026	2	T1AWB1/2

Table 1. The table shows courses evaluated for students in ENG and NL, as well as their current state in the program.

T1AWB1/B2 is a 1st semester course teaching three fundamental pillars of mathematics: analytic geometry, linear algebra, and single-variable calculus. It is followed by T1AWM1/2 in the 2nd semester, which covers multivariate calculus of scalar functions, differential equations, and vector-valued functions. The last course in the trajectory is T2AWS1/2, a second-year course, which focuses on signal transforms and mathematical systems theory.

2.2 Correlation Analysis, Means and Percentiles

Correlation study is as the third most commonly used method for quantitative analysis in educational research journals (Case & Light 2011). Several correlations coefficients can be used to study interdependence for various kinds of variables (Asuero 2006). In this study, both Pearson's correlation coefficient (*r)* and Spearman's rank correlation (ρ) were calculated between the samples from both datasets.

All tests are scored on a 20-point scale, except the SAT scores. However, since these are interval variables, they can undergo bivariate correlation analysis (Bryman 2015). To check the null hypothesis $\boldsymbol{H_0}$, a significance test (t-test) was used.

$\boldsymbol{H_o}$: No correlation exists between the two sample sets.

$\boldsymbol{H_A}$: There exists a significant correlation between the two sample sets.

$\boldsymbol{\alpha} = .05$

A significance level of $\boldsymbol{\alpha}$ =.05 was chosen, as is common practice in educational research (Del Siegle 2023).This analysis is used to answer both research questions. For **RQ1**, we start with finding correlation coefficients between Ijkingstoets scores and each of the NL program courses' scores: T1AWB1, T1AWM1 and T2AWS1. This is also done with SAT and ENG courses T1AWB2, T1AWM2, and T2AWS2. We further use values of means and percentiles of Ijkingstoets scores of students who successfully passed in the Math courses during the program. This helps us find a threshold bracket for the Ijkingstoets. For **RQ2**, we have used that same bivariate correlation analysis with $\boldsymbol{\alpha}$ =.05 on courses that are taken in 1st, 2nd and 3rd semester. The results are included in a joint plot comprising of histograms and scatter plots with a line of best fit with 95% confidence interval, providing a visual representation of the interdependence of the sample sets.

3 RESULTS

Limitations should be stated before discussing the results. There is an absence of information about those students who did not complete the course or left the program midway. There are students who switch from ENG to NL or vice-versa, whose scores have not been considered. Additionally, if a student attempted a course exam multiple times, only their best score was retained. The size of the data set for each bivariate comparison ranges between 80-700. For further details, the author can provide the code for each sample set considered. Each correlation coefficient has a variance that is dependent on the sample size, these are limits within which 80% of sample *r* values are found (Hole 2015). All course codes and colours used in this section are based on Fig. 1 explaining the trajectories. The analysis was also carried out for ρ, it yields similar values as *r*. Those results have been left out due to conciseness.

3.1 RQ1: Admission Tests vs Mathematics Courses

Table 2 shows the correlation coefficients for NL and ENG and for each admission year. The table is divided into two sections, one for Ijkingstoets and the other for SAT, showing the Pearson's correlation coefficient and the respective p-value for that sample set. Cases where H_A is accepted (p < .05) are shown in green, while cases where H_o is accepted (p ≥ .05) are shown in red. Indicated in yellow are the correlations that may or may not be significant, as their p-values are very close to .05

Ijkingstoets		T1AWB1	T1AWM1	T2AWS1	SAT	T1AWB2	T1AWM2	T2AWS2
2020	*r*	0.41	0.23	0.25		0.10	0.16	0.13
	p	<.001	.02	.04		.54	.34	.57
2021	*r*	0.17	0.12	0.12		0.42	0.40	0.03
	p	<.001	.05	.13		<.001	<.001	.87
2022	*r*	0.24	0.22	0.16		0.23	0.11	-0.02
	p	<.001	.01	.16		.02	.29	.90
2023	*r*	0.49				0.17		
	p	<.001				.09		

Table 2. Correlation coefficient r and two-sample t-test with p values, for courses in NL(Left) and ENG(Right).

3.2 RQ1: Ijkingstoets vs Passed in Mathematics Courses

Admission year	Ijkingstoets	T1AWB1 ≥ 10	T1AWM1 ≥ 10	T2AWS1 ≥ 10
2020	Mean	14.99	14.90	15.17
	Q1-Q2-Q3	12 - 17 - 18	14 -15 -17	12-17-18
2021	Mean	9.60	9.34	9.35

	Q1-Q2-Q3	6 - 10 - 13	6 -10 -13	6 -10 -13
2022	Mean	9.82	10.53	10.79
	Q1-Q2-Q3	8 - 10 -12	8.5 -11- 12	9 -11-12
2023	Mean	15		
	Q1-Q2-Q3	14 -15 -17		

Table 3. Mean and Quartiles (25,50 and 75) for Ijkingstoets scores, from students who passed the respective courses in NL.

To pass a course, a student must receive a score of 10/20 or higher in the evaluation, which is considered a 'success'. In Table 3, the mean score of Ijkingstoets for the years 2021 and 2022 differs from the ones in 2020 and 2023, as the test had a different method of grading. We do this only for Ijkingstoets as there are more significant correlations than that for SATs.The mean indicates the average score in the Ijkingstoets of those students who passed the course.

3.3 RQ2: Correlation among Mathematics Courses

Course pairs	Language	*N*	*r*
T1AWB1-M1	NL	717	0.75
T1AWB1-S1		441	0.38
T1AWM1-S1		432	0.22
T1AWB2-M2	ENG	381	0.82
T1AWB2-S2		209	0.41
T1AWM2-S2		201	0.33

Table 4. Sample size and r-value for course pairs in NL (purple) and ENG (blue)

The scatter plots in Figure 2 indicate a line of best fit, created using the regression plot. The shaded edge of each line indicates the confidence interval. The histograms display frequency on the y-axis. Unlike the previous analysis, the data set for each course is not divided annually. The scores from the years 2020, 2021 and 2022 are combined into one data set, for each course, as the correlations for each year showed similar *r* values. The sample size *N* and the *r* values for each of the pairings in ENG and NL are indicated in Table 4.

4 Discussion & Conclusions

RQ1: The first thing to notice is that the *r*'s for which we accept the alternate hypothesis are indeed all positive correlation values. In general, <u>Ijkingstoets has a higher correlation to exam results than SAT</u>. As stated previously, we must treat results carefully in ENG. In contrast to NL, students in ENG come from various countries with different educational systems. While rejecting H_A for most cases in ENG it is possible that we made a type I error and those variables would be correlated. The data set for ENG has more factors than NL that may have had an effect on the r values to show non-linearity.

There are twice as many significant correlations in Table 2 for Ijkingstoets than for SAT. These correlations are not very high but more significant than the ones between ENG courses and SAT. This is most clear for T1AWB1 and T1AWM1, which are taken in the first year of the program. However, the linear relation is not as strong as students move into the 2nd and 3rd semesters. This indicates that the interdepedence of the admission tests with courses decreases as time passes.

SAT is a standard test that international students can take. However, it may not be the best indicator of admission requirement. Perhaps students starting in ENG need to be informed about their SAT scores not being the best indicator of their success in it. Comparing the topics tested in Ijkingstoets vs. SAT reveals that the latter does not test calculus, whereas it is a recurring topic in the three courses.

Another factor to consider is that the Ijkingstoets is a Flemish examination based on the secondary school curriculum that is taught in Flanders, which are aligned better with the topics of T1AWB1/2, T1AWM1/2 and T2AWS1/2. The nature of this test is mandatory but not binding, which means the low scorers can also start the program and also contribute to the *r* value. This is another major difference between the SAT and the Ijkingstoets. Since the SAT has a cut-off admission criterion, only high scorers are in the data set. These low scores that exist for the Ijkingstoets contribute to the positive yet low value of the correlation coefficient for NL, unlike the SAT scores.

The above discussion suggests that we could use Ijkingstoets as a predictor for student "success".

We find the range of the Ijkingstoets scores that would predict the passing of the course (≥10) using Table 3. Each year shows a mean score greater than 9, which indicates that students who “almost pass” the Ijkingstoets are highly likely to pass the courses. This conclusion needs to be made keeping in mind the nature of the Ijkingstoets as there are students who might not percieve the test as an important one or one that is high stakes. Table 2 also shows quartiles, which gives us a range for each year. A recurring pattern that is observed is that the quartile range is consistent for all courses, in a single year. The years 2021 and 2022 have a range of 6-13 and 8-12 already indicating that if a student is in this range they pass all 3 mathematics courses.

RQ2: The *r* values in Table 3 are all significant based on the t-test, hence indicated in green. This shows that each mathematics course in the curriculum is interdependent with each other as well as across the two language mediums. It is important to note that the topics taught in each of these courses are different but not mutually exclusive and each introduces pre-requisite knowledge for other disciplines such as mechanics, dynamics, and statistics.

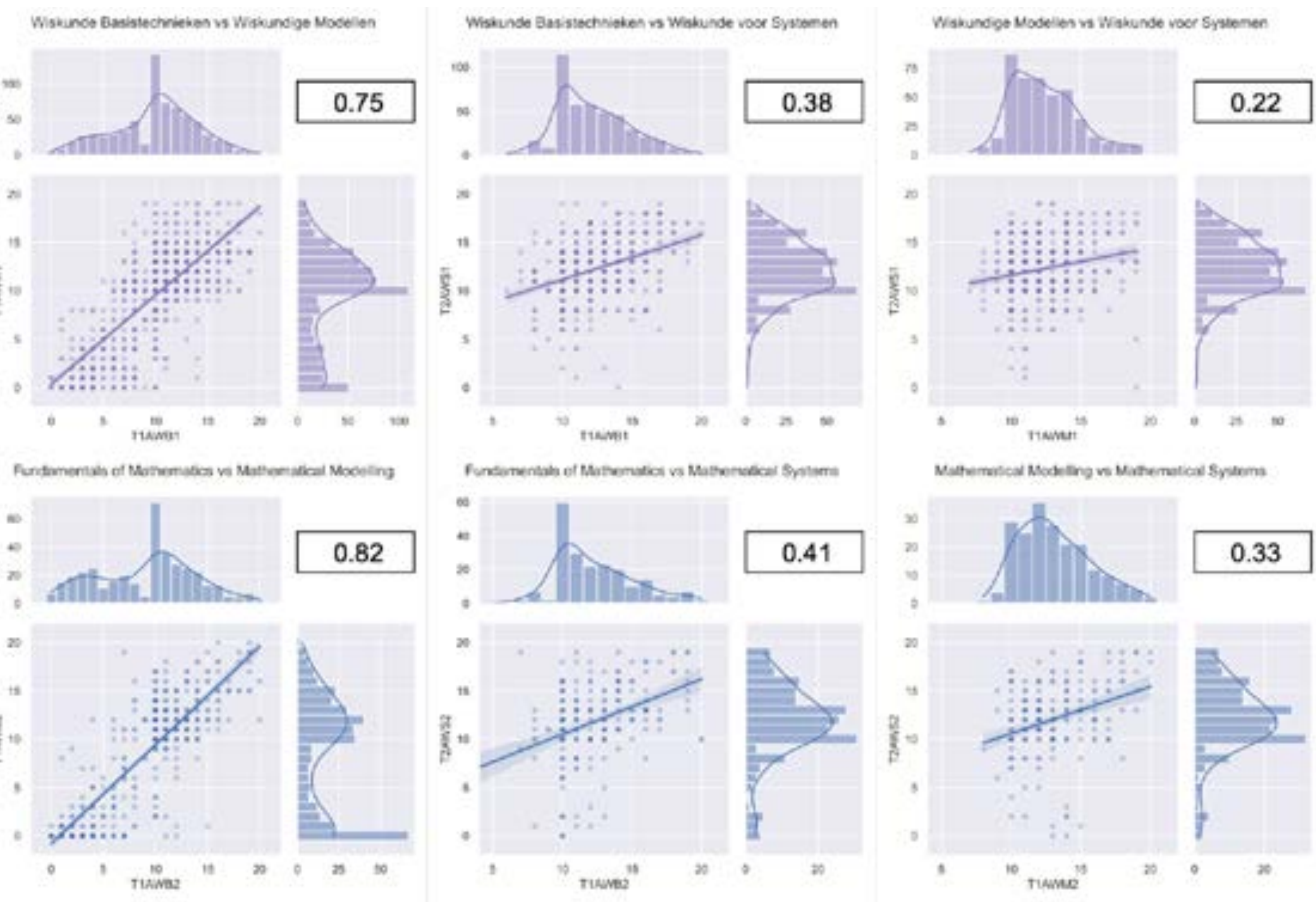

Fig 2: Each plot contains a scatter plot and line of best fit for the scores obtained on two courses. It also shows a histogram with its kernel density estimator (KDE) for each course. The value r is shown in the black box. Purple (top row): NL Blue (bottom row): ENG

The correlations between T1AWB1/M1 is 0.75 and T1AWB2/M2 0.82. These values are signifcantly higher compared to the ones calculated with the admission tests. The sample set is larger as there are no dropouts. T1AWB1/S1 and T1AWB2/S2 show 0.41 and 0.38 respectively, which is positive but lower than between the 1st year courses. The line of best fit for ENG shows slopes higher than those of NL, analogous to the correlation values. We notice the value of N in Table 4. reduces for the 2nd and 3rd courses and the drop out percentage is higher for NL students.

New research questions arise based on this analysis: Do Flemish students realise that the program is not fit for them based on first year scores? Are international students motivated to perform better? Some students' perceptions are affected based on their scores, especially the scores of the Ijkingstoets (Hanssens 2023). We also see a higher correlation between T1AWB1/2 and T2AWS1/2 than T1AWM1/2 and T2AWS1/2 indicating that students get more positive results in the 3rd semester/2nd year. This could be because they take time to adapt to the evaluation procedure or to understand the curriculum better and that students are confident about their choice of program. Reading into the histograms of Figure 2, for the course T2AWS1/2 and T1AWM1/2 we notice the count being higher for grades ≥ 10. The curves peak at values higher than the passing grade, indicating students aim and manage to score higher than how they performed in the 1st semester.

5 Recommendations & Future Work

Interpretation of attempts as a factor in the future analysis: This study only retained each student's highest score for each course as the data points in ENG and NL. However, all students get multiple chances to pass the course and each attempt familiarises the student with the course content as well as the exam questions. We propose to use the factor of average number of attempts for a student to successfully pass a course. This could be used to check the difficulty level of the course. However, even though it has the same content, no two tests are the same, so this would be a difficult factor to implement while finding these correlations (DePascale & Gong 2020).

Non-significant p values to be studied further: We have said that some correlations are insignificant based on p values ≥ .05. These non-significant results are common and often misrepresented in educational research. These misinterpretations have to be corrected, mostly via theory and practice. The non-significant r values in this paper could be interpreted further using models. (Edelsbrunner & Thurn 2024, Andrade 2019).

Using Positioning Test as a control group: The Ijkingstoets in English, also known as the Positioning Test, is available to students. This is mostly accessible to European students who manage to arrive in Belgium in time for the test. This set could serve as a good control group, but the frequency of these data points does not compare to those of SAT and Ijkingstoets. There are several international tests that are also accepted as pre-requisites: ACT, OPMDT and Benchmark Tests. They have the same limitation as the positioning tests.

Predictive Models to create informed remediation: Admission tests help students make an informed decision about the program before they start it. They could choose to drop out and start another program or choose remediation. The other option is to build a predictive model that informs them about their progress during the study. The prediction with a confidence interval would make them aware of where they stand in the trajectory. This could also have a major counter effect: instead of motivating students, it might lead students to taking their coursework lightly.

6 Acknowledgements

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REFERENCES

Andrade C. (2019). The *P* Value and Statistical Significance: Misunderstandings, Explanations, Challenges, and Alternatives. *Indian journal of psychological medicine*, *41*(3), 210–215. https://doi.org/10.4103/IJPSYM.IJPSYM_193_19

Asuero, A. G., Sayago, A., & González, A. G. (2006). The correlation coefficient: An overview. In *Critical Reviews in Analytical Chemistry* (Vol. 36, Issue 1, pp. 41–59). https://doi.org/10.1080/10408340500526766

Booth, S (2004), 'Learning and teaching for understanding mathematics', Paper presented at 12th SEFI seminar on teaching mathematics, 2004/06/14.

Booth, S. (2008). Learning and teaching engineering mathematics for the knowledge society. *European Journal of Engineering Education*, *33*(3), 381–389.

https://doi.org/10.1080/03043790802090232

Bryman, A. (2015). *Social Research Methods* (5th ed.). Oxford University Press.

Shaw, C. T., & Shaw, V. F. (1997). Attitudes of first-year engineering students to mathematics—A case study. *International Journal of Mathematical Education in Science and Technology*, *28*(2), 289–301. https://doi.org/10.1080/0020739970280210

Case, J. M., & Light, G. (2011). Emerging methodologies in engineering education research. *Journal of Engineering Education*, *100*(1), 186–210. https://doi.org/10.1002/j.2168-9830.2011.tb00008.x

DePascale, C., & Gong, B. (2020). Comparability of individual students' scores on the "https://naeducation.org/wp-content/uploads/2020/04/2-Comparability-of-Individual Students'-Scores-on-the-"Same-Test".pdf

Del Siegle, University of Connecticut, Accesesed on 01/12/2023 https://researchbasics.education.uconn.edu/correlation/

Edelsbrunner, P. A., & Thurn, C. M. (2024). Improving the utility of non-significant results for educational research: A review and recommendations. *Educational Research Review*, *42*. https://doi.org/10.1016/j.edurev.2023.100590

Field, A. P. (2009). Discovering statistics using SPSS : (and sex and drugs and rock "n" roll). SAGE Publications.

Fonteyne, L., Acke, S., Hanssens, J., Marconato, A., Schütz, J., Tambuyzer, B., de Laet, T., & Melis, I. Validiteitsrapport Ijkingstoetsen *February 2023*.

Hanssens Leuven, J. K., Greet Langie Leuven, B. K., Carolien Van Soom Leuven, B. K., Hanssens, J., Langie, G., & van Soom, C. (2023). Students' Perceptions of Low Stakes Positioning Tests at the Start of Higher STEM Education: A Mixed Methods Approach. *International Journal of Education in Mathematics*, *11*(5), 1094–1112. https://doi.org/10.46328/ijemst.2889

Hole, G. (2015) *Research Skills One, Correlation interpretation, Graham Hole v.1.0.. Eight things you need to know about interpreting correlations*.

IJkingstoets : Industrieel ingenieur industriële wetenschappen (in)

https://www.ijkingstoets.be

Pinxten, M., Van Soom, C., Peeters, C., De Laet, T., & Langie, G. (2019). At-risk at the gate: prediction of study success of first-year science and engineering students in an open-admission university in Flanders—any incremental validity of study strategies? *European Journal of Psychology of Education*, *34*(1), 45–66. https://doi.org/10.1007/s10212-017-0361-x

The Digital SAT ® Suite of Assessments Specifications Overview. (n.d.). 2024 https://satsuite.collegeboard.org/media/pdf/digital-sat-test-spec-overview.pdf

Educating the Whole Engineer – Educational Experiences that Have Impact in a Civil Engineering Problem Based Learning Programme

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Conference Key Areas: *#2. Educating the whole engineer: teaching through and for knowing, thinking, feeling and doings. #16: Improving higher engineering education through researching engineering education*
Keywords: *PBL, Student-centred learning, Civil Engineering*

ABSTRACT

In 2008 the University of Limerick (UL) launched Ireland's newest Civil Engineering programme - this presented a unique opportunity for the designers to transform how civil(ian) engineers are educated to better serve modern society. An academic team of six engineers, possessing significant industry experience, combined their expertise on 'how' to engineer by drawing on personal reflections and on their 'traditional' (didactic) undergraduate education. The outcome of these deliberations led to the creation or a modern educational programme that stimulates and motivates students to engage in the interesting challenges faced by civil engineers today.

A core value of the resulting programme is the pedagogy chosen for delivery. The programme adopts a Problem Based Learning (PBL) ethos in which students work in small teams to develop solutions to open-ended real-world problems. These problems drive the learning of the various syllabii.

In 2022, the impact of this decision was assessed by gathering feedback from the first ten years of programme graduates via an online survey. While the survey

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addressed many aspects of the graduates' educational experience, this paper focuses exclusively on the learning experiences listed by the graduates that impacted their development as an engineer. These experiences are discussed in terms of the skills and attributes specified in expert reports on the habits of mind that need to be developed in engineering education, for example (Goodhew 2014).

1 INTRODUCTION

Becoming a Chartered Engineer in Ireland is a two-step process involving a period of formal instruction in a four (or five) year degree, this is followed by a period of mentored training in practice (typically four years). This paper focuses on the first step which includes providing the student engineer with a strong understanding of engineering fundamentals through meaningful learning experiences.
In addition to the core technical skills, accrediting professional bodies require evidence that graduates can demonstrate the ability to creatively solve problems, to work on their own initiative in addition to being effective team players. They must also demonstrate the ability to collaborate across disciplines and be effective communicators. In the view of the authors, this is best done by creating learning experiences that integrate these skills through carefully contextualised challenges. The challenges draw on students' prior knowledge and experiences and often cross subject and discipline boundaries. The following section provides a summary of the research literature that influenced the design of the UL civil engineering programme.

1.1 The Evolution of 'Challenge' Based Education

The roots of traditional engineering educational date back to the late 18th and 19th Century in response to the skills demanded by the industrial revolution. Since this time, there has been exponential advances in digital technology that dramatically changed the focus of 21st century education. The advent of the worldwide web means the transmission of content is less important than it was in the past. In the intervening period (circa 260 years) since the industrial revolution, the content of engineering programmes has adapted to the emerging issues such as climate change and the protection of the environment.Our teaching approach however has remained essentially unchanged - most universities and colleges follow the well trammelled instructional strategy of lectures, labs and tutorials.Since the 1960's there has been a significant movement towards student centred learning models. According to (Prince and Felder 2006), the efficacy of the student-centred approach is supported by research findings that students learn by fitting new information into existing cognitive structures and are unlikely to learn if the information has few apparent connections to what they already know and believe. Student centred methods can be characterised as constructivist methods, building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing versions presented by their teachers – although there are dissenting voices on the latter claim (Kirschner et al. 2006 and Didau 2010).

(Redish and Smith 2008) identify the convergent view of many researchers that an engineering education not only requires students to be proficient in traditional engineering fundamentals such as mechanics, mathematics, dynamics and technology but also to develop the skills necessary for learning to embed this knowledge in real-world situations. Therefore, programmes need to schedule time within the semesters to develop and hone these skills (Rodriguez-Laegacha et al 2015 and Akinci-Ceylan et al 2022).

In a report commissioned by the US National Centre on Education and the Economy, (Pellengrino 2006) recommends re-thinking and re-designing curriculum, instruction (teaching) and assessment to develop the ‘adaptive expertise’ required by the modern-day engineer. This is consistent with (Biggs 1999) constructive alignment approach where the curriculum is designed so that the learning activities and their assessment are aligned with the learning outcomes of the programme.

In (Goodhew’s 2014) report prepared for the Royal Academy of Engineering, he remarks how a stagnant traditional engineering programme is no longer sufficient to engage the minds of students of the 21st Century - acknowledging that ‘today’s students are no longer the people our educational system was designed to teach,’ (Prensky 2001). This is explicitly addressed in the American Society of Civil Engineers (ASCE) second edition of the Civil Engineering Body of Knowledge for the 21st Century (ASCE 2013) by calling for specific training of faculty in the science of teaching and learning and offers guidance on how this may be achieved. The Royal Academy of Engineering report (Goodhew 2014) explores the ‘habits of mind’ that must be inculcated in student engineers. The six habits of mind identified in the report are: systems thinking, adapting, problem-finding, creative problem-solving, visualising and improving, coupled with a positive attitude towards making things and making things work better. A similar list has been put forward by the National Academy of Engineering. The consistency between both lists and the development of these habits in our educational programmes requires a different approach to the traditional didactic model which, unfortunately, is still adopted in many engineering programmes. The following section briefly summarises how the civil engineering programme at UL is implemented using a PBL pedagogy.

1.2 The University of Limerick Civil Engineering Programme

At UL each academic year contains two semesters and each semester comprises five modules each worth 6 ECTS. The integration of Problem Based Learning (PBL) activities throughout the four-year undergraduate degree is shown in Table 1.

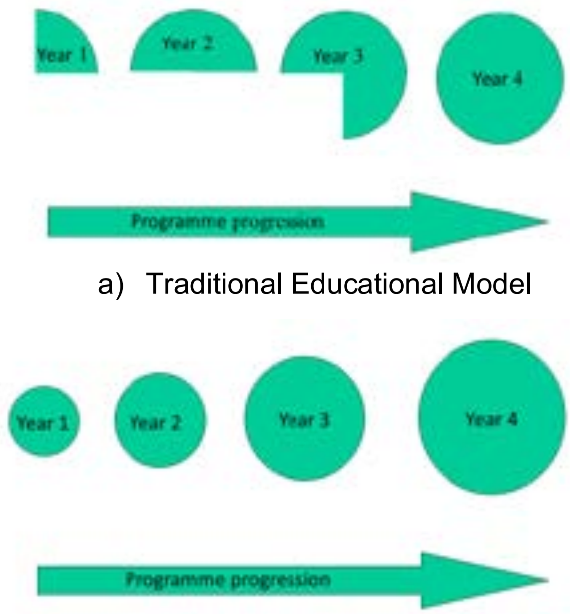
The teaching of technical content endeavours to meet a ‘just in time’ delivery so the course material arrives as it is needed by the student at each stage of the PBL trigger.

Table 1: Distribution of PBL triggers throughout the UL Civil Engineering Programme

Year & Semester		Modules				
Year	*Semester*	*Module 1*	*Module 2*	*Module 3*	*Module 4*	*Module 5*
Year 1	Semester 1	PBL1				
	Semester 2	PBL 2				
Year 2	Semester 1	PBL 3	PBL4	PBL 5		
	Semester 2	PBL 6	PBL 7	PBL 8		
Year 3	Semester 1	PBL 9: IDP				
	Semester 2	8 Month Work Experience				
	Semester 3					
Year 4	Semester 1	PBL 10	PBL 11	FYP		
	Semester 2	PBL 12	PBL 13	FYP		

** FYP = Final year project*

The UL model favours a process model over a traditional content driven model. This is illustrated in Figure 1 where the traditional educational approach of students receiving knowledge on an incremental basis culminating in a required body of knowledge after four years is shown in Figure 1 a). This contrasts with the illustration in Figure 1 b) where the PBL problem solving process remains the same year-on-year, but the complexity of the challenges increases as the students move through the programme.



a) Traditional Educational Model

b) The UL model

Figure 1: Traditional versus UL models for educating engineers

Both models deliver the same content but the UL model develops a holistic approach to problem solving.

The UL programme also encourages the development of reflective practitioners by highlighting the significant learning benefits that accrue from reflection (prior to) as well as on (after) action. (Cosgrove and O’Reilly 2020) describe how work in this area has been instrumental in guiding how reflective practice is incorporated into various PBL triggers.

Details on the structure, implementation and assessment of the various PBL triggers are not presented here but Figure 2 provides a pictorial overview of PBL 6 from semester 2 of year 2. The trigger requires students to design of a flood embankment to protect vulnerable campus accommodation from inundation when the River Shannon bursts its banks (Figure 2 (a)). The remaining images show the sequence of tasks involved in establishing the ground profile and selecting a suitable soil for constructing the dam (b) determining the soil properties via in-situ testing (c) identifying failure modes using model dam experiments (d) classifying soils in the laboratory (e) working in teams to advance the design (f) analysing seepage through the dam (g) evaluating the design using a trial embankment (h) and formally presenting the design to the client (i). A comprehensive account of this trigger is provided in (Phillips and Quilligan 2014).

a) 2015 Campus Flooding
b) Trial Pit Excavation
c) In-situ strength testing
d) Model earthen dam experiments
e) Laboratory testing
f) PBL Group work
g) Seepage analysis
h) Testing a trial design embankment
i) Presenting the design

Figure 2: Flood Embankment Design Activities

2 Research Methodology

A survey was designed to gather information on the lived experience of graduates of the UL PBL educational experience. The study evaluates how key engineering skills identified by the profession are developed through the PBL pedagogy. Because of space limitations, this paper focuses on the responses to just two of fourteen questions executed in an online survey using Qualtrics ® software. The questions are: 1) List the most memorable (impactful) learning experiences from your undergraduate studies at UL and 2) Explain why the learning experiences listed in the previous question stand out. A small selection of graduate reflective comments linked to these two questions are also offered to provide additional insight on why these learning activities had an impact on their professional development.

2.1 Survey Design

The number and order of the survey questions were organised such that essential data for the study was gathered in the initial questions. To avoid survey fatigue, questions requiring qualitative feedback were limited to two questions. A range of question formats such as MCQs, Likert and Drag and Drop were adopted to provide variety in the online interaction experience and to enhance participant engagement with the survey. The guidance provided in Nulty (2008) on the avoidance of systematic bias in the survey responses was followed in both the survey design and the coding process used in the interpretation of the qualitative data. This guided against tendencies to misrepresent and misinform summative judgements regarding the efficacy of the programme's instructional strategy.

In the end, fourteen questions gathering both quantitative and qualitative data featured in the survey. The quantitative data provides general information on the graduates such as gender, further education, civil engineering sub-discipline and employment details. The results from the quantitative questions are presented using a combination of graphs or charts. The qualitative questions allow the graduates to provide supporting statements on their answers to quantitative questions using written reflections on their educational experiences. The process adopted for coding of qualitative data involved reading the graduate responses from all survey participants. Then five of the responses were selected at random and re-read in detail but this time text that appears to identify or capture specific skills required by industry was highlighting. In vivo coding was used to extract verbatim, keywords and phrases from the reflections to identify the key themes emerging from their undergraduate learning experiences. Keywords from these responses were used to develop a preliminary coding system and this coding system was used to code the remaining responses. This process led to the addition of new codes when data that did not fit within existing codes was encountered. Saturation was deemed to be achieved when no new themes emerged from reading the graduate responses. Once all the feedback was coded, all the data with a particular code was examined and this process resulted in some of the codes being combined and others were split into subcategories. The survey was piloted in advance to check for bias and leading questions. Six people participated in the pilot; two UL civil engineering graduates; two engineers, one working in professional practice and the other in academia and two non-engineers one of whom is an expert in teaching and learning. Feedback from the pilot was used to improve the quality and clarity of the survey questions. The civil engineering graduates used in the pilot survey were not included in the final survey results. This research received ethics approval from the University ethics committee and informed consent was obtained from each participant prior to taking the survey. In total 232 engineers graduated from the UL undergraduate civil engineering programme between 2012 and 2022 and survey responses from sixty graduates (n = 60) were received, representing a response rate of 26%. The respondents (92% of which are male) were typically between 22 and 32 years of age. Fifty-eight percent of the respondents had over 5 years experience and fifteen of these have 10 years experience.).

3 Results

The goal of every education system is to develop people so they can positively contribute to society through their work and private lives. Acquisition of knowledge is essential to this mission, so the two questions presented as part of this paper were to ascertain which instructional techniques used in the programme had the greatest impact in their development as an engineer.

3.1 Experiences that Positively Impacted on Graduate Learning

Graduates selected from a list of trigger experiences from the programme and identify the activity that was the most impactful or memorable as a learning experience. Sixty respondents listed 137 learning experiences from their four years in UL. Figure 3 shows most of these involve doing, making, collaborating, communicating and teamwork activities. Conceive, design, build and test projects had the highest impact at 20 % followed by the year 3 Integrated Design Project at 18% - this single project integrated the knowledge from all five modules in semester 1 of year 3 (Table 1). Working in teams while undertaking PBL activities accounts for 14% and the mentored eight-month cooperative education experience was next at 7%. Notable also at 6% is the cross-disciplinary experience between law, civil engineering and construction management students. In this trigger, the engineers act as expert witnesses on real construction failure cases in moot court (see Phillips, 2013).

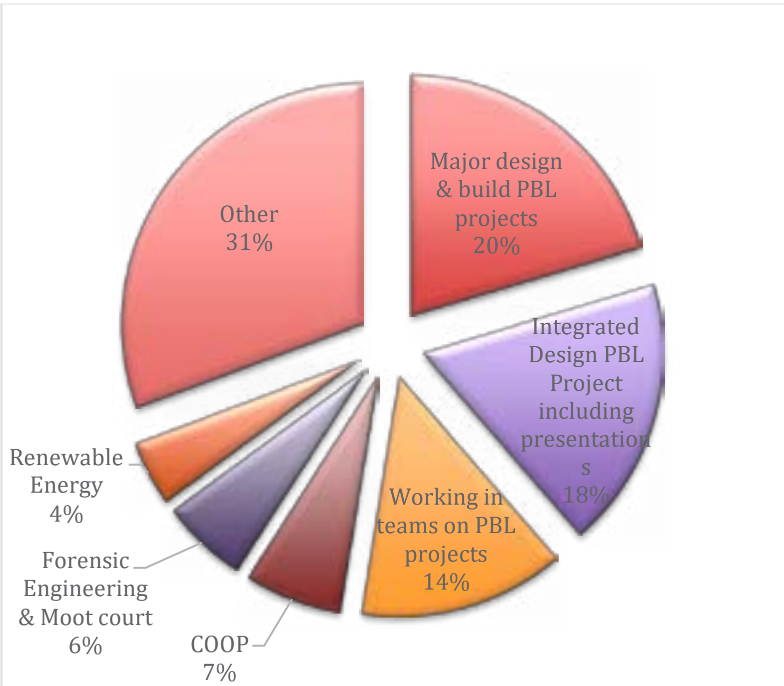


Figure 3: Most impactful/memorable learning experiences.

Undertaking sustainable energy projects such as evaluating a site's potential for the generation of electricity from wind energy are also highly valued by graduates. Many of the remaining 31% of activities listed under 'other' involve tasks that help develop professional skills essential for engineers such as sketching, project presentations and technical interviews, site visits, final year research projects, laboratory activities, use of physical props to demonstrate theoretical concepts e.g. strut behaviour and the laws of friction. These findings are congruent with the aspirational 'habits of mind' outlined in section 1.1. The results also corroborate the research findings by (Prince and Felder 2006) that students remember more when they are actively involved in the learning process.

Fifty-seven of the respondents provided comments to support their selection of impactful learning experiences. Figure 4 **Error! Reference source not found.**illustrates the graduates' feedback correlates strongly with the desirable 'habits of mind' listed section 1.1. The results support the claim that engineering graduates of programmes with a strong PBL emphasis develop these 'additional benefits' (Mills and Treagust 2003; Kolmos and Holgarrdt 2019). There is significant support for the development of abilities that integrate knowledge within and across modules to arrive at viable engineering solutions to open-ended problems. Graduate feedback on 'learning by doing' provided numerous examples of how these experiences strengthened the graduates' understanding of theoretical engineering concepts. For example, one respondent with ten years professional experience offered the following comment on a design-build-test challenge in PBL 2:

"These learning experiences gave an insight into what being an engineer is, developing a design and following that design to reality as opposed to a more traditional design project in an academic environment where often a lot of things are simplified and the true structural behaviour is not revealed. This experience revealed the 'devil is in the detail' and more subtle structural behaviours that can only be revealed from testing your own design."

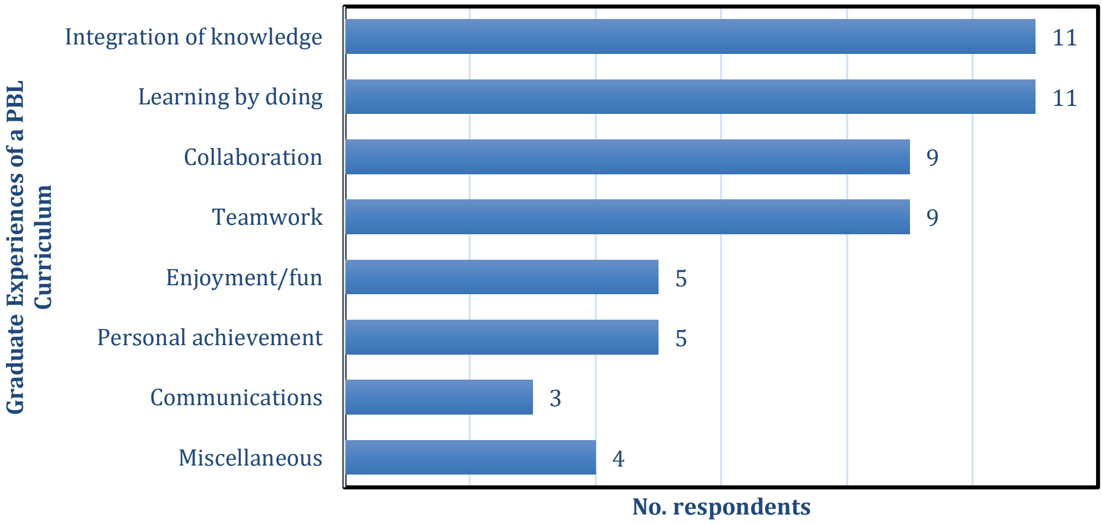


Figure 4: Classification of feedback linked to most impactful learning experiences (n=57)

Items falling under miscellaneous in Figure 4 include; a sense of being part of a unique educational experience, the value of learning from historic engineering failures, development of creative abilities, ownership (of the acquired knowledge), sharing ideas, passion for learning, integration of knowledge, leadership and an acknowledgement of the need to 'adapt' their (technical) language when interacting with non-engineers.

4 SUMMARY

The benefits of 'learning by doing' in engineering education features strongly in the graduate feedback. Graduates see it as a valuable tool in improving understanding of engineering design concepts and it also contributes to the development of the type of professional engineer discussed in section 1.1. Teamwork skills developed through PBL projects along with collaboration skills between different disciplines (architecture, construction management and law) are perceived by the graduates as being beneficial in preparing them for their professional lives. A sense of achievement from successfully completing open-ended engineering challenges is also reported in the feedback as is the enjoyment and fun experienced during the learning activities; one graduate described it as "*Working hard without it feeling like hard work."* Many graduates found the diverse nature of assessment tools employed throughout the programme for example, undertaking end of module interviews and presentations equipped them with good communication skills to succeed in industry. Finally, the graduates found being educated through PBL was a distinct advantage in developing their ability to tackle the types of problems they face in everyday practice (ie systems thinking, adapting, problem-finding, creative problem-solving, visualising and improving) along with becoming more proficient independent learners.

REFERENCES

ASCE, *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future*, 3rd Ed., ASCE (2019), Press ISBN (print): 978-0-7844-0965-7ISBN (PDF): 978-0-7844-7222-4, Available at https://ascelibrary.org/doi/book/10.1061/9780784409657 Accessed 21/04/22.

Akinci-Ceylan, S., Cetin, S, Ahn, B., Surovek, A., and Cetin, B. *Investigating problem solving processes of students, fqculty qnd prqcticing engineers in civil engineering,* J of Civil Engineering Education, Vol 148, Issue 1, 2022.

Biggs, J. What the Student Does: teaching for enhanced learning, *Higher Education Research & Development*, 18:1, 57-75, DOI: 10.1080/0729436990180105, 1999.

Cosgrove, T. and O'Reilly, J. Theory, practice and interiority: an extended epistemology for engineering education. *European Journal of Engineering Education*, *45*(1), pp.38-54. (2020).

Didau, D. *What if everything you knew about education was wrong*, Crown House Publishing Limited, Carmarthen, Wales, UK. (2015).

Goodhew, P.J. Teaching Engineering: All you wanted to know about education but were afraid to ask, September, 2014, *Royal Academy of Engineering*, ISBN 978-1-907207-22-8.

Kirschner, P., Sweller, J. and Clark, R.E., Why unguided learning does not work: An analysis of the failure of discovery learning, problem-based learning, experiential learning and inquiry-based learning*. Educational Psychologist*, *41*(2), pp.75-86. 2006.

Kolmos, A. and Holgaard, J.E., Employability in engineering education: Are engineering students ready for work?. In *The Engineering-Business Nexus* (pp. 499-520). Springer, Cham. 2019.

Mills, J.E. and Treagust, D.F. Engineering education—Is problem-based or project-based learning the answer. *Australasian journal of engineering education*, *3*(2), pp.2-16, 2003.

National Academy of Engineering, *Habits of Mind*, Link engineering website https://www.linkengineering.org/Explore/what-is-engineering/5808.aspx

Nulty, N. *The adequacy of response rates to online and paper surveys: what can be done?*, Assessment & Evaluation in Higher Education, 33:3, 301-314, DOI: 10.1080/02602930701293231, 2008.

Phillips, D.T. All the World's a Stage - Reflections on a Forensic Engineering Moot Court Experience. In *Proceedings of the Fifth International Conference on Forensic Engineering* ASCE/ICE, 2013.

Phillips, D., and Quilligan, M. "Teaching an introductory course in soil mechanics using problem based learning." Paper presented *iCEER 2014- McMaster, Hamilton, Ontario, Canada, August 24-26, 2014.* https://www.ece.mcmaster.ca/faculty/bakr/iCEER2014-McMaster_Digest.pdf

Prensky, M. Digital Natives, Digital Immigrants, On the Horizon (NCB University Press, Vol. 9 No. 5, October 2001)

Prince, M.J. and Felder, R.M. Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education*, *95*(2), pp.123-138, 2006.

Redish, E.F. and Smith, K.A., 2008. Looking beyond content: Skill development for engineers. *Journal of Engineering Education*, *97*(3), pp.295-307.

Rodriguez-Largacha, Garcia-Flores, MF, Fernandez-Sanchez, G., Fernandez-Heredia, Millan, MA, Martinez, JM, Vilardaga, I, and Bernaldo, MO. *Improving student participation and motivation in the leqrning process,* J. Prof. Issues in Engineering Education and Practice, ASCE, Vol 141, Issue 1, 2015.

Royal Academy of Engineering, 2014. *Thinking like an engineer Implications for the education system*, A report for the Royal Academy of Engineering Standing Committee for Education and Training. ISBN: 978-1-909327-08-5 Available at https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report (Accessed 21/03/22).

ASSESSING THE SHIFT IN ENGINEERING STUDENTS' INITIAL KNOWLEDGE AND FIRST-YEAR RESULTS OVER A DECADE

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ABSTRACT

Recent years have seen a shift in the qualifications students have before enrolling in undergraduate engineering programs in the UK. This shift includes numerous changes to the UK A-level syllabus, particularly in key subjects such as Mathematics and Physics. The Covid-19 pandemic also resulted in a reduction in the depth and breadth of the syllabus delivered at secondary school level several transitioning cohorts. Given these circumstances, it became crucial to review and compare the entry-level knowledge of recent students with their predecessors.

A decade ago, the authors, along with several collaborators from UK universities, initiated a project aimed at easing students' transition to university. The project entailed the development of an online questionnaire to quantify the knowledge, understanding, and attributes of incoming engineering students. This report draws on the transition results from that study and compares them with those of recent cohorts. The outcomes at the end of the first year were also compared. The results indicated a decline in performance on the transition survey in various areas, and particularly poorer performance in a mechanics module at the end of the first year. Interestingly, despite students from more recent cohorts achieving higher entry grades, the overall performance seems to have declined, accompanied by an increase in failure rates. This downward trend underscores the importance of addressing any gaps during the transition phase and necessitates a comprehensive review and remapping of the curriculum.

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1 INTRODUCTION

1.1 Engineering Students Transitioning to University

The importance of robust mathematical and analytical skills for engineering students is universally recognised, with most undergraduate engineering degrees containing a high proportion of modules requiring skills and knowledge in these areas. However, studies reveal skills gaps between the expected knowledge of incoming students and reality, particularly in mathematics (Tsui and Khan, 2023) and (Kent and Ross 2003) and mechanics topics (Hawkes and Savage, 2000) and (Lee et al, 2008).

Beginning in 2010, a study at the authors' institution, in collaboration with other UK universities, identified gaps in transitioning students in these areas through means of a transition questionnaire which assessed new student knowledge and understanding of key fundamentals in Mathematics, Physics, Technology and Professional Skills. Despite high A-level grades, first-year students showed gaps in Mathematical, Mechanical, and Manufacturing knowledge (McCartan 2015). This insight informed curriculum changes at that time, highlighting the need for continuous review in light of significant shifts in secondary and higher education sectors.

Subsequent alterations to secondary level syllabi are believed to have impacted the foundational knowledge and skills of students transitioning into engineering undergraduate degrees, especially in A-level Mathematics and Physics. A review of these changes was scheduled for 2020 but was superseded by the Covid-19 pandemic. The potential long-term effects of the educational disruption caused by the pandemic (Pick et al, 2022), coupled with early anecdotal evidence of poorer outcomes for student cohorts transitioning to university post-lockdown (Francis and McClure, 2021), has now necessitated a review to determine if significant changes in student knowledge and skills had transpired over the past decade.

1.2 Rationale

The issues highlighted above have prompted a review of students' knowledge upon entry and their outcomes in the first year. The initial step involved reissuing the previously developed transition study to compare the knowledge and skills of recent first-year students with those from a decade ago. Results were then correlated with student outcomes as indicated by module averages and the number of resits at the end of the first year. The aim of the study is to establish if there have been changes in entry level skills and knowledge and in which areas, and to establish if these changes have impacted outcomes in first year. This should in turn provide preliminary insights for required curriculum modifications or support structures.

2 METHODOLOGY

2.1 Entry Profile

The School offers two main versions of the degree programmes in Mechanical and Aerospace Engineering: a 3 year Bachelor of Engineering honours degree (BEng Hons) and a 4 year integrated Master of Engineering honours degree (MEng). The entry requirements in 2011 and 2012, and from 2019 onwards are summarised in table 1. It can be seen that grade requirements have increased on the BEng pathway from BBC in 2011 to ABB in 2019, and on the MEng pathway from AAB to AAA.

Students have been required to have Mathematics at A level in all years, and at least one other mathematical/science related qualification from a selected range.

The A level grades at entry of the students from each of the cohorts were analysed. This was problematic for the students entering in 2021 as the group did not sit formal final A level examinations due to the pandemic, but instead were awarded grades based on a combination of performance in mock and previous examinations and work completed in school. For this reason, the entry qualifications for students for the academic year 2019-2020 (pre-pandemic) was also included for comparison to determine if there has been a shift in subject or grade profile.

Table 1: Entry Requirements 2011-2023

Entry year	BEng Hons	MEng Hons
2011	BBC including Mathematics and at least one from Physics (preferred), Biology, Chemistry, Design/Technology, Further Mathematics or Double Award Applied Science.	AAB including Mathematics and at least one from Physics (preferred), Biology, Chemistry, Design/Technology or Further Mathematics.
2012	BBB (including Mathematics + Physics/Chemistry/Biology/Technology/ Applied Double Award Applied Science)	AAB including Mathematics and at least one from Physics (preferred), Biology, Chemistry, Design, Further Mathematics or Applied Double Award Science.
2019	ABB including Mathematics and at least one from Physics (preferred), Biology, Chemistry, Further Mathematics, Technology and Design or Double Award Life & Health Sciences.	AAA including Mathematics and at least one from Physics (preferred), Biology, Chemistry or Further Mathematics.

2.2 Transition Survey

This work uses the original web-based questionnaire developed in 2010 and detailed by McCartan (McCartan, 2015). The questionnaire consists of forty questions on knowledge, skills and reasoning in Mathematics, Mechanics, Thermofluids, Nuclear, Electrical, Materials, Manufacturing, Technology, and Professional Skills. Each question permits a “not sure” response to minimise guessing and the rubric emphasises that it is not a test. The questionnaire is given to first year students on entry to the university. A copy of the questions can be found at this survey link.

The survey results give the percentage of successful responses for each of the years, 2011, 2012, 2021 and 2022 and for each of the relevant study areas. Each ten-year period is then compared (2011 & 2021, 2012 & 2022) to determine if there are any differences that can be identified in the pre-entry knowledge, skills, or reasoning over the ten-year period, for students transitioning into first year in Mechanical and Aerospace Engineering degree programmes.

Initially a statistical analysis was carried out to compare the numbers of students answering each question correctly using a two-sample z-test. The standard error (SE) was calculated according to *Eq. (1)*, where p_1 is the proportion of correct answers in group 1, where p_2 is the proportion of correct answers in group 2 and n_1 and n_2 are the sample sizes of group 1 and group 2 respectively.

$$SE = \sqrt{\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}} \quad (1).$$

The SE value was then used to calculate the *z* test statistic (the number of standard deviations away from the mean) from *Eq. (2)*. The *z* score was then correlated with *p*-values for each question. Increases or decreases were deemed to be significant with a *z* value of greater than 1.96 or less than -1.96, correlating with a *p*-value of less than 0.05, which is equivalent to a 95% certainty level.

$$z = \frac{p_1 - p_2}{SE} \quad (2).$$

The areas showing an improvement or decline in each of the ten-year periods were then highlighted and matched to the general topic areas.

2.3 Module Results

Students entering the programmes currently study four year-long core engineering and science modules (Mathematics, Thermodynamics and Fluid Mechanics, Mechanics of Materials and Dynamics) in addition to two more practical modules. In the 2011 and 2012 intake years, the modules were instead run as eight half modules, four in the first semester and four in the second semester. Results for the first-year students at the end of year exam board were analysed across 2011, 2012 and 2021, 2022. For the 2011 and 2012 years the results for the two half modules which were equivalent to current full modules were averaged to allow a comparison to be drawn. Results were also included for the pre-pandemic 2019 cohort to assess any differences that may be attributable to the issues caused by the 2021 intake students not having sat formal A level exams, as discussed in 2.1.

3 Results

3.1 Entry Qualifications

The percentage of first year students entering through the A level qualification with A levels in key subjects is shown in figure 1 for 2012, 2021 and 2022. A full breakdown is not available for 2011. A notable drop is seen in students offering Physics A level between 2012 and 2022, with some reduction also seen in the percentage of entrants with A levels in Chemistry, Biology and Technology and Design.

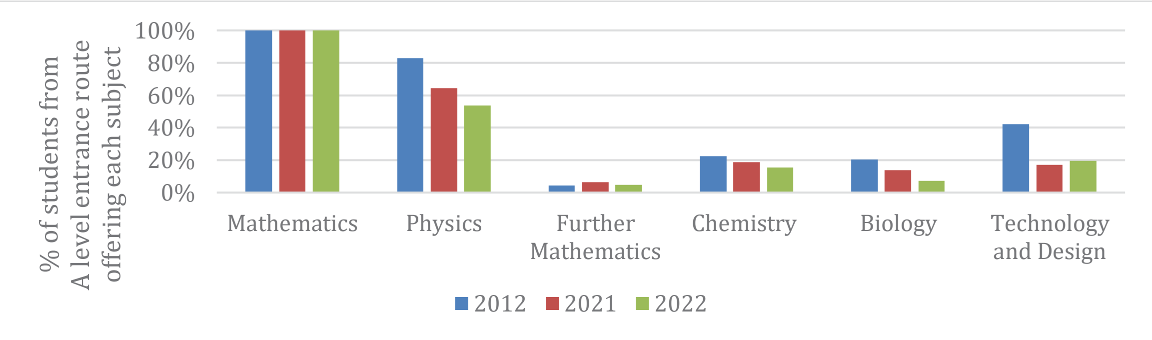

Fig 1: Percentage of A level entrants with key subjects

In line with the increase in entry requirements between 2012 and 2022, a shift in the grade profile of students can also be seen (figure 2). Comparing 2012 and 2022 shows an increase in the percentage of students with A and A* grades in Mathematics (45% in 2012 to 85% in 2022).

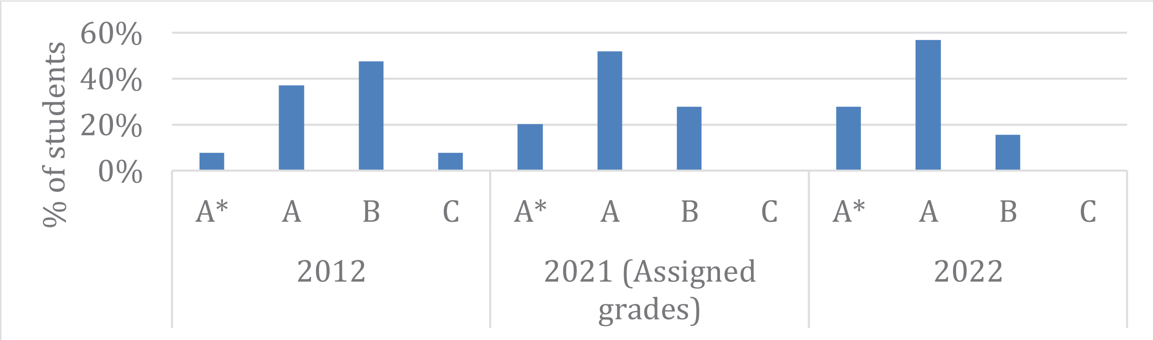

Fig 2: Grade profiles in A level Mathematics

While the number of students offering Physics at A level has fallen notably from 83% to 54%, the grade profile for those offering the subject has shifted slightly to higher grades, with 23% of students holding an A or A* grade in 2012 compared to 32% in 2022 (figure 3). Despite the 2021 entry students receiving assigned grades based on class work, the grade profiles are not out of line with 2022.

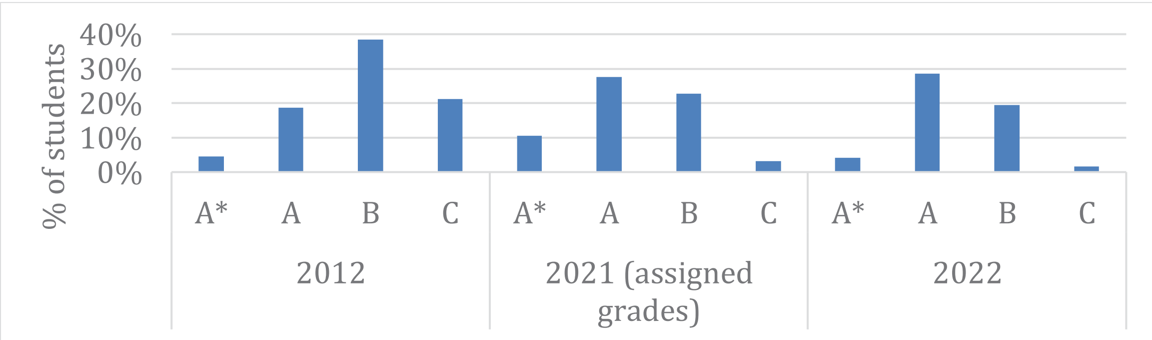

Fig 3: Grade profiles in A level Physics

3.2 Transition Survey Responses

Figure 4 shows a graphical representation of the results by question for the four years examined in the survey. The response rates out of the whole first year cohort for the survey were: 74% in 2011 (102 students participated), 86% in 2012 (124 students returns), 68% in 2021 (84 returns) and 42% in 2022 (62 returns). Overall average scores across the years were similar, at 61%, 62%, 66% and 64% from 2011 to 2022. For most questions, the results across all four years are also remarkably similar, however some clear differences can be seen when comparing the 2011/2012 individual question data to that of 2021/2022.

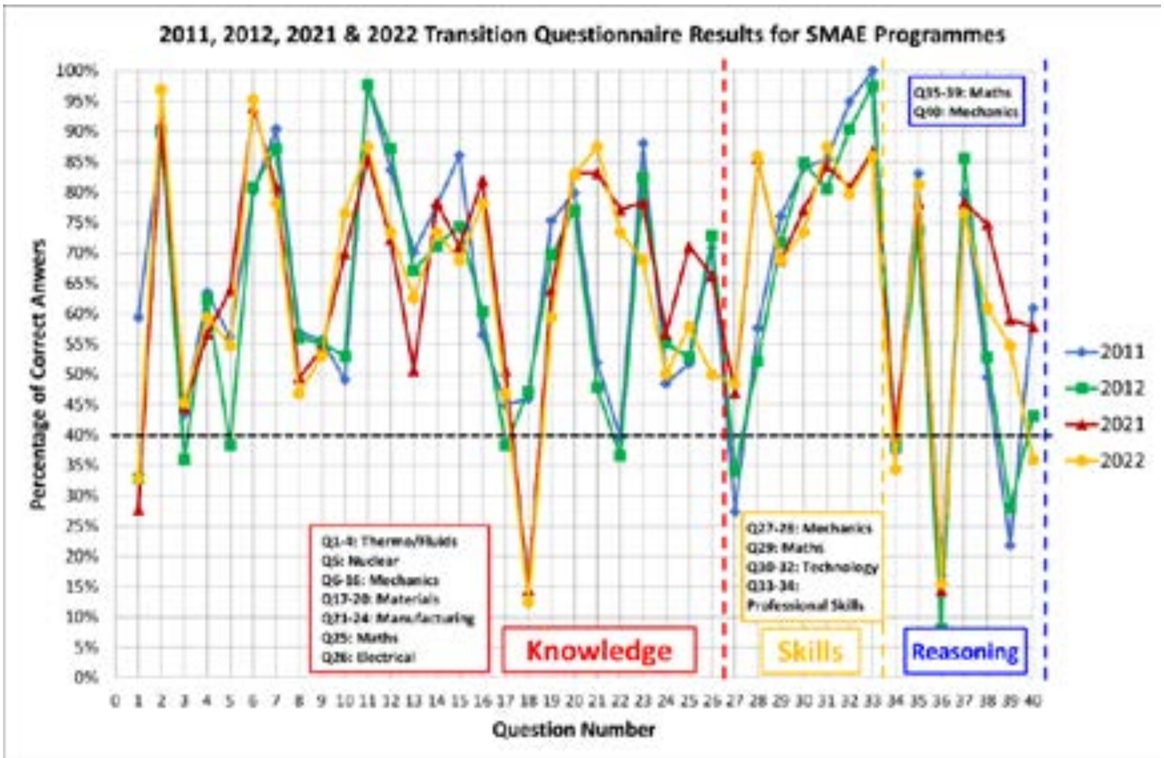

Fig 4: Scatter Plot of Transition Questionnaire Results

Table 2: Identified areas of changes in performance and statistical analysis.

No.	Description	2011	2012	2021	2022	Delta 2021-2011	Delta 2022-2012	Consistent trend	SE 2011/21	z 2011/21	SE 2012/22	z 2012/22	p 2011/21	p 2012/22	Consistently significant change
1	Thermo - heat metal - does hole size increase etc	**59.38%**	**32.80%**	**27.71%**	**32.81%**	-31.66%	0.01%	No	0.07	-4.58	0.07	0.00	0.00	1.00	No
2	Thermo - heat transfer - frying pan, sun radiator	**89.12%**	**89.87%**	**91.57%**	**96.88%**	2.44%	7.01%	INCREASE	0.04	0.56	0.03	2.00	0.57	0.05	No
3	Thermo - boiling point of water at altitude	**43.48%**	**36.00%**	**44.58%**	**45.31%**	1.10%	9.31%	INCREASE	0.07	0.15	0.08	1.22	0.88	0.23	No
4	Fluids - water flowing in conical pipe	**63.44%**	**62.40%**	**56.63%**	**59.38%**	-6.81%	-3.03%	DECREASE	0.07	-0.94	0.08	-0.40	0.35	0.69	No
5	Physics - nuclear power	**56.12%**	**38.40%**	**63.86%**	**54.69%**	7.73%	16.29%	INCREASE	0.07	1.07	0.08	2.12	0.28	0.04	No
6	Mechanics - identify vector and scalar quantities	**80.14%**	**80.67%**	**93.98%**	**95.31%**	13.83%	14.65%	INCREASE	0.05	2.92	0.04	3.29	0.00	0.00	Yes - postive
7	Mechanics - energy	**90.43%**	**87.20%**	**80.72%**	**78.13%**	-9.70%	-9.08%	DECREASE	0.05	-1.86	0.06	-1.50	0.06	0.14	No
8	Mechanics - pulley systems	**56.98%**	**56.00%**	**49.40%**	**46.88%**	-7.58%	-9.13%	DECREASE	0.07	-1.03	0.08	-1.18	0.30	0.24	No
9	Mechanics - gears	**55.68%**	**55.20%**	**54.22%**	**53.13%**	-1.46%	-2.08%	DECREASE	0.07	-0.20	0.08	-0.27	0.84	0.79	No
10	Mechanics - 4 stroke engine cycle	**49.13%**	**53.00%**	**69.88%**	**76.56%**	20.75%	23.56%	INCREASE	0.07	2.94	0.07	3.37	0.00	0.00	Yes - postive
11	Mechanics - statics - truss	**97.78%**	**97.60%**	**85.54%**	**87.50%**	-12.24%	-10.10%	DECREASE	0.04	-2.96	0.04	-2.29	0.00	0.02	Yes - negative
12	Mechanics - Newtons 2nd law	**83.72%**	**87.20%**	**72.29%**	**73.44%**	-11.43%	-13.76%	DECREASE	0.06	-1.87	0.06	-2.16	0.06	0.03	No
13	Mechanics - moments - seesaw	**70.11%**	**67.20%**	**50.60%**	**62.50%**	-19.51%	-4.70%	DECREASE	0.07	-2.74	0.07	-0.63	0.01	0.53	No
14	Mechanics - statics - tension, compression, shear	**77.78%**	**71.20%**	**78.31%**	**73.44%**	0.54%	2.24%	INCREASE	0.06	0.09	0.07	0.32	0.93	0.75	No
15	Mechanics - CoG - aeroplane baggage effect	**86.05%**	**74.40%**	**71.08%**	**68.75%**	-14.96%	-5.65%	DECREASE	0.06	-2.48	0.07	-0.80	0.01	0.43	No
16	Mechanics - units	**56.55%**	**60.34%**	**81.93%**	**78.13%**	25.38%	17.78%	INCREASE	0.06	3.92	0.07	2.60	0.00	0.01	Yes - positive
17	Materials - properties of steel and aluminium	**44.94%**	**38.40%**	**50.60%**	**46.88%**	5.66%	8.48%	INCREASE	0.07	0.77	0.08	1.10	0.44	0.27	No
18	Materials - titanium	**46.07%**	**47.20%**	**14.46%**	**12.50%**	-31.61%	-34.70%	DECREASE	0.06	-5.04	0.06	-5.65	0.00	0.00	Yes - negative
19	Materials - composites	**75.28%**	**69.60%**	**63.86%**	**59.38%**	-11.43%	-10.23%	DECREASE	0.07	-1.68	0.07	-1.37	0.09	0.17	No
20	Materials - identify which is metal, polymer or composite	**79.92%**	**77.00%**	**83.13%**	**82.81%**	3.22%	5.81%	INCREASE	0.06	0.56	0.06	0.95	0.57	0.34	No
21	Manufacturing - production processes	**51.98%**	**47.80%**	**83.13%**	**87.50%**	31.15%	39.70%	INCREASE	0.06	4.84	0.06	6.46	0.00	0.00	Yes - positive
22	Manufacturing - production processes	**39.55%**	**36.64%**	**77.11%**	**73.44%**	37.56%	36.80%	INCREASE	0.07	5.62	0.07	5.19	0.00	0.00	Yes - positive
23	Manufacturing - production processes	**88.00%**	**82.40%**	**78.31%**	**68.75%**	-9.69%	-13.65%	INCREASE	0.06	-1.75	0.07	-2.01	0.08	0.05	No
24	Manufacturing - production processes	**48.48%**	**55.20%**	**56.63%**	**50.00%**	8.14%	-5.20%	No	0.07	1.11	0.08	-0.67	0.27	0.50	No
25	Maths - trig - id trig graphs	**51.76%**	**52.80%**	**71.08%**	**57.81%**	19.32%	5.01%	INCREASE	0.07	2.75	0.08	0.65	0.01	0.52	No
26	Electrical - circuits	**70.93%**	**72.80%**	**66.27%**	**50.00%**	-4.67%	-22.80%	DECREASE	0.07	-0.68	0.08	-3.04	0.50	0.00	No
27	Mechanics - units	**27.37%**	**34.13%**	**46.99%**	**48.44%**	19.62%	14.31%	INCREASE	0.07	2.79	0.08	1.87	0.01	0.06	No
28	Mechanics - scale of different objects	**57.68%**	**52.27%**	**85.54%**	**85.94%**	27.86%	33.67%	INCREASE	0.06	4.47	0.06	5.35	0.00	0.00	Yes - positive
29	Maths - significant figure	**76.00%**	**71.65%**	**68.67%**	**68.75%**	-7.33%	-2.90%	DECREASE	0.07	-1.11	0.07	-0.41	0.27	0.68	No
30	Technology - identify different saws	**84.09%**	**84.80%**	**77.11%**	**73.44%**	-6.98%	-11.36%	DECREASE	0.06	-1.19	0.06	-1.76	0.24	0.08	No
31	Technology - identify different saws	**85.37%**	**80.53%**	**84.34%**	**87.50%**	-1.04%	6.97%	No	0.05	-0.20	0.06	1.27	0.85	0.21	No
32	Technology - identify different screw heads	**94.90%**	**90.40%**	**80.72%**	**79.69%**	-14.18%	-10.71%	DECREASE	0.05	-2.92	0.06	-1.86	0.00	0.06	No
33	Professional Skills - Microsoft Office	**100.00%**	**97.40%**	**86.75%**	**85.94%**	-13.25%	-11.46%	DECREASE	0.04	-3.56	0.05	-2.47	0.00	0.01	Yes - negative
34	Professional Skills - Gantt Chart	**37.23%**	**38.40%**	**39.76%**	**34.38%**	2.52%	-4.03%	No	0.07	0.35	0.07	-0.54	0.73	0.59	No
35	Maths - trig identity	**83.00%**	**73.60%**	**78.31%**	**81.25%**	-4.69%	7.65%	No	0.06	-0.80	0.06	1.21	0.42	0.23	No
36	Maths - comprehension and percentages	**16.84%**	**8.00%**	**14.46%**	**15.63%**	-2.38%	7.63%	No	0.05	-0.45	0.05	1.46	0.66	0.15	No
37	Maths - graphs and percentages	**79.78%**	**85.60%**	**78.31%**	**76.56%**	-1.46%	-9.04%	DECREASE	0.06	-0.24	0.06	-1.45	0.81	0.15	No
38	Maths - pie charts and percentages	**49.48%**	**52.80%**	**74.70%**	**60.94%**	25.21%	8.14%	INCREASE	0.07	3.67	0.08	1.06	0.00	0.29	No
39	Maths - differentiation	**21.84%**	**28.00%**	**59.04%**	**54.69%**	37.20%	26.69%	INCREASE	0.07	5.49	0.07	3.56	0.00	0.00	Yes - positive
40	Mechanics - statics	**60.92%**	**43.20%**	**57.83%**	**35.94%**	-3.09%	-7.26%	DECREASE	0.07	-0.43	0.08	-0.96	0.67	0.34	No

3.3 Statistical analysis of changes in performance

Table 2 presents data on the performance in the survey over the four years. Questions are highlighted in red where a decrease is seen comparing both 2011/2021 and 2012/2022, and in green where a consistent increase is seen in both years. Seventeen questions show a decrease across the decade in both sets of comparator years. Of these, eight are mechanics questions, with the remainder spread across a variety of areas. Consistent statistically significant decreases to the 95% confidence level across both sets of years are only seen in three questions. Seventeen questions show an increase in student performance in both sets of years, five in mechanics, five in manufacturing and materials, and a spread across the other areas. Five questions showed statistically significant increases in both sets of years.

3.4 Performance at the end of year 1

The averages and standard deviations of module marks for the four core modules are presented in figures 5 and 6 for students on the BEng and MEng degrees respectively. Aerospace and Mechanical Engineering students are combined in the presented results. For Mathematics, the average values across the years analysed have remained relatively flat, although 2022-23 was the lowest year for both MEng and BEng students. Mechanics of Materials shows the most obvious drop in performance comparing the pre-Covid years to the latest two years analysed, and averages are out-of-line with the other modules. This may correspond to the reduction in performance in mechanics-related questions in the transition survey, and to the reduction in the percentage of students completing an A level Physics qualification coupled with a reduction in the mechanics content of the A level Mathematics syllabus. Dynamic Systems has been very consistent over the years. Thermodynamics and Fluid Mechanics showed a large drop in performance for the BEng students in 2018-19, but subsequent interventions and changes in the module have led to an upswing in results for these students.

It is notable that the attainment gap between MEng and BEng students seems to have narrowed over the years in the majority of the modules, potentially due to the entrance grade requirements to the degree programmes being raised and the difference in BEng and MEng requirements narrowing. However, it is clear that the uplift in intake requirements has not resulted in an uplift in performance, which is in fact slightly lower overall, and first-time failure rates are clearly higher (figure 7).

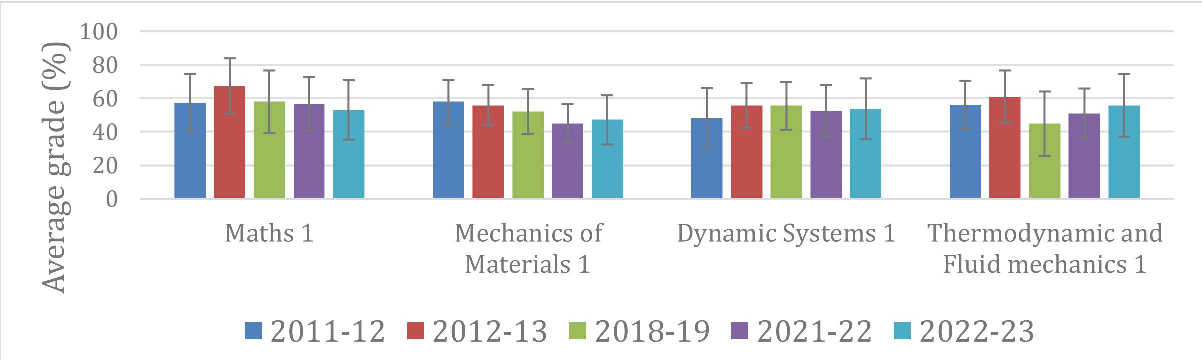

Figure 5: End of year 1 averages in core modules - BEng Students

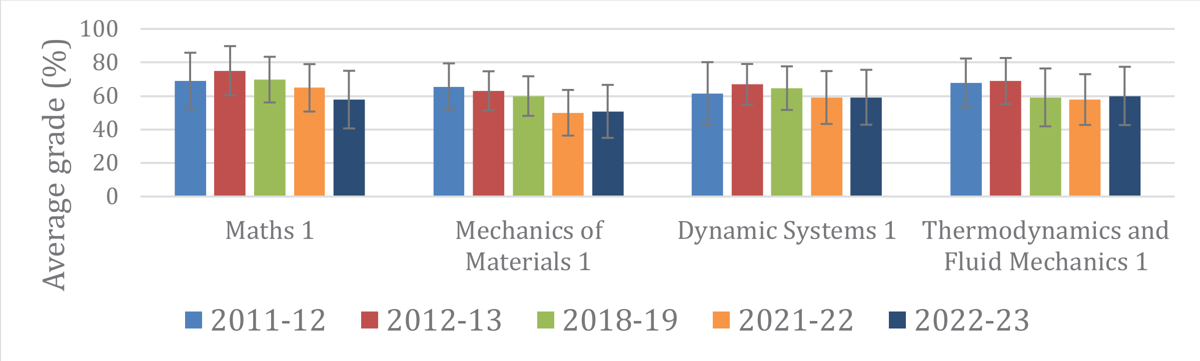

Figure 6: End of year 1 averages in core modules - MEng Students

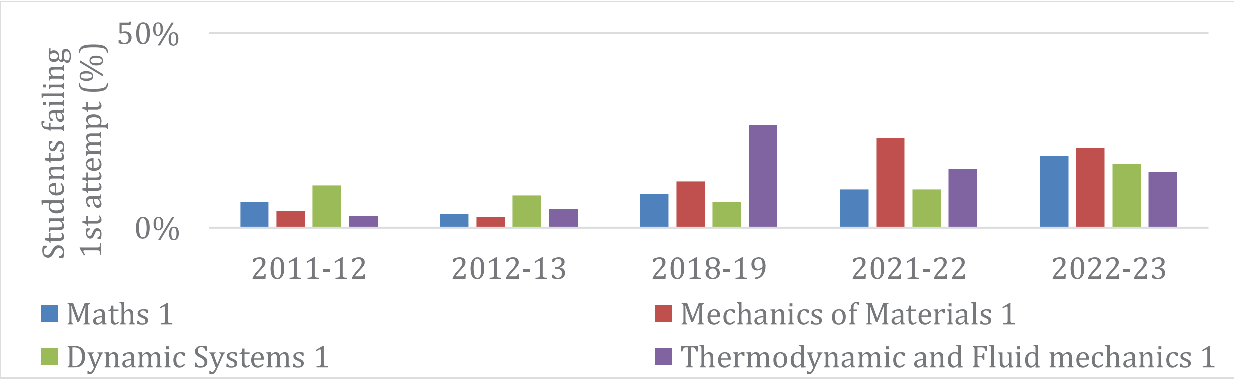

Figure 7: Percentage of students failing on first attempt

4 CONCLUSIONS

Overall, the results suggest that there are certain shifts in student entry level knowledge and understanding in some key engineering-related topics comparing recent years with a decade ago. The transition survey results indicate declines in performance in some areas, around half of which are in mechanics topics, but there are increases in others. Entry level qualifications of the students are higher than they were a decade ago, but most module averages show slight declines, and overall failure rates at the end of year 1 are higher. A reduction in performance in the year 1 Mechanics of Materials module in particular is likely due to the reduction in students entering the programmes with an A level Physics qualification, coupled with reduction in Mechanics content in the A level Mathematics syllabus. Some of this decrease may also be due to the incomplete coverage of the syllabus during and in the immediate aftermath of the Covid-19 pandemic.

Regardless of the reasons, the university has limited control over pre-entry knowledge, but must proactively respond to the needs of changing cohorts of students entering the programmes. This study has indicated that there is a need for a timely remapping of entry knowledge and skills, and recalibration of the current year one syllabus to be carried out to ensure that students transition successfully into their engineering degree programmes. However, the picture is a complex one, and it is difficult to present a fully controlled comparison of current and historical results given the variety of factors that have changed over the years and further in-depth analysis will be required to draw out clear causal factors and trends. The next steps in the work will involve a more detailed mapping of A level syllabi and student entry knowledge to the current stage 1 curriculum to identify any mismatches, and to identify other factors that may be at play. This will then allow some curriculum design recommendations to be made. Results of this study will be presented in due course.

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REFERENCES

Tsui, T., Khan, N. 2023. "Is Mathematics a Barrier for Engineering?" *International Journal of Mathematical Education in Science and Technology* 54 (9): 1853-1873.

Kent, P., Noss, R. 2003. "Mathematics in the University Education of Engineers." Accessed from https://www.researchgate.net/publication/246780000_Mathematics_in_the_University_Education_of_Engineers.

Hawkes, T., Savage, M. 2000. *Measuring the Mathematics Problem*. London, UK: Engineering Council.

Lee, S., Harrison, M.C., Robinson, C.L. 2008. "Identifying What Makes a Good Question in a Mechanics Diagnostic Test." *International Journal of Mechanical Engineering Education*.

McCartan, C.D. 2015. "A Transition Study to Support Curriculum Reform." In *Proceedings of the 11th CDIO Conference*, Chengdu.

Pick, L., McCartan, C., Fee, K., Hermon, J.P. 2022. "The Experiences of Students Transitioning Back to In-Person Learning Post Covid-19." In *Proceedings of SEFI 50th Annual Conference, Barcelona, 2022*

Francis, N., McClure, L., Willmott, C. 2021. "Preparing for the Covid Cohort." *The Biologist*. Accessed from https://www.rsb.org.uk/biologist-covid-19/preparing-for-the-covid-cohort-2.

Engineering Education Accreditation Frameworks: History and Global Expansion of the Washington Accord and EUR-ACE Label

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ABSTRACT

In this exploratory study, we set out to reconstruct and critically analyse the history of two engineering education accreditation frameworks with a global reach: the Washington Accord (WA), and the EUR-ACE label. Because these two frameworks have significantly expanded over the last decade, such a historical analysis would be beneficial in outlining the values and motivations associated with each of them, contributing to a deeper understanding of their current and future efforts. To achieve

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this, we analysed 35 of approximately 360 documents retrieved from current and previous versions of websites officially related to each of these frameworks. Documents from older versions of the websites were retrieved through the Internet Archive's Wayback Machine. Our analysis procedure started with descriptive coding of the documents, followed by a reflective analysis of the codes, which led to the identification of themes relevant for the focus of this work. In this paper, we report the preliminary results of our analysis. Our results suggest that both WA and EUR-ACE are motivated by economic aspects of mobility, competitiveness, and economic pressure. Framing our results through the geopolitics of knowledge and Fanon's zone of being/non-being reveals the colonial dimensions of these two frameworks.

1 INTRODUCTION

This paper provides an exploratory historical analysis of two global accreditation frameworks in engineering education: the European Accredited Engineer (EUR-ACE) and the Washington Accord (WA). Understanding the values embedded in these two dominant accreditation frameworks and their historical context is paramount to frame their current and future expansion efforts. This becomes important as global dynamics prompt more countries to uncritically consider implementing quality assurance systems originating in the Global North as they seek to remain globally competitive (Sánchez-Chaparro et al. 2022; Blanco Ramírez 2014). Such approaches, in addition to the colonial history of the engineering profession, lead to a risk of challenging or displacing the local values and strengths of existing engineering education systems (Nasr 2014; Eichhorn 2020). Therefore, historical research lends itself well to this topic, as it can expose the evolution of perspectives and approaches in these accreditation frameworks, allowing for a more critical perspective on accreditation platforms with global influence (Schrag 2021).

As a response to changes driven by globalization, the International Engineering Alliance (IEA) and the European Network for Accreditation in Engineering Education (ENAEE) emerged as two key international organizations that established equivalencies between engineering degrees in different regions through accreditation. These organizations' efforts gained traction because of ideas such as international competitiveness of engineering programs, facilitating the mobility of engineering students and professionals, and potential economic gains (Augusti 2009; Alam and Kootsookos 2021; Turhan, Sengul, and Koyuncu 2015; Mohd Said et al. 2013; Aoudia 2022). To establish such equivalencies, these two organizations maintain engineering accreditation frameworks that direct accreditation agencies in different countries to adopt similar learning outcomes and assessment procedures in engineering programs (IEA 2014; Alam and Kootsookos 2021; ENAEE 2021). The WA, originated in 1989, describes the accreditation framework maintained by the IEA, whereas ENAEE's accreditation framework is described through the EUR-ACE label, which originated in the mid-2000s. These two frameworks now have a large global presence, with the WA currently having over 20 full signatories and 7 provisional signatories (IEA 2023), while 15 different accreditation agencies are authorized to award the EUR-ACE label (ENAEE 2022).

Prior research on these two frameworks has tended to emphasize their technical aspects and not their historical backgrounds. For example, Aoudia (2022) compared the requirements for the two accreditation frameworks to understand which would be an appropriate entry point for engineering accreditation in Saudi Arabia. Other studies more directly compare the standards themselves, highlighting the similarities and different nuances in defining and assessing knowledge, skills, and competencies (Freeston 2009; Hanrahan 2009). Another type of work focuses on analysing specific aspects of these standards, for example in terms of degree outcomes related to engineering ethics (Jesiek, Zhu, and Vinod, Forthcoming). As a contrasting example, Alam and Kootsookos (2021) briefly compare the two frameworks while providing a more detailed historical background for each; however, their work on the history of these two frameworks was mostly descriptive. The current literature is still lacking in more detailed and critical historical analyses of these two frameworks.

To provide the historical and contextual analyses presented below, we collected and examined historical documents made available by the organizations (IEA and ENAEE) and their members at different points in time. The overarching research question guiding this study is: *What are the values and motivating circumstances for the establishment and expansion of the WA and EUR-ACE accreditation frameworks?* The specific research question we answer through our preliminary analysis in this paper is: *What are the factors used to justify the creation and expansion of the WA and EUR-ACE accreditation frameworks?* These factors could be of economical, political, or technical nature; and identifying them can help us critically examine what these frameworks have been accomplishing in a global scale.

2 LITERATURE REVIEW

2.1 Globalization and engineering

Due to its ties to economical activities and the development of technologies, engineering is a key part of globalization, simultaneously driving and being driven by it. Globalization can be understood as the process of changing the mobility of people, goods, behaviours, and services, as they encounter less or more barriers to traverse different regions or jurisdictions (Lechner and Boli 2015; Ritzer and Dean 2015). The globalization movement has been accelerated by the evolution of technology and the expansion of economic markets, creating a network of global interdependence (Ritzer and Dean 2015; Sen 2015; Sklair 2015; Weiss 1999). Engineering and other forms of scientific knowledge are frequently at the forefront of technological and economic development and can thus be strategically controlled by high-income countries to emphasize their role in global dynamics (Freeman 2010). Thus, globalization leads to concerns around the competitiveness of engineers in a global job market and the standardization of products, processes, and services that ensure global compatibility (Acosta 2010; Freeman 2010). Engineering education is, therefore, also affected by global influences such as transnational education (Alam and Kootsookos 2021), exchange or academic visitor programs (Freeman 2010; Downey et al. 2006; Johri and Jesiek 2014), and international validation of program structures and outcomes, frequently through accreditation (Nasr 2014).

2.2 Colonialism and engineering education

Although most forms of settler-based colonization came to an end after the end of World War II, colonial legacies remain and new forms of colonization emerged. Colonial legacies can be identified through systems and structures that were created during colonial times but persist to this day. In higher education (HE), for example, it is argued that universities were built in colonies to serve colonial interests (educating settlers and local elites, maintaining the status of universities in the colonizing countries as superior, and operating in ways disconnected from local problems and realities), which still shape how these institutions operate today in former colonies (Abrokwaa 2017; Guzmán-Valenzuela 2023). As for new forms of colonization, political and economic factors uphold structures and actions that maintain existing dynamics for the exploitation of natural resources and labour by former colonial powers (Pearson et al. 2019; Sayed and Agndal 2022; Wijesinghe, Mura, and Bouchon 2019). These new forms of colonization manifest themselves in HE through university ranking systems, quality assurance models, and recognition of only certain forms of knowledge (Blanco Ramírez 2014; Sánchez-Chaparro et al. 2022; Kells 1999). These issues extend to engineering education due to its place in HE and the previously explored connections between engineering and globalization. In a review of literature about decolonizing engineering education, Seniuk Cicek et al. (2023) identify that this type of work addresses an assumed superiority of Western engineering standards and the education of engineers to serve in a neoliberal system. Thus, decolonization in engineering education within HE institutions can take the form of revising program structures by incorporating indigenous knowledge and pedagogies that highlight the needs and values of local communities.

3 THEORETICAL FRAMEWORK

The theoretical approach used in this work is directly informed by the dynamics of globalization and decolonial thought in engineering education. More specifically, we use Shahjahan and Morgan's (2016) conceptualization of decolonial thought, based on geopolitics of knowledge and zones of being. The geopolitics of knowledge aspect comes from Mignolo's (2003) work, which establishes that the power relations embedded in knowledge systems derive from the social context in which those systems emerged. Thus, the expansion and domination of these knowledge systems is facilitated through these power relations, potentially shaping knowledge in a global scale. The aspect of zones of being (and non-being) derives from Fanon's (1967) work, which originally discussed these aspects in relation to racism. Fanon defines beings as people who are recognized through their social systems as worthy of having rights, while non-beings are those without such recognition. The existing structures compel those in the zones of non-being to seek recognition from those in the zones of being so they can be valued. Within global dynamics, Shahjahan and Morgan (2016) contextualize this idea in terms of peripheral countries seeking to emulate HE standards to be acknowledged in a global knowledge system.

In their original work, Shahjahan and Morgan (2016) utilized this framework to analyse OECD's Assessment of Higher Education Learning Outcomes (AHELO) initiative. The authors classify this initiative as a form of establishing global spaces of equivalence for HE, which they define as socially constructed spaces where various events can be described and compared according to standard norms. Moreover, they describe these spaces as "universalized, delocalized, and depoliticized so that they are seen as legitimate comparative measures." (pp. 92–93). Following this definition, we understand the accreditation frameworks of interest to this study as variations of global spaces of equivalence specific to engineering education, and thus we use this framework to contextualize our findings.

4 METHODS

This study uses historical research methods and qualitative analysis methods. The reconstruction of historical events was carried out through the analysis of documents related to the IEA and to ENAEE. In both instances, the document retrieval process started with the official websites for both organizations and snowballed to include publications historically included in their online material, using the Wayback Machine's archive as a source. Most documents retrieved using the Wayback Machine were located using the service's URL function, which lists all archived assets associated with the specified web domain. We filtered the assets for PDFs and office suite documents. For ENAEE, the domains were enaee.eu and feani.org; and for IEA, the domains included ieagreements.org and washingtonaccord.org. Additional publications were sought as we found names of relevant actors for the development of both frameworks and clear gaps in the documentation were found (e.g., no copy of the original 1989 version of the WA). The final breakdown of documents and their broad categories are reported in Table 1.

Table 1. Description and numbers of document types retrieved. Duplicates are not included in the document count.

Document category	Description	# of documents retrieved
Official document	Documents published by either IEA or ENAEE documenting their working procedures, guidelines, and other official manifestations. Also includes legal documents related to either organization.	157
Presentation	Presentations made during meetings or conferences held by the IEA or ENAEE.	71
Academic publications	Includes publications made by authors who attended the meetings and conferences held by the IEA or ENAEE. These publications typically have presentations associated with them.	47
Program documents	Documents that detail the topics and schedule of meetings/conferences organized by the IEA or ENAEE. Also includes commentaries and wrap-up documents discussing the events as a whole.	27
External documents	Documents created by external organizations (including accreditation agencies in the countries that are part of the accords) that reference activities done in partnership with the IEA or ENAEE, or that document certain	61
Total	-	363

For this paper, we analysed 36 (10%) of the retrieved documents using reflexive thematic analysis. We chose the documents analysed at first as to prioritize overviews on the current state and history of the frameworks. After examining some documents, we pivoted our focus to the presentation documents, which offered more insights into the principles that were guiding the discussions and decisions being made in the context of the two frameworks. To build a preliminary understanding of the general circumstances that led to the creation and the expansion of these accreditation frameworks, we started our analytical process with coding. Given this more general goal and our research questions, the first author mainly relied on descriptive coding strategies. As outlined by Saldaña (2013), descriptive coding identifies the general topic that each passage focuses on, and helps in identifying patterns within the data, which can be helpful when dealing with large amounts of data. Later, the first author engaged in reflexive analysis of the codes to identify themes relevant to the research questions, discussing the process with the other authors (Braun and Clarke 2012; Byrne 2022). After jointly discussing our findings, we were only confident in the evidence that we had to support one of these themes. The other potential themes shall be expanded upon in future versions of this work, when we are done analysing all the documents we retrieved.

5 RESULTS

This paper presents the results of an exploratory analysis of these documents. In this section, we will detail a single theme we identified that has been pertinent for the establishment and expansion of both accreditation frameworks. We call this theme “Pressure for Going Global”. The first element of this theme is the promotion of mobility for engineering professionals. Documents related to the WA consistently emphasize the ability of engineers who earned their degree from accredited programs in any of the signatory countries to have their education credentials recognized by other signatories—effectively enabling them to directly practice engineering or seek authorization from the local authorities. In other words, one of the main motivators of this accord is establishing a mutual recognition of engineering qualifications between signatories: “Through the Washington Accord, which comprises this Agreement, the Rules and Procedures, the signatories recognise the substantial equivalence of such programmes in satisfying the academic requirements for the practice of engineering at the professional level.” (IEA 2023a, 5). Similarly, ENAEE established mobility as a core goal for the EUR-ACE label, being particularly influenced by the effects of economic integration within the European Union. Additionally, the integration of HE across Europe through the Bologna Process motivated ENAEE to frame mobility not only for engineering professionals, but also for engineering students. For both organizations, maintaining the mobility of engineering students and professionals stands at the core of their mission, with recent expansion efforts further strengthening this aspect.

The second element of “Pressure for Going Global” is that of competitiveness for engineering professionals. Because of global economic integration, engineers are now frequently expected or encouraged to perform their work in different countries or regions. As such, it is the desire of both IEA and ENAEE to ensure that engineering graduates in countries that follow their accreditation frameworks remain competitive in the global job market. In a presentation given shortly after the establishment of ENAEE and the EUR-ACE label, Giuliano Augusti, who had a key role in leading ENAEE in its early years, wrote: “The lack of an European accreditation system, notwithstanding the prestige of many National systems and of some Academic titles, in a global job market puts the European engineer in a objectively weak position, when confronted with the several existing international recognition agreements.”

(Augusti 2008, 7). For the IEA, this idea is expressed more implicitly in their documents. In recent times, their concerns over competition are made implicit under globalization: “The international recognition and portability of both educational qualifications and professional competency is becoming increasingly important in this age of global interdependence but unbalanced global development, which requires movement of engineering skills around the world” (IEA 2014, 4).

The following quote from a paper presented at an ENAEE Annual Conference co-authored by Giuliano Augusti demonstrates the points just outlined: “...it must not be forgotten that the original motivation behind EUR-ACE was, and still is, to establish a pan-European accreditation system of quality engineering education, extensively accepted by the broad engineering stakeholders community: indeed, the lack of such a system still involves great difficulties in trans-national recognition and mobility of European engineering students and graduates, that EUR-ACE is trying to overcome.” (Augusti et al. 2013, 3).

The final element of our theme consists of economic pressures influencing the creation and expansion of the accreditation frameworks. An example of this is that the Washington Accord was drafted explicitly considering the development of the European Economic Community (EEC). Ray Meyer, the representative of Engineers New Zealand in when the accord was drafted wrote: “As a background to the deliberations, developments in Europe were also considered. The EEC becomes a single and important market in 1992 and access to this market for engineering goods and services will be important” (Meyer 1989, 38–39). For the expansion of the WA, the 25th anniversary document states that, after some years of the accord’s existence, “the growth in interest by other organisations indicated the need for more structure and formality” (IEA 2014, 10). This quote suggests that the WA was pressured by external accreditation agencies to consider expanding, potentially so that these other organizations could enjoy the indirect economic benefits of being part of this group—consequences of the mobility and competitiveness elements highlighted previously. More recently, the IEA has partnered with UNESCO and the World Federation of Engineering Organizations (WFEO) to promote their perspectives on quality of engineering education.

For ENAEE, economic pressures are more directly mentioned in their documents, guiding both the original establishment of the accreditation framework and its expansion. The initial development of EUR-ACE framework happened as a consequence of the Bologna Process, which is one of the key strategies in the economic development of the European Union. As a more specific example, their expansion efforts in Central Asian countries were carried out through the QUEECA (Quality of Engineering Education in Central Asia) project. One of the goals of QUEECA was to “promote the practice of transnational recognition of engineering qualifications and facilitate engineering graduates mobility, taking into account the Central Asian regional economy and integration also in the global educational space” (Augusti 2013, slide 20). This quote evidences how an interest in promoting the economic integration of Central Asia with the global economy partly drove the EUR-ACE expansion to that region. Similar goals and statements can be seen in the MEDACCR (On-line Quality Assurance and EUR-ACE Accreditation of Engineering Programmes in the Mediterranean Area) project.

6 DISCUSSION

6.1 Globalization and engineering accreditation frameworks

Many of the aspects of globalization outlined in the literature review were relevant in the documents analysed. First, the element of mobility identified as one of the main motivators for these accreditation frameworks is aligned with the of changing the flow of engineering students and professionals globally. However, as highlighted by Ritzer and Dean (2015), mobilities can also be hindered through globalization, and we should consider how the creation and expansion of these frameworks might also negatively impact the mobility of students and professionals who are trained outside of these accords. The conformity of certain accreditation agencies to one of the accords but not the other also has the potential of negatively affecting mobilities in certain regions, as the two frameworks coexist in some jurisdictions (e.g., Turkey, Peru, Russia). Second, the element of competitiveness directly relates to the literature in globalization because it represents instances of regions being motivated to ascertain their economic competitiveness by establishing mechanisms to dictate the value of engineering degrees. As established by Freeman (2010), strategic control of scientific and engineering knowledge constitutes a strategy that dominant countries can use to promote their long-term economic dominance.

6.2 Colonialism in engineering education accreditation

In light of the geopolitics of knowledge, it is important to highlight that the WA and EUR-ACE frameworks emerged in the Anglosphere and in Europe, respectively. As such, the social context on which these systems came to be conceptualized and developed is aligned with the dominant knowledge systems in engineering. Therefore, the establishment and expansion of these systems was facilitated on a global scale. Our analysis indicates that proponents of these systems were aware of such dynamics, as both systems were proposed, at least in part, to help maintain the epistemic and economic dominance of those regions. The expansion of these frameworks to regions outside their initial scope might be influenced by countries in the zone of non-being wanting to move to to the zone of being in the case of those joining the WA and those involved in ENAEE’s QUEECA project. In that sense, countries that adopt such frameworks outside the Global North continue the historical valuing of colonizer interests as they follow existing rules in hopes of having “world-class” institutions (Abrokwaa 2017; Blanco Ramírez 2014; Guzmán-Valenzuela 2023). However, a more complete analysis of the documents is needed to confirm this hypothesis. Finally, the theme we highlighted through our analysis demonstrates a significant alignment with findings from (Shahjahan and Morgan 2016): “the fetishized prizes of this [academic] Olympiad are primarily: a globally competitive labor force, credential mobility, and accountability practices.” (p.105). Our findings thus add to the literature by providing parallels between previous findings in other areas and in engineering education, specifically for a globally competitive labour force and credential mobility.

7 SUMMARY AND ACKNOWLEDGEMENTS

Accreditation frameworks in engineering such as the WA and EUR-ACE have been successfully established and continue to expand globally, providing mechanisms for enhancing the mobility of engineering students and professionals. However, these accreditation frameworks have social and political consequences that the engineering community needs to be conscious of. Thus, through an exploratory analysis of historical documents associated with EUR-ACE and WA, this paper provided an initial perspective on how these systems operate under globalization and colonialist perspectives. We highlight how the idea of global engineering education is currently enabling new forms of epistemic dominance. Even though some level of global cooperation on accreditation frameworks for engineering education would be beneficial for a multitude of reasons, we need to understand the impacts of doing so on local systems of engineering education to avoid losing their existing strengths. Due to its exploratory nature, only a portion of the documents retrieved were analysed, meaning that there are likely more nuances to some of the ideas discussed in here. In our future research, we intend complete the analysis of all documents we retrieved, looking to understand how much voice new accreditation agencies have over making their processes distinct and locally relevant. Additionally, we wish to further triangulate the findings of our analyses through interviews with current and past members of ENAEE and IEA. This paper can thus inform research to better understand the motivations of countries seeking to join the IEA or ENAEE, and what the dynamics between these organizations and incoming countries are.

REFERENCES

Abrokwaa, Clemente. 2017. “Colonialism and the Development of Higher Education.” In *Re-Thinking Postcolonial Education in Sub-Saharan Africa in the 21st Century*, edited by Edward Shizha and Ngoni Makuvaza, 203–20. Rotterdam: SensePublishers. https://doi.org/10.1007/978-94-6300-962-1_12.

Acosta, Carlos. 2010. *Global Engineering: Design, Decision Making, and Communication*. Boca Raton, FL: CRC Press.

Alam, Firoz, and Alexandra Kootsookos. 2021. *Engineering Education: Accreditation & Graduate Global Mobility*. 1st ed. Boca Raton: CRC Press. https://doi.org/10.1201/9781351182003.

Aoudia, Mouloud. 2022. “Appropriateness of the International Accreditation Frameworks of Engineering Education to the Academic Engineering Programs in Saudi Arabia: A Comparative Study.” *International Journal of Advanced and Applied Sciences* 9 (3): 123–32. https://doi.org/10.21833/ijaas.2022.03.014.

Augusti, Giuliano. 2008. “ENAEE: A No-Profit European Association; EUR-ACE: A Pan-European ‘Labelling’ System for Accredited Engineering Programmes.” Presented at the Engineering Deans’ Conference, EUR-ACE session, Berlin, Germany, February 25.

Augusti, Giuliano. 2009. “EUR-ACE: The European Accreditation System of Engineering Education and Its Global Context.” In *Engineering Education Quality Assurance: A Global Perspective*, edited by Arun S. Patil and Peter Gray, 41–50. Dordrecht ; New York: Springer.

Augusti, Giuliano. 2013. “New ‘Markets’ for EUR-ACE: A Central Asia Project and a Proposal for the Mediterranean Basin.” Presented at the ENAEE Annual Conference, Leuven, Belgium, September.

Augusti, Giuliano, Claudio Borri, Michele Betti, and Elisa Guberti. 2013. “New ‘Markets’ for EUR-ACE: A Central Asia Project and a Proposal for the Mediterranean Basin.” In , 8. Leuven, Belgium: ENAEE.

Blanco Ramírez, Gerardo. 2014. “Trading Quality across Borders: Colonial Discourse and International Quality Assurance Policies in Higher Education.” *Tertiary Education and Management* 20 (2): 121–34. https://doi.org/10.1080/13583883.2014.896025.

Downey, Gary Lee, Juan C. Lucena, Barbara M. Moskal, Rosamond Parkhurst, Thomas Bigley, Chris Hays, Brent K. Jesiek, et al. 2006. “The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently.” *Journal of Engineering Education* 95 (2): 107–22. https://doi.org/10.1002/j.2168-9830.2006.tb00883.x.

Eichhorn, Stephen J. 2020. “How the West Was Won: A Deconstruction of Politicised Colonial Engineering.” *The Political Quarterly* 91 (1): 204–9. https://doi.org/10.1111/1467-923X.12773.

ENAEE. 2021. “EUR-ACE Framework Standards and Guidelines.” https://www.enaee.eu/wp-content/uploads/2023/11/EAFSG-approved-4-Nov-2021.pdf.

ENAEE. 2022. “EUR-ACE Label Awards: Authorization Period.” https://www.enaee.eu/wp-content/uploads/2022/01/authorization-period_-January-2022.pdf.

Fanon, Frantz. 1967. *Black Skin, White Masks*. Translated by Charles Lam Markmann. New York, NY: Grove Press.

Freeman, Richard B. 2010. “Globalization of Scientific and Engineering Talent: International Mobility of Students, Workers, and Ideas and the World Economy.” *Economics of Innovation and New Technology* 19 (5): 393–406. https://doi.org/10.1080/10438590903432871.

Freeston, Ian. 2009. “Progressing Towards Global Standards in Engineering Education.” In *ENAEE Workshop*. Brussels: ENAEE.

Guzmán-Valenzuela, Carolina. 2023. “Dismantling New and Old Forms of Colonialism: Border Thinking in Latin American Universities.” *Globalisation, Societies and Education* 21 (2): 187–203. https://doi.org/10.1080/14767724.2022.2095988.

Hanrahan, Hu. 2009. “Toward Consensus Global Standards for Quality Assurance of Engineering Programmes.” In *Engineering Education Quality Assurance: A Global Perspective*, edited by Arun S. Patil and Peter Gray, 51–71. Dordrecht ; New York: Springer.

IEA. 2014. “1989–2014: 25 Years Washington Accord: Celebrating International Engineering Education Standards and Recognition.” International Engineering Alliance. https://www.ieagreements.org/assets/Uploads/Documents/History/25YearsWashingtonAccord-A5booklet-FINAL.pdf.

IEA. 2023a. “Accord Rules and Procedures.” International Engineering Alliance.

IEA. 2023b. “Washington Accord: Signatories.” 2023. https://www.ieagreements.org/accords/washington/signatories/.

Jesiek, Brent K., Qin Zhu, and Gouri Vinod. , Forthcoming. “Foundational Perspectives on Ethics in Engineering Education.” In *The Routledge International Handbook of Engineering Ethics Education*, edited by Tom Børsen, Shannon Chance, Diana A. Martin, Gunter Bombaerts, Roland Tormey, and Thomas T. Lennerfors.

Johri, Aditya, and Brent K. Jesiek. 2014. “Global and International Issues in Engineering Education.” In *Cambridge Handbook of Engineering Education Research*, edited by Aditya Johri and Barbara M. Olds, 655–72. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139013451.040.

Kells, H R. 1999. “National Higher Education Evaluation Systems: Methods for Analysis and Some Propositions for the Research and Policy Void.” *Higher Education* 38 (2): 209–232. https://doi.org/10.1023/A:1003704015735.

Lechner, Frank J., and John Boli, eds. 2015. *The Globalization Reader*. Fifth edition. Chichester, West Sussex, UK : Malden, MA: Wiley.

Meyer, Ray. 1989. “Mutual Recognition of Engineering Qualifications.” *New Zealand Engineering* 44 (4): 38–39.

Mignolo, Walter D. 2003. “Globalization and the Geopolitics of Knowledge: The Role of the Humanities in the Corporate University.” *Nepantla: Views from South* 4 (1): 97–119.

Mohd Said, Suhana, Chee-Onn Chow, N. Mokhtar, Rahizar Ramli, Tuan Mohd Yusoff Shah Tuan Ya, and Mohd Faizul Mohd Sabri. 2013. “Accreditation of Engineering Programs: An Evaluation of Current Practices in Malaysia.” *International Journal of Technology and Design Education* 23 (2): 313–28. https://doi.org/10.1007/s10798-011-9180-6.

Nasr, Karim J. 2014. “Towards a Converged and Global Set of Competencies for Graduates of Engineering Programs in a Globalization-Governed World.” *Ideas for Better Education & Training for Engineers* 18 (March):15–32.

Pearson, Zoe, Sara Ellingrod, Emily Billo, and Kendra McSweeney. 2019. “Corporate Social Responsibility and the Reproduction of (Neo)Colonialism in the Ecuadorian Amazon.” *The Extractive Industries and Society* 6 (3): 881–88. https://doi.org/10.1016/j.exis.2019.05.016.

Ritzer, George, and Paul Dean. 2015. *Globalization: A Basic Text*. 2. ed. Malden, MA, USA.: Wiley Blackwell.

Sánchez-Chaparro, Teresa, Bernard Remaud, Víctor Gómez-Frías, Caty Duykaerts, and Anne-Marie Jolly. 2022. “Benefits and Challenges of Cross-Border Quality Assurance in Higher Education. A Case Study in Engineering Education in Europe.” *Quality in Higher Education* 28 (3): 308–25. https://doi.org/10.1080/13538322.2021.2004984.

Sayed, Zehra, and Henrik Agndal. 2022. “Offshore Outsourcing of R&D to Emerging Markets: Information Systems as Tools of Neo-Colonial Control.” *Critical*

Perspectives on International Business 18 (3): 281–302. https://doi.org/10.1108/cpoib-07-2020-0089.

Schrag, Zachary M. 2021. *The Princeton Guide to Historical Research*. Skills for Scholars. Princeton Oxford: Princeton University Press.

Sen, Amartya. 2015. “How to Judge Globalism.” In *The Globalization Reader*, edited by Frank J. Lechner and John Boli, Fifth edition, 19–24. Chichester, West Sussex, UK : Malden, MA: Wiley.

Seniuk Cicek, Jillian, Stephanie Masta, Tom Goldfinch, and Bruce Kloot. 2023. “Decolonization in Engineering Education.” In *International Handbook of Engineering Education Research*, by Aditya Johri, 1st ed., 51–86. New York: Routledge. https://doi.org/10.4324/9781003287483-5.

Shahjahan, Riyad A., and Clara Morgan. 2016. “Global Competition, Coloniality, and the Geopolitics of Knowledge in Higher Education.” *British Journal of Sociology of Education* 37 (1): 92–109. https://doi.org/10.1080/01425692.2015.1095635.

Sklair, Leslie. 2015. “Sociology of the Global System.” In *The Globalization Reader*, edited by Frank J. Lechner and John Boli, Fifth edition, 63–70. Chichester, West Sussex, UK : Malden, MA: Wiley.

Turhan, Cigdem, Gokhan Sengul, and Murat Koyuncu. 2015. “A Comprehensive Assessment Plan for Accreditation in Engineering Education: A Case Study in Turkey.” *International Journal of Engineering Education* 31 (5): 1270–1281.

Weiss, Linda. 1999. “Globalization and National Governance: Antinomy or Interdependence?” *Review of International Studies* 25 (5): 59–88. https://doi.org/10.1017/S0260210599000595.

Wijesinghe, Sarah N.R., Paolo Mura, and Frederic Bouchon. 2019. “Tourism Knowledge and Neocolonialism – a Systematic Critical Review of the Literature.” *Current Issues in Tourism* 22 (11): 1263–79. https://doi.org/10.1080/13683500.2017.1402871.

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Understanding the Support Mechanisms Available to First-Year Mathematics Students: A Case Study from South Africa

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ABSTRACT

Only about 54% of South African Engineering students graduate from the four-year professional engineering qualification within five years. One of the biggest stumbling blocks in many engineering programs is mathematics, which in South Africa often comprises a significant part of the first year of an engineering degree program. Research indicates that there is an articulation gap between student preparedness and institutional responsiveness in South Africa. In response to this articulation gap, the Diagnostic Mathematics Information for Student Retention and Success (DMISRS) project engages with mathematics educators from various South African higher education institutions to find solutions collectively and collaboratively to issues surrounding the retention and success of students in STEM programmes with a focus on the teaching and learning of Mathematics. It can be argued that South African higher education mathematics curricula do not consider sufficiently the preparedness of the students they teach and are not adequately responsive to the needs of students. This article reports on the results of a baseline survey of South African Mathematics departments undertaken as part of the DMISRS project, with participants teaching mathematics in engineering as well as other disciplines. The

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results show that while various student support mechanisms are implemented in first-year mathematics courses in South Africa, educators rate these as being of varying effectiveness. Overall, there appears to be insufficient attention given to questions of curriculum, content and student support in first-year mathematics courses, particularly where these are offered to engineering students.

1 INTRODUCTION

Throughput rates, or successful completion of university degrees, in South Africa have long been a concern for academics and society at large, and have been discussed by various authors (*inter alia*, Scott et al., 2007; Case et al., 2013; Du Plessis and Gerber, 2012; Frith and Prince, 2016). While access to higher education has widened in recent decades, many students fail to successfully graduate. In 2014, the number of students enrolled in South African higher education institutions was close to a million (CHE, 2016: p.3). However, about 40% of all registered students dropped out of their studies by the end of regulation time, and only 27% obtained their degrees in the regulation time (CHE, 2013).

It is acknowledged that "poor performance in Science, Technology, Engineering and Mathematics (STEM) Education and professional programmes is of particular concern, given the short supply of high-level skills in these fields" (CHE, 2013). The ratio of engineers to population in South Africa is very low compared to other countries: 1:3166 in South Africa, compared to 1:389 in the USA and 1:130 in China (Grayson et al, 2013: p.343). This is of concern, given the lack of high-level skills in the South African engineering field and the need for engineers in order for the country to achieve its developmental goals. A study in 2009 by the Council for Higher Education showed that only 54% of South African Engineering students enrolled for a four-year professional bachelor's degree in 2000 graduated within five years (CHE, 2009: p.36) and referred to a "growing gulf" between enrolment and graduation in Engineering between 1989 and 2010. In a further study in 2013 by the Council for Higher Education, it was shown that only 41% of the 2006 Engineering cohort graduated within 5 years (CHE, 2013: p. 47). This is substantially lower than what it was for the 2000 cohort.

Mathematics is fundamental to all STEM programmes. There is a growing need for capacity development and augmentation of the skills of mathematics educators in HEIs to effectively utilize innovative technologies and data-driven teaching methods, in the context of the challenges and changing landscape of Higher Education. There appears to be a lack of alignment between students' literacy practices and mathematical proficiency, on the one hand, and the academic practices of their chosen disciplines, on the other. This gap results in significant attrition, which continues to widen inequality, and impacts the economy and future development. Even in institutions where forms of curriculum responsiveness such as curriculum-integrated mathematics support are found to be necessary, this is generally not available. There remains a clear national imperative to address the problem of high failure and drop-out rates in STEM programmes, specifically in first-year Mathematics courses.

To this end, the Diagnostics Mathematics Information for Student Retention and Success (DMISRS) project was established to engage Mathematics educators with the needs of their students through investigating and sharing current practices in terms of curriculum-integrated support for mathematics in order to incorporate and facilitate further development and identification of ‘best’ practice in this regard. The project included diagnostic workshops, annual symposia and regular surveys of practice in mathematics teaching in higher education.

2 METHODOLOGY

A baseline survey was sent out to all South African mathematics departments participating in the DMISRS project. The focus of this baseline survey was on the support mechanisms that institutions make available to students in first-year mathematics courses. In total, 11 questions were included in the survey; a mixture of open- and closed-ended questions were included. Twenty-four lecturers from 16 universities completed the baseline survey. Half of the lecturers work directly in a Science faculty while the other half teach mathematics as a service module in other faculties, including many from engineering (as can be seen from Figure 1). Ethics clearance (CHED REC 2019_2) for the research associated with the Diagnostic Mathematics Information for Student Retention and Success (DMISRS) project was received from the Centre for Higher Education Development at the University of Cape Town.

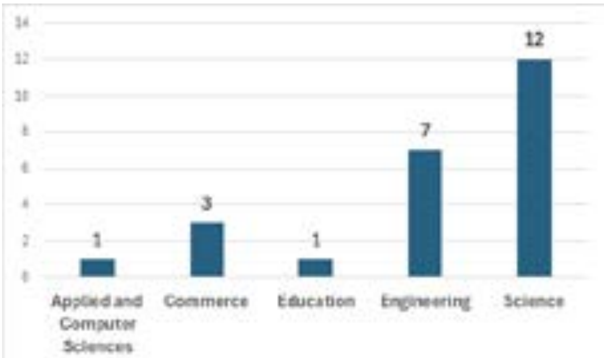

Fig. 1. Number of lecturer respondents per faculty

3 RESULTS

3.1. Admission and Placement

School-leaving mathematics requirements for entry into first-year mathematics courses ranged from level 3 (40-49%) to level 6 (70-79%) with the majority expecting a level 4 (50-59%) (see Figure 2). Of the 16 participating higher education institutions, 6 require their prospective students to write the National Benchmark Tests (NBTs), a set of South African higher education admission tests; only 5 require prospective students to write the NBT Mathematics test, specifically. The majority of the universities (88%) do not use the NBT results for student placement. 75% of universities do not use the results to identify student support needs.

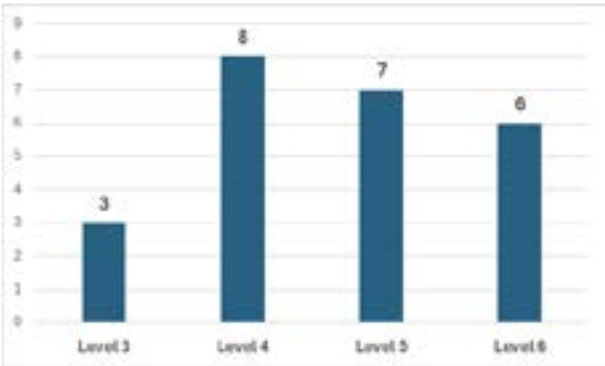

Fig. 2. Number of institutions per NSC mathematics level

Among those institutions who do use the NBTs to identify student support needs, this is done in the following ways:

“If the NBT results are poor, students are put into Extended Studies … with lots of support.”

“Our students are subjected to internal profiling test on academic literacy and mathematics which is then followed by an intense week programme on challenging sections / gaps identified in this test. Tutorial and extra classes are conducted throughout the year as a form of extra support.”

“Mostly with placement of students who need to decant from the mainstream mathematics course to a first semester course done over a year.”

“Organising help from Mathematics Centre.”

3.2. Content of Mathematics Courses

On the question about whether any topics could be excluded from mathematics courses, only 3 lecturers feel that certain topics can be omitted. Two of these lecturers argued the following:

“Topics that do not have any connection with contexts encountered in other non-mathematics disciplines can be omitted. Topics of a purely theoretical nature can safely be avoided.”

“From 1st semester: Applications of the mean value theorem. Anything beyond the basics of binomial theorem. From 2nd semester: Taylor series (or at least anything beyond the basics). The matrix representing a linear map. I am not familiar enough with all the places in the engineering degree where the content of these courses is required. I don't believe there is consensus among engineers on what maths should be taught in first year.”

Lecturers identified a wide array of topics that students generally struggle with. Basic high school competencies were commonly noted by 5 lecturers. Other gaps include: differentiability, curve sketching, logarithms, fractions, calculus, limits, absolute values, among others. Identification of these problems generally stemmed from multiple sources, including the students themselves, as well as test, exam, and assignment performance, and from lecturers’ and tutors’ observations.

3.3. Types of student support offered

3.3.1. Special sessions

Only seven lecturers reported implementing special sessions with their students. These sessions are not compulsory at the majority of universities and are mostly facilitated by the same lecturer who teaches the students in the module. Student participation is voluntary at three universities, forms part of first-year orientation at one university, and is performance-based at three universities. Lecturers' ratings of the effectiveness of these sessions' varied, as seen in Figure 3.

3.3.2. Tutorials

All but two universities report offering tutorials to students. Tutorials are compulsory at most of these universities (82%). The majority of universities cover current lecture material in their tutorials. Content is chosen based on the course outline, lecturer and tutor observations, and student needs. Tutorials seem to be generally well-attended, as reported by most lecturers. Attendance ranges from 60% to 100%. Tutors are most commonly undergraduate students, postgraduate students or lecturers, and undergo training at the majority of universities (90%).

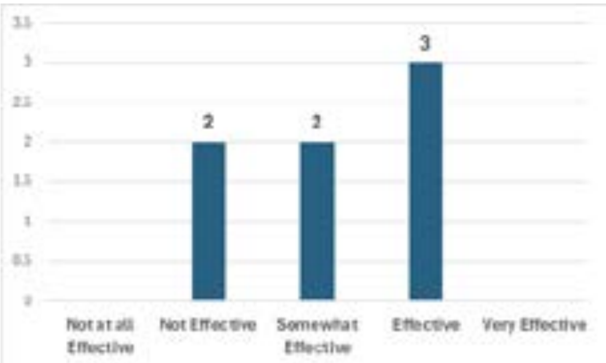

Fig. 3. Lecturers' rating of special sessions effectiveness

As for the effectiveness of this type of student intervention, most lecturers rated tutorials as *somewhat effective* in supporting students (see Figure 4). Thirty-six percent of lecturers offer additional tutorials to students (e.g. on the weekend) and these typically take the form of 'Whiteboard Workshops'. Most lecturers reported that tutors are *often*, or *sometimes*, available to answer student questions. If tutors are not available, students turn to lecturers with their questions (see Figure 5).

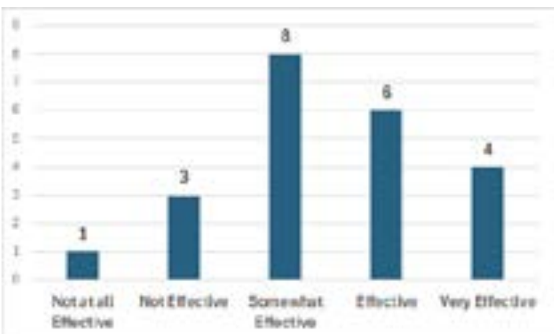

Fig. 4. Lecturers' rating of tutorials' effectiveness

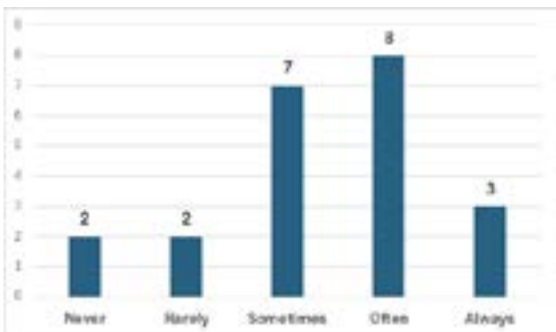

Fig. 5. How often tutors are available to answer students' questions (outside of tutorial sessions)

3.3.3. Additional materials

The majority of lecturers (75%) report that students are provided with additional material to help bridge knowledge gaps. These materials include: online content (e.g. blog posts and videos); additional study material (e.g. lecture notes, exercises solutions, and examples); and other textbooks. Lecturer observations, student requests and students' performance help to determine what materials are provided. These materials are typically made available to students through online platforms. Most universities (78%) monitor whether students access these materials, and report good levels of utilisation (60% - 100%). Generally, this intervention is viewed as an *effective* form of student support (see Figure 6).

3.3.4. Peer support

Just over half of the surveyed lecturers (58%) report that peer support is available to students, with most of these universities actively encouraging students to form peer-support groups. These groups are typically formed within tutorial groups, or universities have a residence mentor/tutorial system. Groups are mostly led by strong students. Students who join these groups are not necessarily weak students – respondents report a mix of strong and weak students. Current lecture/tutorial content is discussed in the groups. The majority of lecturers think that peer groups are a *somewhat effective* form of student support (see Figure 7).

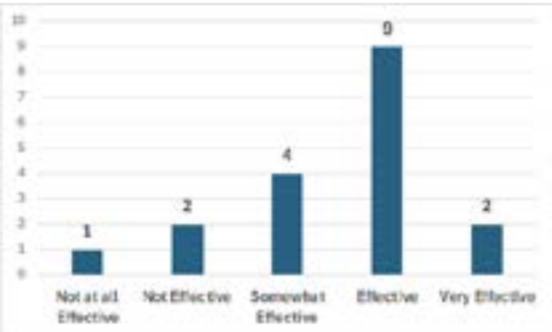

Fig. 6. Lecturers' rating of additional materials' effectiveness

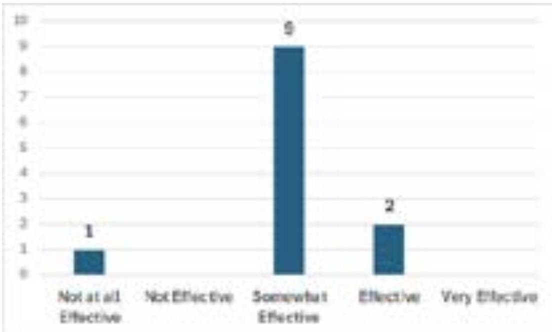

Fig. 7. Lecturers' rating of peer support effectiveness

3.3.5. Hot seats (dedicated one-on-one consultation with tutors and/or lecturers)

Fifteen lecturers (63%) implement hot seats; however, there is some variation in how lecturers understand what constitutes a 'hot seat'. Two lecturers said that they do not implement hot seats, but instead offer a Maths Centre. Another commented: "There are not official hot seats. All lecturers are available at all times" – this means that, in these cases, hot seats cannot be differentiated from lecturer support. Hot seats are mostly available to students every day. However, utilisation by students is fairly low (0% - 40%). When asked whether the person who runs the hot seat communicates with lecturers, they report mixed degrees of communication (see Figure 8). Lecturers rated hot seats as having varying degrees of effectiveness (see Figure 9).

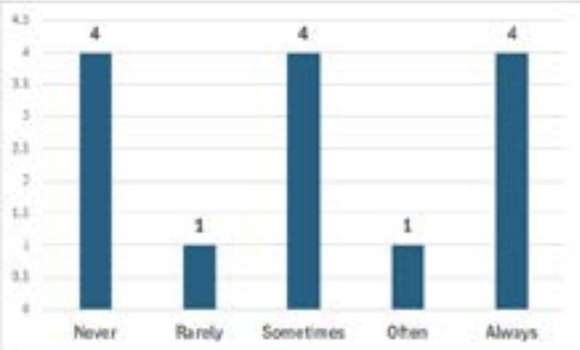

Fig. 8. Frequency of communication between lecturers and the person running the hot seat

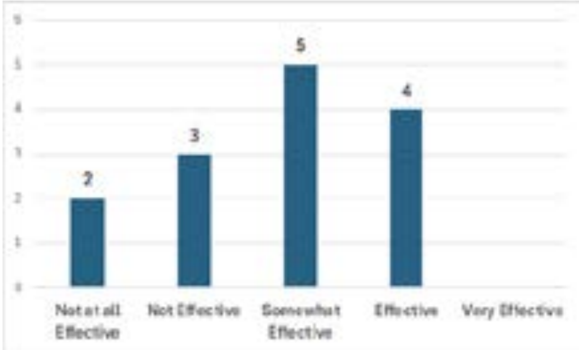

Fig. 9. Lecturers' rating of hot seat effectiveness

3.3.6. Lecturer support

Most universities offer lecturer support to students (92%) on a daily basis (68%). This can take the form of emails, consultations and drop-ins, WhatsApp, and online chat rooms. All students typically make use of this offering. Lecturers perceive this type of support to be manageable for themselves (see Figure 10), and think that this is an effective mechanism of support for students (see Figure 11).

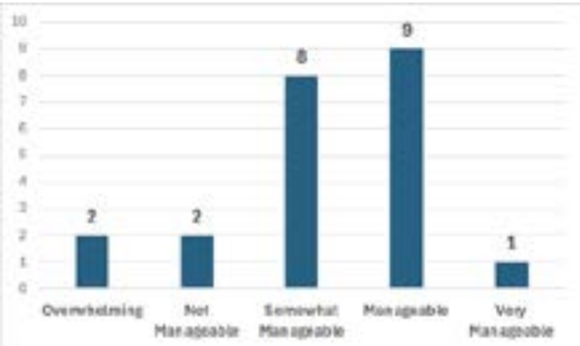

Fig. 10. Degree to which lecturers can manage this type of support

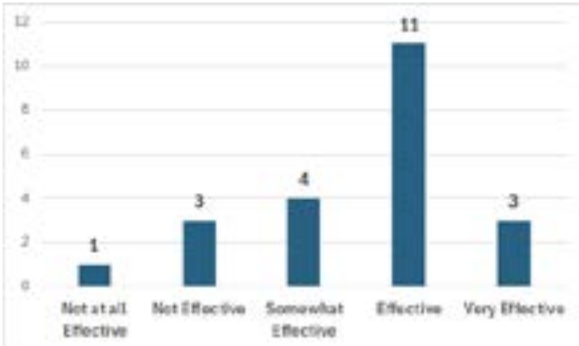

Fig. 11. Lecturers' rating of lecturers support effectiveness

3.3.7. Additional and alternative support

Three lecturers mentioned additional support available to students at their universities:

> "Student Development Support in each faculty."
>
> "The [University's] Learning and Teaching Development Department have workshops with the students."
>
> "Maths Centre available for students."

Many lecturers described the alternative mechanisms that their institutions have in place for those students not coping; most take the form of extended programmes.

3.4. Changes to student support

Half of the lecturers feel that no changes should be made to their current student support offerings, with one commenting: "students need to make more use of the current support services". Another lecturer also emphasised the need for improved self-monitoring among students, and a more meaningful understanding of students' cues among both staff and students:

“Students take time to realise that they are not coping. Often when they do realise it, it is often too late to remedy the situation. I feel we do not utilise assessments effectively and do not teach students how to assess themselves. I also feel that words such as ‘understand’, ‘yes’, ‘ok’ and signals such as nodding are used loosely by both teachers and learners and student[s] learn too late in the year that these cue[s] have [no] meaning in themselves.”

Among those who feel these services could be improved, the need for more tutors was commonly noted. One lecturer mentioned that this is difficult, as their engineering course does not produce enough postgraduate students. Focused attention on individual students was also noted, with one lecturer saying:

“One-to-one consultations are very valuable but time consuming. I suspect I would be more effective if I replaced 80% of my 8 am lectures with online lectures, and made it a requirement for students to make a 5-10 minute consultation with me once a week to report on their progress”.

One lecturer suggested that more online support could be made available, given students have access to adequate internet connectivity and infrastructure. Lastly, one lecturer noted that resource guides are not provided for common content problems. This is important, given how many students appear to struggle with high school competencies: “We have not yet developed resource guides for topics known to be problematic, especially topics done in high school”. Thirteen lecturers (54%) feel as though they need more resources in order to change their student support services. Most noted the need for more tutors. Other needs identified include:

Assessing the effectiveness of student support services;

Budgeting information that can support innovative strategies;

Links to helpful resources (e.g. Khan Academy, videos, free online quizzes, etc.)

Motivating senior students to become tutors; and

Time management skills.

4 DISCUSSION

Timely completion of university degrees, particularly in engineering, has been identified as a significant challenge; this is particularly so in South Africa (see Scott et al., 2007; Case et al., 2013; Du Plessis and Gerber, 2012; Frith and Prince, 2016), but is also present in Europe. For example, Mumenthaler et al. (2023) show that, at EPFL in Switzerland, the failure rate in the first year is close to 35%. Mathematics is fundamental to engineering programmes and often serves as a gatekeeper for students, with the focus often on the underpreparedness of students in terms of mathematics (Mumenthaler et al., 2003). There is, therefore, an imperative to address the problem of high failure and drop-out rates in Mathematics courses. This paper has reported on the results of a baseline survey of South African lecturers in Mathematics departments teaching mathematics in engineering as well as other disciplines.

As can be seen in the results section described above, few universities make use of the diagnostic information provided by university entrance tests to inform their mathematics curricula. This should be a first point of departure for ensuring mathematics courses respond appropriately to the needs of the students admitted therein. In addition, there is a lack of consensus over what content is important in a first-year mathematics course, particularly where these courses are offered to engineering students. This has long been a challenge for engineering education, as reported by the SEFI Mathematics Working Group as early as 1992 (SEFI Mathematics Working Group, 2013). Greater clarity and communication in this regard is required.

A wide array of support mechanisms are implemented in first-year mathematics courses in South Africa. However, the lecturers in this survey rate these support mechanisms as being of varying effectiveness. It is important to note that the lecturers were mathematics educators and therefore tended to more highly rate the support mechanisms they themselves offered. In addition, relatively few lecturers see a need for changes in the way student support is offered in mathematics, despite the poor results often seen in these courses. This is a significant challenge if mathematics is to cease to act as a gate-keeper within STEM programs in general and engineering in particular. Of course, “learning outcomes in mathematics are not dependent solely on good teaching, sufficient resources, or other external considerations” (Pohjolainen et al, 2018, p. 3) but are a result of all of these factors.

5 IMPLICATIONS

The way forward could be that mathematics lecturers need to be working collaboratively in order to deal with the complex problem of low throughput and high failure rates, particularly in mathematics. If mathematics is to become a gateway rather than a gatekeeper for engineering studies, mathematics lecturers will have to see this as a collaborative endeavour. They should also work alongside engineering disciplinary experts to ensure that the mathematics that is being taught is relevant to engineering disciplines. In this regard, it would be important to consider both the curriculum as well as the teaching, learning and assessment approaches employed to ensure alignment between the preparation of students and the demands of the degrees for which students are studying. As such, greater attention will need to be given, not only to providing more support within mathematics courses, but also to more creative and effective mechanisms for supporting first-year students. While this study has sought the views of lecturers, further investigation would need to be done to ascertain students’ perspectives on the effectiveness of the various support mechanisms offered.

REFERENCES

Case, J., D. Marshall. and D. Grayson. "Mind the gap: Science and engineering education at the secondary-tertiary interface." *South African Journal of Science* 109.7-8 (2013): 01-05.

Council on Higher Education. 2009. *The state of higher education in South Africa: a report of the CHE Advice and Monitoring Directorate.* Higher Education Monitor, no.8, October 2009. CHE: Pretoria.

http://www.che.ac.za/sites/default/files/publications/Higher_Education_Monitor_8.pdf

Council on Higher Education. 2013. *A proposal for undergraduate curriculum reform in South Africa: The case for a flexible curriculum structure.* Report of the Task Team on Undergraduate Curriculum Structure, August 2013. CHE: Pretoria.

Council on Higher Education. 2016. Vital Stats: public education 2014. CHE: Pretoria. http://www.che.ac.za/sites/default/files/publications/VitalStats2014%20-%20webversion.pdf.

du Plessis, L. and D. Gerber. 2012. Academic preparedness of students – an exploratory study. *The Journal for Transdisciplinary Research in Southern Africa*, 8(1) July 2012, pp. 81-94.

European Society for Engineering Education (SEFI) A Framework for Mathematics Curricula in Engineering Education: A Report of the Mathematics Working Group

Frith, V. and Prince, R. 2016. Quantitative literacy of school leavers aspiring to higher education in South Africa: lessons from the National Benchmark Quantitative Literacy test. South African Journal of Higher Education. 30, 1. Pp. 138-161.

Mumenthaler, F., Jermann, P., Hardebolle, C., and Tormey, R. Study success and failure of STEM students and the connection to their learning habits. *Proceedings of the 51st annual conference of the European Society for Engineering Education*, pp. 974-982, 2023.

Pohjolainen, S., T. Myllykoski, C. Mercat, and S. Sosnovsky. *Modern Mathematics Education for Engineering Curricula in Europe: A Comparative Analysis of EU, Russia, Georgia and Armenia*. Switzerland: Springer Open, 2018.

Scott, I., Yeld, N. and Hendry, J. 2007. A case for improving teaching and learning in South African higher education. Higher Education Monitor No. 6. Pretoria: Council on Higher Education.

SEFI Mathematics Working Group. *A Framework for Mathematics Curricula in Engineering Education: A Report of the Mathematics Working Group*. Brussels*: European Society for Engineering Education (SEFI),* 2013.

A METHOD FOR CURRICULA MAPPING TO IDENTIFY KEY SUSTAINABILITY COMPETENCE DEVELOPING CONTENT IN ENGINEERING EDUCATION

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ABSTRACT

Engineering education has immense potential in promotion of the types of competencies that are likely to help future engineers make responsible decisions. The written curricula play a significant role in the implementation of engineering education so how to integrate key sustainability competence developing activities in teaching should be clearly communicated in the course descriptions. Mainstreaming sustainability aspects as part of engineering education also calls for more robust means to identify sustainable development content in curricula.

This research examines a method for assessing the extent to which sustainability competencies are currently conveyed in course descriptions in engineering education. The findings suggest the tested method to be a good starting point for

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assessing sustainability competence developing content; however, more work to be necessary for a truly generalisable method. Clear challenge of identifying sustainability competence related content is the varied interpretations of the written curricula content. Supporting academic staff in the integration of sustainability competence developing content in teaching could be enhanced, for example, by arranging workshops that might also increase the understanding on the importance of offering sustainability content for engineering students.

1 INTRODUCTION

Engineering education offers a lucrative basis for the development of the competencies necessary for responsible decision making, as the traditional role of an engineer as a technical problem solver has evolved into a transdisciplinary specialist with a strong role in the sustainability transition (Karvinen, 2024, 23-24).

Responsible decision-making considers the various repercussions of the decision, even beyond temporal and spatial distances. Such consideration requires extensive understanding of the complexities and the causal relations of the potential consequences of the action decided on as well as a strong value base to lean on in the crossfire of conflicted interests (Karvinen, 2024, 18).

The ability to identify and influence the root causes of sustainability challenges is a clear foundation for true transition from unsustainable practises (Ehrenfeld, 2005, 23), yet currently formal education is falling short on equipping graduates with the essential abilities to succeed in this (Voulvolis et al., 2022, 2). A “competence” as a term can be defined as the matrix of “knowledge, skills and attitudes that together allow the competent individual to perform successfully” (Wiek et al., 2011, 204).

A consensus on the most essential competencies for enhancement of the sustainability transition is growing and many frameworks name systems thinking, anticipatory, normative, strategic, and interpersonal competencies as the key sustainability competencies (KSCs) (Wiek et al., 2011, Redman and Wiek, 2021, and Brundiers et al., 2021). Systems thinking competence refers to the ability to analyse complex systems across domains and anticipatory competence to the ability of analysing, evaluating, and drafting future vision (Wiek et al., 2011, 207-209). Normative and interpersonal competence refer to abilities of negotiating and communicating sustainability values (Wiek et al., 2011, 209-211) whereas strategic competence refers to the ability of implementing change by applying knowledge to finding solutions to sustainability challenges (Wiek et al., 2011, 210).

The assessment of the efficacy of initiatives aimed at fostering the growth of the specified Key Sustainability Competencies (KSC) among students presents a methodological challenge, since development of a competence, let alone a set of competencies, is highly subjective. Learning is always reliant on the pre-existing skillset, so the increase of KSCs is dependent on the existing competence set of the learner (Brunders et al. 2021, 23). Measuring the learning outcome and the efficiency of the activities aiming at learning is therefore challenging; the learning result being dependent on each learner’s initial level, personal learning abilities and a wide range of other variables. Allocation of the learning outcome to a specific activity is likewise challenging. The development of a competence is not limited to the confinement of a formal educational institution but is affected by all stimuli encountered by the learner. The dilemma of understanding the urgent need for KSC building content in education but lacking the tools for their promotion is a concern for higher education institutions (HEIs) that, for their part, carry the responsibility of mainstreaming education for sustainable development (UN, 2015).

The discussion on the types of competencies likely to promote responsible behaviour is ongoing. Even after reaching a clear consensus on the competencies to focus on, it is obvious that "*competencies are not naturally developed in teaching-learning settings, instead they require targeted and ongoing efforts*…" (Brundiers et al., 2021, 26). Engineering education commonly relies on the documented curriculum to lay the base for course content and learning assessment, so supporting the teaching staff in competence developing course implementation should be clearly communicated as elemental parts of course descriptions. If they are not, their integration in course implementation is dependent on the responsible teacher's personal interest, potentially resulting in polarization of learning (Routaharju et al., 2024, 125). Tangible and robust instruments for the assessment of sustainability competence development need more attention (Redman and Wiek, 2021, 128).

Educational content in HEIs is based on the course content and learning objectives defined in curriculum, which should provide the academic staff with the necessary instruments for integrating KSC enhancing activities in teaching. This research examines a method for assessing the extent to which sustainability competencies are currently conveyed in course descriptions in engineering education. The research questions addressed are:

1) "How do university engineering degree course descriptions support teaching *staff in sustainability competence integration in course implementation?*" and

2) "*Does curricula content analysis provide an adequate method for the assessment of key sustainability competence developing content in engineering education?*".

2 METHODOLOGY

2.1 Curricula mapping

Lappeenranta-Lahti University of Technology (LUT) offers studies in fields of technology, business, and social sciences (LUT, N.d.a.). The Faculty of LUT School of Energy Systems (LES) consists of departments in Energy technology, Electrical engineering, Mechanical engineering, and Sustainability science. (LUT, N.d.b.). The integration of sustainable development education should not be limited to students studying sustainability science. Instead, it should encompass the entire faculty. This broadened scope was applied to the empirical portion of our study. However, due to time constraints, it was necessary to establish a limit for data collection. The focus was specifically on the documented course descriptions that were acquired from the student information system LUT Sisu (2023).

Figure 1 presents a flow diagram of the course description selection procedure. The first inclusion criteria for course descriptions were set to be language ("courses taught in English") and organizer ("School of Energy Systems at LUT") resulting in 613 course descriptions. English language courses were selected to ease the analysis, as English is the language of the KSC description terminology. Initial screening for the exclusion of theses, internship, and orientation courses resulted in

555 course descriptions that were sampled to narrow the data for the analysis. The samples were decided from courses titled “Introduction to…” (29 course descriptions), “Advanced…” (27 course descriptions) and “Basic(s) of…” (14 course descriptions) in order to ensure examples of different level courses to be included. The remaining 489 course descriptions were randomly sampled for thirty more descriptions to include in the analysis. Some of the original sample course descriptions were excluded during the analysis iteratively, e.g., due to insufficient information given in the course description or being orientation or seminar courses, leaving the final sample size to be eighty-nine course descriptions.

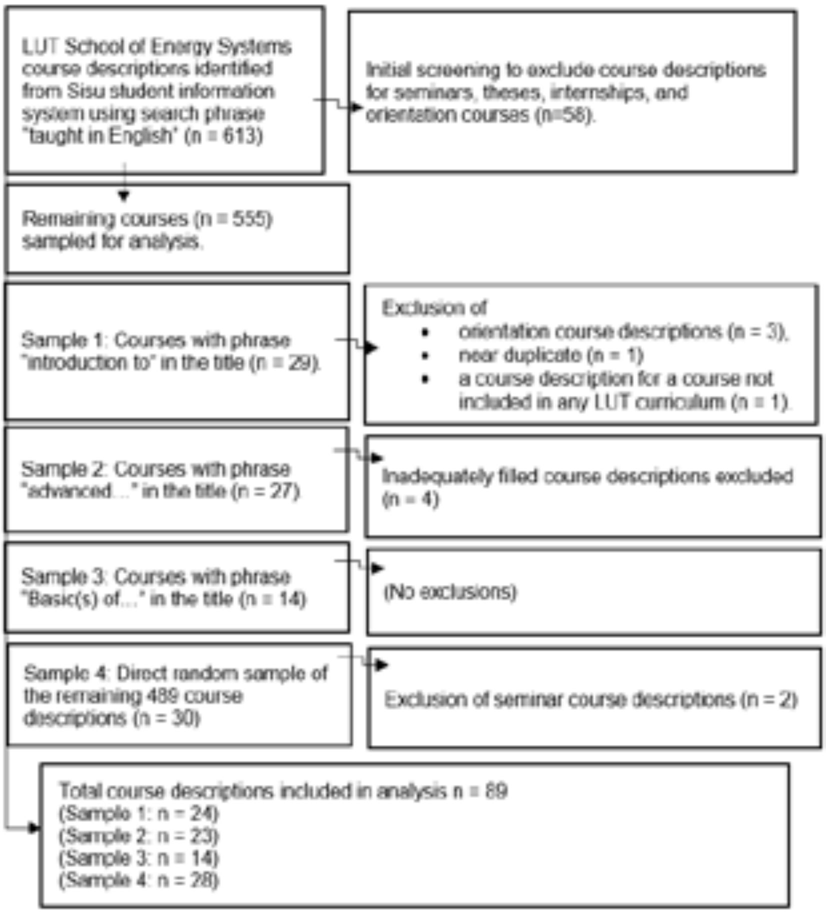

Figure 1. Course description selection procedure

The KSC definitions and examples presented in two framework suggestions (Wiek et al., 2011 and Brundiers et al., 2021) were used as a basis of a matrix (table 1) designed as a one-page guiding tool to be used in analysis of the selected course descriptions. Both the learning objectives (LO) and course content (CC) descriptions were included in the analysis, but due to the limitations of this paper these were treated as equal elements of the course descriptions. Comparing and analysing their different weights would make for an interesting topic for a further study.

The analysis was carried out as deductive content analysis (Elo and Kyngäs, 2008, 111) with the matrix content as units of analysis. Each selected course description was read and content relating to the KSCs was highlighted. The definitions of the KSCs and the guiding questions listed in the matrix were used to help the text analysis. Occurrences of each KSC as well as the justification of identifying each occurrence as a manifestation of a KSC related content were documented. Since the aim was to determine the number of course descriptions that were likely to support the teaching staff in integrating KSC developing activities in teaching, each KSC was only taken into account once per course description even in cases where a course description contained several mentions of the same KSC. The variation of course extents was not considered in the analysis either.

Table 1. Matrix used in course description analysis

	Key Sustainability Competence				
	systems thinking	**anticipatory**	**normative**	**strategic**	**interpersonal**
Condensed Definition (Wiek et al. 2011 and Brundiers et al. 2021)	The ability to collectively analyse complex systems across different domains and scales.	The ability to collectively analyse, evaluate and draft future vision.	The ability to collectively map, specify, apply, reconcile, and negotiate sustainability values ("values competence").	The ability to collectively design and implement interventions toward sustainability.	The ability to motivate enable and facilitate collaborative and participatory sustainability problem solving.
Learning objectives (LO) "Can this LO be achieved without these competencies?"	Does the LO include a reference to system understanding or identification? Is the LO linked to modelling or system analysis? Does the LO include requirements for system element or dynamic comprehension? Does the LO include other aspects linked to systems thinking competence?	Does the LO indicate the use of future envisioning tools (e.g. backcasting)? Does the LO include aspects of scenario building? Does the LO include other aspects linked to anticipatory competence?	Does the LO name identification of sustainability aspects in the course context? Does the LO include other aspects linked to normative competencies?	Does the LO demonstrate designing interventions towards more sustainable practises? Does the LO include an aspect of implementation? Does the LO include other aspects linked to strategic competence?	Does the LO include aspects of cooperation? Does the LO include aspect of self-reflection? Does the LO include communication development (incl. reporting skills)? Does the LO include other aspects linked to interpersonal competence?
Course content (CC) "Can the topic be covered without using these competencies?"	Does the CC include aspects that imply a link to systems thinking?	Does the CC include aspects that imply a link to anticipatory competence?	Does the CC include aspects that imply a link to normative competencies?	Does the CC include aspects that imply a link to strategic competence?	Does the CC include aspects that imply a link to interpersonal competence?

2.2 Matrix testing by comparison analysis

After the initial analysis, a set of twenty (five from each of the four samples) course descriptions were selected to be analysed by another researcher using the same matrix to test it for generalisability. Descriptions of courses taught by the second analyser were excluded prior to sampling and the second analyser did not have access to the original findings before or during the analysis. The course selection was based on the original findings to ensure all KSCs would be represented in the comparison analysis as extensively as possible. The second analyser carried out a text analysis of the selected course descriptions highlighting which part of the course descriptions manifested KSC related content as described in the matrix, and documented their justifications of which KSCs were in question and why. The findings were then compared to the original analysis findings of these twenty course descriptions to determine the frequency of similar findings and to compare the justifications given for identification of KSC related content in course descriptions.

3 RESULTS

3.1 Key Sustainability Competencies documented in course descriptions

The initial course description analysis indicated systems thinking competence to be the most commonly present KSC in course descriptions (70/89) with strategic competence being the second most common one (32/89). The frequency of KSC occurrences in the analysed course descriptions and examples of the key terminology listed as justifications for the selections are presented in Table 2.

Table 2. Course description analysis results

	Key Sustainability Competence				
	systems thinking	anticipatory	normative	strategic	interpersonal
Occurrence in all (n= 89) course descriptions	70 (79%)	15 (17%)	14 (16%)	32 (36%)	30 (34%)
Examples of content related to this competence.	Ability to identify system elements, control of systems, conversion of xxx system, identification and description of system elements, life cycle phases, structure of a xxx (system), system characterization, system component, system stocks, system understanding.	Envision alternatives, envisioning future, history and ongoing change, opportunity and challenge identification, scenario comparisons.	Identification of sustainability impacts in context, naming impacts in context, ethics, sustainability challenges in the context, understanding sustainability in context.	Noting restrictions and abilities, application of theory, application of xxx case study, applying knowledge, design and implement, design intervention.	Ability to communicate, communication and team working, communication and management, debate, network, explain the importance, express, research, critically evaluate, making judgements, collaboration, self-management.

The KSC analysis indicates the majority of course descriptions contain at least some elements related to the KSCs. Out of the eighty-nine analysed course descriptions no KSC related content was identified in only six descriptions (about 7 % of the analysed course descriptions). This suggests sustainability competence enhancing content to be relatively well represented in engineering education course descriptions, although for more reliable results the analysis should be extended to a larger number of course descriptions in several HEIs. In three of the cases the most likely reason for no identified KSC content was the difficulty of understanding the course description overall. Unfamiliarity with the terminology used to describe course contents and learning objectives was a clear challenge of the course description analysis suggesting a need to develop the method further. The use of such a tool could be coupled with interviews of the course description authors or the teaching staff responsible for organizing the courses in question to ensure more accurate interpretations of the descriptions. This could also help teaching staff in becoming more involved in the process of integrating sustainability competence developing content in teaching, which may be a more effective method of mainstreaming education for sustainable development than mere curricula alterations (Routaharju et al., 2024, 123).

The dominance of systems thinking competence in the number of KSC occurrences can reflect the nature of study content in the School of Energy systems, since engineering education generally relies on understanding of system elements. This may also lead to systems thinking being the most concrete and thus possibly the simplest to identify in written course descriptions. The same may explain why strategic and interpersonal competencies were identified in about one third of the analysed course descriptions: many engineering courses aim at helping students learn to design interventions and communicate their progress effectively. The results suggest anticipatory and normative competencies may not be effectively communicated in engineering course descriptions. Testing such an analysis on curricula of some other field and comparing the results would make for an interesting topic for further research.

Each course was treated as one unit not considering the variation in extents or level of studies. These would make interesting issues to consider should such a tool be tested elsewhere.

3.2 Comparison analysis

Only four out of the twenty course descriptions subjected to the comparison analysis returned the same result on all five KSCs (Table 3.). The same findings were at their lowest for anticipatory competence (13/20) and at their highest for interpersonal competence (18/20). The similar outcomes for systems thinking (14/20), strategic (15/20), and anticipatory competencies fluctuated within this range. While these results quantitatively suggest a relatively high similarity, the analysis of the justifications listed as the basis of each finding reveal a difference of thinking even in part of the course descriptions returning a similar result. This implies qualitative content analysis, even with the same set of units of analysis, does not return a generalisable result of the KSC content in course descriptions. Furthermore, this suggests teaching staff interprets course descriptions very subjectively so supporting them in integration of KSC developing content in course implementation should entail more than adding relevant terminology in course descriptions and learning objectives.

Table 3. Comparison analysis similar findings

	Justifications (A)	Justifications (B)
systems thinking competence		
Introduction to IoT-Based Systems (4 ECTS) (LUT Sisu, 2023)	identification of IoT systems	define systems, information, and communication
Advanced Course on Software Business (3 ECTS) (LUT Sisu, 2023)	models	connections between the economic system and the industry
anticipatory competence (no occurrences)		
normative competence (no occurrences)		
strategic competence		

Basics of Software Product Management (6 ECTS) (LUT Sisu, 2023)	design interventions	product strategy
interpersonal competence		
Advanced Course in Electronics (6 ECTS) (LUT Sisu, 2023)	communication, presentation	group discussion

3.3 Limitations

It is important to remember that course descriptions only provide the foundation for course implementations, and this research started with the assumption of course descriptions being used for this purpose by the academic staff responsible for course implementations, and the descriptions being accurate and up-to-date. A more thorough view on if this indeed is the case would improve the reliability of the findings. The different interpretations made in the content analysis highlight the challenge of qualitative analysis but can also be seen as an indication of how differently teaching staff interprets course descriptions. Thus, the results indicate course descriptions alone are not enough to support the academic staff in integrating KSC developing content in teaching. For a better outcome, the matrix should be coupled with other methods, such as workshops or informative sessions for the teaching staff, to help understand the nature of the KSCs and to allow a more comprehensive understanding of how they are manifested in courses of varied contextual contents.

Even if the curricula mapping matrix still needs to be improved to provide an adequate tool for assessing the degree of KSC developing content in engineering education courses, the matrix could serve as a basis for developing a guiding tool in course design when creating new curricula. This would require a more thorough analysis of the course description elements and a consideration of the course extents. The matrix could help engineering educators identify the connection between the pedagogical strategies used in their field of expertise and the KSCs with such a tool. The increase of such effort, after all, it required for the mainstreaming of KSC developing content in engineering education.

4 SUMMARY

This research set out to test a method of assessing the extent to which key sustainability competencies are currently conveyed in course descriptions in engineering education. Selected course descriptions were analysed using a guiding tool based on the KSC frameworks by Wiek et al. (2011) and Brundiers et al. (2021).

The examination of the KSC related content in written course descriptions revealed that while several course descriptions were found to contain content related to the KSCs, the method used for analysis still needs improvement. Comparing the content analysis results by two different researchers also indicates differences in how the course descriptions and the KSCs are interpreted. Such a matrix could be used as a starting point for designing course descriptions supporting the academic staff in their efforts to integrate more KSC developing content in course implementation, especially if the staff was also offered some other content helping them identify the KSCs related content in their field of expertise.

REFERENCES

Brundiers, K., Barth, M., Cebrián G., Cohen, M., Diaz, L., Doucette-Remington, S., Dripps, W., Habron. G., Harré, N., Jarchow, M., Losch, K., Michel, J., Mochizuki, Y., Rieckmann, M., Parnell, R., Walker, P., Zint, M. “Key competencies in sustainability in higher education—toward an agreed-upon reference framework.” *Sustainability Science* 1(16), 2021: 13–29. https://doi.org/10.1007/s11625-020- 00838-2

Ehrenfeld, John R. “The Roots of Sustainability.” *MIT Sloan management review* 46, no. 2 2005: 23-26.

Elo, S. and Kyngäs, H. “The qualitative content analysis process.” *Journal of advanced nursing* 62(1), 2008: 107-115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Karvinen, M. *Supporting agency for sustainability: Exploring the contributions of universities and workplaces to the sustainability competencies and agency of engineering graduates.* Helsinki: Aalto University publication series, 2024

LUT SISU Student information system, accessed March 22nd, 2023, https://sisu.lut.fi/student/search/main

LUT. “Introducing the University”. LUT university website. N.d.a. Accessed March 6th 2024, https://www.lut.fi/en/about-us/introducing-university

LUT. “LUT School of Energy systems.” LUT university website. N.d.b. Accessed March 6th 2024, https://www.lut.fi/en/about-lut/faculties/lut-school-energy-systems

Redman, A. and Wiek, A. “Competencies for advancing transformations towards sustainability”. *Frontiers in Education*. 6 2021: 1-11. https://doi.org/10.3389/feduc.2021.785163

Routaharju, L., Naukkarinen, J., Väisänen, S. and Soukka R. ”Ammattikorkeakoulun insinöörikoulutus kestävyysmurroksen edistäjänä”. *Focus Localis* 52:1, 2024: 112-130.

United Nations (UN). “Transforming our World: The 2030 Agenda for Sustainable Development.” Accessed February 21st 2024, sdgs.un.org

Voulvoulis, N., Giakoumis, T., Hunt, G., Kioupi, V., Petrou, N., Souliotis, I. and Vaghela, C.. “Systems thinking as a paradigm shift for sustainability transformation.” *Global Environmental Change* 75(2022) 102544, 2022: 1-7. https://doi.org/10.1016/j.gloenvcha.2022.102544

Wiek, A., Withycombe, L. and Redman, C. “Key competencies in sustainability: a reference framework for academic program development.” *Sustainability science*. 6(2), 2011: 203–218. https://doi.org/10.1007/s11625-011-0132-6

EDUCATION FOR A HOPEFUL AND SUSTAINABLE FUTURE FOR ENVIRONMENTAL ENGINEERING STUDENTS

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Keywords: *Environmental engineering, Education for Sustainable Development, sustainability agency*

ABSTRACT

Engineering education has great potential to enhance the sustainability transition by ensuring future engineers possess the abilities to act as catalysts for the change. Contrarily to this aim, studies on environmental sustainability challenges can lead to increased eco-anxiety. This research delves into the intersection of learning and sustainable development, specifically examining how environmental engineering students engage with elements of their studies that foster a vision of a hopeful and sustainable future. Environmental engineering students were interviewed to allow them to express their views on sustainable development overall and in connection to their studies. The findings imply that environmental engineering students primarily interpret sustainable development in terms of natural resource use and the available tools, such as circular economy for enhancing resource efficiency. Students also

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associate the concepts of “circular economy” and “life-cycle thinking” with the sustainability transition and their future roles as catalysts for change. These practical instruments can help students develop a sense of sustainability agency.

1 INTRODUCTION

Sustainable development, although having been discussed for decades, is still a rather ambiguous concept especially in the context of education (Karvinen, 2024, 11, 46). The role of education is to promote both individual and societal development and give an insight into the happenings of the world around us. It is clear that the sustainability transition requires awareness and increased understanding of the sustainability challenges along with their potential solutions, but for genuine effectiveness the sense of sustainability agency is needed (Sterling, 2014, 90). Defining sustainable development (SD) as the type of development that allows current generations to fulfil their needs, without compromising the ability of future generations to do the same (The World Commission on Environment and Development, 1987, 16) can make it difficult to connect the aim with daily operations.

An environmental engineer is expected to have a thorough understanding of natural sciences and technology, as the basis of many environmental engineering applications rely on natural processes. The characteristics of the environmental engineering professional field seem to automatically facilitate development of holistic viewpoints and understanding of cause-effect relationships, which, in turn, should contribute to the strengthening of student and graduate sustainability competencies (Wiek et al., 2011, 207-209). Despite this, students and graduates of the field don’t automatically connect their studies to sustainable development (Karvinen, 2024, 54-55). Increasing awareness of exceeding the planetary boundaries (Richardson et al., 2023) may even lead to eco-anxiety (Vercammen et al. 2023, 13) that may decrease the sense of sustainability agency further.

This research delves into the intersection of learning and sustainable development, specifically examining how environmental engineering students engage with elements of their studies that foster a vision of a hopeful and sustainable future. The research questions addressed are: 1) “*How is sustainable development defined by environmental engineering students?”* and 2) “*Which elements of environmental engineering studies promote hopeful future scenarios for students?*”. Student views on sustainable development in connection to their professional field and the elements of their education that help them gain a sense of sustainability empowerment and hopefulness about their future can be used as a starting point in developing environmental engineering education towards better facilitating the sustainability transition on its part. Environmental engineering students were interviewed to collect data on their views on sustainable development overall and in connection to their studies. Both deductive and inductive qualitative content analysis were used for data analysis and interpretation.

2 EDUCATION FOR SUSTAINABLE DEVELOPMENT IN ENVIRONMENTAL ENGINEERING EDUCATION

An elemental part of education for sustainable development (ESD) is supporting the set of values likely to encourage transformative action towards a more sustainable future (Anastasiadis et al., 2021, 273). The process of sustainability agency building consists of steps from the value basis of common good to understanding brought about by increased knowledge and building up to empowered agency (Pacis and VanWynsberghe, 2020, 583, Sterling, 2014, 90). These elements of sustainability agency formation by increased awareness on sustainable development and the set of skills increasing the ability to act towards sustainable development are visualized in Figure 1.

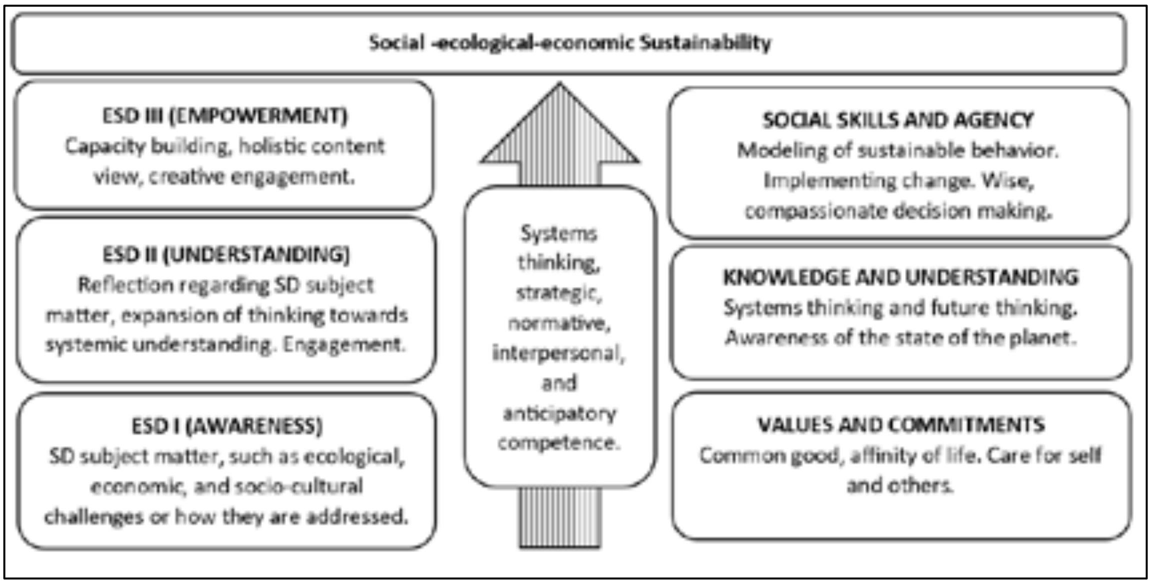

Figure 1. Visualisation of the connections of Sterling (2015, 98) ESD (on the left), Pacis and VanWynsberghe (2020, 583) LfS CCF (on the right) and the KSC (Wiek et al., 2011, 203) (in the middle) frameworks. Translated from Routaharju et al. (2024, 116)

The discussion on the types of competencies that could facilitate the transition to sustainability has identified systems thinking and anticipatory competencies as two examples of the key sustainability competencies (KSCs) (Wiek et al. 2011, 207-209). Advancing systems thinking competence of students will allow them to identify, analyse and understand challenges related to sustainability along with their root causes more effectively. Coupled with anticipatory competence they will become better equipped in envisioning sustainability supporting scenarios (Wiek et al. 2011, 207-209). These elements are important factors of hopeful future scenarios especially in the field of environmental engineering that understandably focuses on the environmental problems faced. Supporting the development of interpersonal, normative, and strategic competencies can also help push aside potential eco-anxiety by allowing students to communicate and share sustainability values and possibilities to apply their knowledge for a more sustainable future.

Mainstreaming education for sustainable development is far from complete. There is evidence that sustainability efforts in universities seem to focus more on the operational sustainability than educating sustainability (Karvinen, 2024, 45). Communicating efforts to improve campus energy efficiency or waste sorting can model organizational sustainability culture, but for a more robust impact sustainability content should be integrated in educational content.

3 METHODOLOGY

3.1 Data collection and the demographic

The data collection was focused on bachelor's degree in environmental engineering students at South-Eastern Finland University of Applied Sciences (Xamk). The degree is designed to be a four-year degree (240 ECTS CU) preparing students for a variety of professional roles (Xamk, N.d.). The focus was narrowed further to students enrolled on courses taught by one of the researchers during data collection. This focus was decided to ensure data availability, as previous experiences suggest students to be more willing to share their views with a familiar lecturer. The learning objectives and arrangements for these four courses had been prepared prior to the research data collection so no conflict of interest was assumed in this sense. A clear distinction between data collection participation and student evaluation on the ongoing courses was also made to avoid biased responses.

The sample of interviewees was opportunistic, as students were invited to a voluntary individual interview and asked to allow their course work product to be used as research data. Only a few students gave consent to using their course work product in the research, so this data was iteratively excluded to ensure anonymity of participants. The interview focus was on studies overall, not only the ongoing courses at the time of data collection. A total of 18 interviews were given, when 108 students were invited to give one, so about 17 % of the demographic was interviewed. A more extensive data collection (e.g. conducting similar interviews in several universities) would increase the generalisability of the results, but as the aim was to get an understanding of student views to be used for educational practice improvement and better facilitation of sustainability agency formation the sample was seen as an adequate starting point. Delving into the topic more extensively would make for an interesting topic for further research.

The majority of the interviewees were over halfway through their environmental engineering degree programme studies (Table 1). Two of the interviewees were completing a Finnish environmental engineering degree, the majority being from the international group with English as their teaching language. Age variation or other background information is not revealed to protect the anonymity of the participants.

Table 1. Interviewees

Gender	Stage of studies	Curriculum	Interview language
Male: 8	1st or 2nd year: 7	English environmental engineering degree: 16	English: 10
Female: 10	3rd year: 11	Finnish environmental engineering degree: 2	Finnish: 8

The interviews were semi-structured with the interviewees first being asked to define, in their own words, the phrases "*sustainable development*", "*sustainable development awareness*" and "*sustainable development skills*" and then asked to reflect on how their personal sustainable development awareness and skills had changed during their environmental engineering studies. These concepts were selected as they represent components of sustainability agency formation (see Figure 1.). Students were also asked to share examples of the types of educational activities they felt had facilitated this change and encouraged to share other thoughts related to the topic of education for sustainable development. The interviews were conducted on Teams collaboration tool and recorded to ease later transcription and data coding phases.

3.2 Data analysis

The transcripts were analysed using both inductive and deductive content analysis (Puusa and Juuti, 2020, 79). The inductive analysis was carried out first to reveal demonstration of learning for sustainable development in how students described their study experiences. Inductive analysis was selected to ensure all possible views would be included without the constraints of preselected analysis units. The initial in-vivo coding was followed by thematic grouping to identify central concepts arising from the data. These themes were then abstracted to facilitate interpretation into outcomes (Figure 2).

The interview themes (sustainable development, sustainable development awareness and sustainable development skills) were used as analysis units in the deductive content analysis. This analysis was conducted to ensure any outcomes possibly missed in the inductive analysis would be included in the conceptualization phase. Some quantification was also used for the presentation of the results.

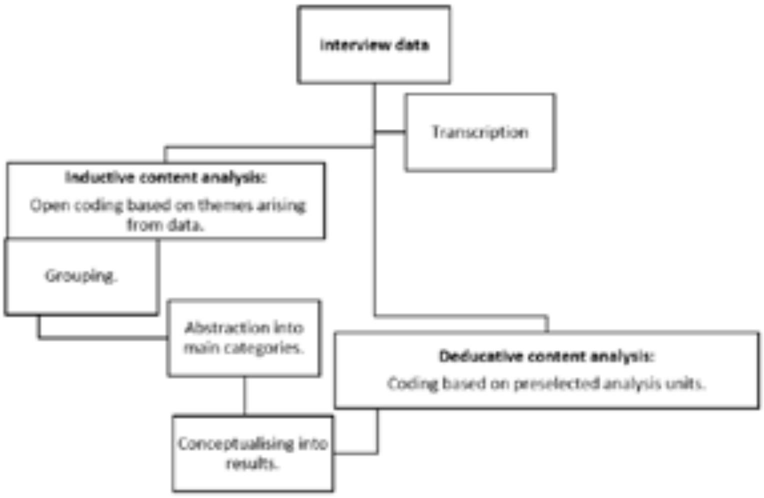

Figure 2. Flow diagram of the data analysis process

4 RESULTS

The interviewed students frequently associated "*sustainable development*" with concepts of "*circular economy*" or "*resource efficiency*", as presented in Table 2. This implies, as anticipated, that environmental engineering students define sustainability mainly from the perspective of natural capital and resource use. Some mentioned "the future" or "future generations", indicating consciousness of responsibility extending beyond the present. The term "Sustainable development awareness" was connected to the significance of understanding the overall need for sustainability. An aspect of personal involvement through taking action or spreading knowledge was also demonstrated. The aspect of taking action by applying knowledge and making informed decisions was also prominently featured in the definitions for "sustainable development skills".

Table 2. Definitions for sustainable development terminology by environmental engineering students. The number of interviewees (out of the total 18) using each phrasing indicated in parentheses.

Sustainable development	Sustainable development awareness	Sustainable development skills
Circular Economy (5/18)	Understanding the need for SD (consequences of past actions) (10/18)	Applying knowledge to practice (develop, improve, manage) (13/18)
Resource efficiency (4/18)	Personal ability to influence and to take action (CE) (5/18)	Making informed decisions (5/18)
Future (generations) (4/18)	Spreading knowledge and applying it into practice (3/18)	
Well-being (1/18)		
Decision-making (1/18)		
Damage minimization (1/18)		
Sustainable consumption (1/18)		
UN SDGs (1/18)		

The elements of sustainable development learning, as conceptualized from the outcomes of the interviews, are visualised in figure 3. Many of the interviewed students mentioned a personal motivation or interest in environmental or sustainability issues prior to the beginning of their studies, but emphasized this interest being increased further during their studies through subject matter studies and the peer group. The increased understanding of the sustainability challenges and their consequences coupled with the potential tools to take on these challenges were described to lead to believing a change for the better is still possible.

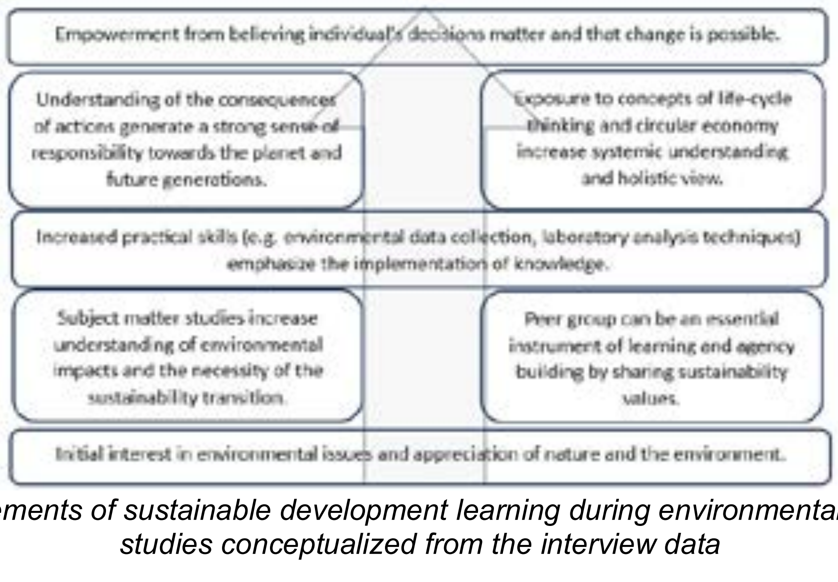

Figure 3. Elements of sustainable development learning during environmental engineering studies conceptualized from the interview data

Many students described a development of a sense of empowerment during their studies. The described process was quite similar to the steps visualised in Figure 1. starting with an initial value basis and awareness on the issues and though improved understanding leading to empowerment and agency (Sterling, 2015, 98, Pacis and VanWynsberghe, 2020, 583).

The interviewees described how studies on the subject matter had increased understanding of the need for a transition to sustainability. Understanding of the consequences of actions also led to a sense of responsibility for the planet and future generations. Several interviewed students identified practical, experimental courses, such as sampling, laboratory analysis and real or simulated working life projects as being effective in development of holistic and systemic understanding of sustainability issues. Introduction to the principles of life-cycle thinking and circular economy seems to not only increase understanding of the systemic nature and complexity of the sustainability challenges but also to assist students in their sustainability agency development. The increased need to apply sustainability values in decision-making from personal, professional, and societal perspectives was expressed by a majority (10/18) of the interviewees and it was often coupled with a description of how circular economy and the life-cycle approach could be used as instruments of the sustainability transition. It seems that studying these concepts can promote sustainability agency by reinforcing the belief in the potential for change. It may also allow students to feel their studies will eventually help contribute to the change for their part. Based on the results it seems focusing on concrete tools, such as the practical implementation of circular economy business models or life cycle assessments, can help students envision more optimistic future scenarios.

Students pursuing a career in environmental engineering can be expected to value ecological sustainability, which puts a strong emphasis on protecting the natural ecosystems, but the peer group was mentioned by many as strengthening this value base even further. The peer group had a strong role in sustainability agency formation for this part. Group-based learning tasks as well as learning sessions involving peer discussions were seen particularly beneficial especially in international student groups:

"…*that we have students from so many different countries…and different cultural backgrounds…that certainly expands our worldview*." (Interviewee 15)

The results that indicate presenting students with not only the challenges, but also actionable and preferably tangible tools for addressing them can benefit their agency formation:

"…*during these studies I realized that my two little hands and my little brain can help …to make something different…".* (Interviewee 11)

The results suggest the initial interest on ecological sustainability may play a major role in the selection of the study field, but the sense of sustainability agency is formed by learning about the possible ways to make a difference.

While the results indicate some directions on the elements of environmental engineering education, which can help students cope with the increasing environmental concerns, it should be noted the sample size is quite small due to resource constraints. Since there were only two interviewees following the Finnish environmental engineering curriculum, the possible differences between views of students following it and the English environmental engineering curriculum were not discussed. Inviting students to give an interview to a familiar lecturer also poses a possible source of bias, which could have been avoided by an external party conduct the interviews. The decision not to was based on previous experiences of students being very reluctant to take part in such data collection. A more extensive data collection would allow to make more transferable conclusions; however, the results already provide a starting point for educational practice development in environmental engineering development. The findings indicate environmental engineering students benefit from the types of educational activities that present them with opportunities for connecting theoretical information with hands-on assignments and sharing their thoughts with their peers. Applying these findings in other engineering education fields would make for an interesting topic for further research – after all, mainstreaming education for sustainable development only succeeds if all study fields are involved.

5 SUMMARY AND ACKNOWLEDGEMENTS

Environmental engineering students can be expected to have an interest in environmental issues and finding solutions to the current ecological sustainability challenges. Increased awareness on ecological problems; however, can lead to anxiety that may hinder sustainability agency development.

Understanding how environmental engineering students interpret sustainable development helps to identify the types of educational activities that may help them in developing sustainability awareness, understanding and empowered agency. Student interviews imply that environmental engineering students primarily interpret sustainable development in terms of natural resource use and the available tools, such as circular economy, for enhancing resource efficiency. Students also associate the concepts of “circular economy” and “life-cycle thinking” with the sustainability transition. Such concepts can help students identify their personal future roles as catalysts for change and strengthen their sense of sustainability agency. Such sense can be the primary component of seeing the future as hopeful.

We are very grateful for all the students taking the time to give an interview and allowing their views to be used as data sources.

REFERENCES

Anastasiadis, S., Perkiss, S., Dean, B., Bayerlein, L., Gonzalez-Perez, M., Wersun, A., Acosta, P., Jun, Hannah and Gibbons, B. “Teaching sustainability: complexity and compromises”. Journal of Applied Research in Higher Education. Vol. 13 No. 1, (2021): 272-286. https://doi.org/10.1108/JARHE-02-2020-0029

Karvinen, M. *Supporting agency for sustainability: Exploring the contributions of universities and workplaces to the sustainability competencies and agency of engineering graduates.* Helsinki: Aalto University publication series, 2024

Pacis, M. and VanWynsberghe, R. "Key sustainability competencies for education for sustainability: Creating a living, learning and adaptive tool for widespread use", *International Journal of Sustainability in Higher Education*, Vol. 21(2020)3: 575-592. https://doi.org/10.1108/IJSHE-12-2018-0234

Puusa, A. and Juuti, P. *Laadullisen tutkimuksen näkökulmat ja menetelmät*. 2nd edition. Helsinki: Gaudeamus, 2020.

Richardson, K., Steffen, W., Lucht, W., Brendtsen, J., Cornell, S., Donges, J., Drüke, M., Bala, G., Von Bloh, W., Feulner, G.,Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M. Huiskamp, W., Kummu, M., Mohan C., Nogués-Bravo, D., Petri, S., Porkka, M., Rahmstorf, S., Schaphoff, S., Thonicke, K., Tobian, A., Virkki, V., Wang-Erlandsson, L., Weber, L. ja Rockström, J. ”Earth beyond six of nine planetary boundaries.” *Science advances*. 9(37) (2023): 1-16. DOI: 10.1126/sciadv.adh245

Routaharju, L., Naukkarinen, J., Väisänen, S. and Soukka R. ”Ammattikorkeakoulun insinöörikoulutus kestävyysmurroksen edistäjänä”. *Focus Localis* 52:1, (2024): 112-130.

Sterling, S. Separate Tracks or Real Synergy? Achieving a Closer Relationship between Education and SD. *Journal of Education for Sustainable Development* 2(8), (2015): 89–112.

Vercammen, Ans, Sandhya Kanaka Yatirajula, Mercian Daniel, Sandeep Maharaj, Michael H Campbell, Natalie Greaves, Renzo Guinto, et al. “Investigating the Mental Health Impacts of Climate Change in Youth: Design and Implementation of the International Changing Worlds Study.” *Challenges (Basel)* 14, no. 3 (2023): 34-.

Wiek, A., Withycombe, L. and Redman, C. “Key competencies in sustainability: a reference framework for academic program development.” *Sustainability science*. 6(2), (2011): 203–218. https://doi.org/10.1007/s11625-011-0132-6

World Commission on Environment and Development. Our Common Future. Oslo: UN, 1987.

Xamk. “Degree Programmes: Bachelor of Environmental Engineering”. Xamk Website. N.d. Accessed February 19th. 2024, https://www.xamk.fi/en/education/degree-programmes/

COURSE PERCEPTION DIFFERENCES AMONG STEM STUDENTS IN A MULTI-CULTURE COURSE: A CASE STUDY IN US

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Conference Key Areas: *Diversity, equity and inclusion in our universities and in our teaching, Curriculum development and emerging curriculum models in engineering*
Keywords: *Course Perceiving, STEM Education, Multi-culture, Higher Education*

ABSTRACT

Students' course learning and perception are crucial tools for evaluating the effectiveness of courses and the outcomes of school education. Previous research highlights disparities in college learning based on factors such as gender, family socioeconomic status (SES), and cultural backgrounds. However, the influence of these factors on STEM (Science, Technology, Engineering, Medicine) students' learning and perceptions remains unexplored. This study draws from cultural capital theory and Hofstede's cultural dimensions theory to examine the influence of these factors on students' perceptions in a multicultural course. We observed a course at a well-known US public university during the summer term of 2023, designed to improve STEM students' math teaching skills at the high school level. Through qualitative interviews, the study revealed that within a multicultural course: 1. There are no obvious gender differences in STEM students' encountering cultural problems and course learning expectations; 2. Culture factors influence students' teaching style perceptions and encountering cultural problems when attending class..3. Family SES might influence students' course learning expectations and encountering cultural problems when attending class.These findings emphasize the importance of culture factors and family SES on STEM students' learning.

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1 INTRODUCTION

1.1 Background and Research Questions

Multicultural learning environments are prevalent in modern U.S. society. How do STEM students learn and feel in a multicultural class? Past studies have highlighted that international and immigrant students perceive differences in their courses compared to their local peers (Bal and Perzigian 2013). Specifically, these studies suggest that cultural differences can negatively affect students' participation in courses. Additionally, Reeder et al. (2004) found that different cultural communication patterns increase miscommunication, and the greater the perception of cultural differences between participants in an activity, the more frequent the incidents of miscommunication. Therefore, this poses challenges for educators. Parrish et al. (2010) argue that multicultural environments are vital for education, requiring culturally adapted teaching methods. Educators must not only meet students' needs but also adjust their teaching styles to suit diverse cultural backgrounds.

With the increasing presence of immigrant and international students in STEM education, it is crucial for STEM education providers to comprehend the diverse educational values and cultural expectations of students and their impact on learning. Consequently, there is a pressing need to develop new theories and conduct empirical research to offer guidance for the successful design and delivery of cross-cultural STEM courses.

To investigate the differences in learning perceptions among STEM students from diverse backgrounds and provide beneficial guidance, this study examines a summer course offered by a well-known U.S. university, designed for STEM students to learn how to teach high school math. The course utilized Environment-based Learning (EBL), emphasizing fieldwork, discussions, and teamwork It consisted of two parts: observation at a high school followed by lectures. The lectures introduced course content, followed by discussions in small groups. Six STEM students from diverse cultural backgrounds enrolled in the course, with over half being second-generation immigrants. Due to differences in cultural factors, family SES, gender and other factors, these students held varying opinions and attitudes towards learning perceptions in the course.

This study addressed the following three questions:

1. Are there any gender differences in STEM students' perceptions of a multicultural course, and if so, what are they?

2. Are there any culture differences in STEM students' perceptions of a multicultural course and if so, what are they?

3. Are there any family SES differences that influencing STEM students' perception of a multicultural course and if so, what are they?

1.2 Theoretical Framework

Cultural Capital Theory

Cultural Capital Theory, formulated by the French sociologist Pierre Bourdieu, emphasizes the role of various forms of "capital" beyond economic wealth in perpetuating social inequality (Bourdieu 1986). Bourdieu's theory, particularly relevant in educational contexts, examines how cultural capital influences educational outcomes (DiMaggio 1982). For instance, individuals from higher socio-economic backgrounds often possess greater cultural capital, such as familiarity with the educational system and access to extracurricular activities, providing them with an advantage in education (DiMaggio 1982; Huang 2019).

Hofstede's Cultural Dimension theory

Hofstede's cultural dimension theory stands as one of the most widely employed frameworks for the examination of cross-cultural communication. Hofstede developed a four-dimensional model of cultural differences, encompassing

power distance, uncertainty avoidance, individualism versus collectivism, masculinity versus femininity (Hofstede 1984; Hofstede 1986).

According to Hofstede's Cultural Dimension theory, China exhibits high power distance, moderate masculinity, low individualism, and uncertainty avoidance. South Korea, on the other hand, demonstrates high power distance, indicating acceptance of unequal power distribution, alongside low individualism, emphasizing group harmony. The country also displays a moderate masculinity score, balancing competitiveness with the quality of life, and high uncertainty avoidance, showing a preference for structure and stability.

The U.S. is marked by very high individualism, emphasizing individual rights and achievements, and high masculinity, reflecting a competitive culture. Meanwhile, Mexico exhibits high power distance, accepting hierarchical inequalities, and low individualism, valuing group loyalty. Mexico also shows a high masculinity score, valuing competitiveness and material success, and high uncertainty avoidance, preferring rules and predictability (Hofstede Insights 2024).

This framework is commonly employed to characterize cultural behaviors originating from different societies. Collis et al. (1999) proposed the "flexible" approach, suggesting that courses should be adaptable enough to encompass diverse cultural perspectives rather than rigidly adhering to predetermined content.

In our study, we integrate the aforementioned two theories to explore the genuine and precise differences in how family SES, gender, and culture factors influence STEM students' perceptions in a multicultural learning environment. The following figure 1 outlines the theoretical framework for our study. We use parents' occupation to measure family SES and consider teaching style, learning attitude, learning expectations, and if encountering cultural problems when attending class as aspects of course perceptions.

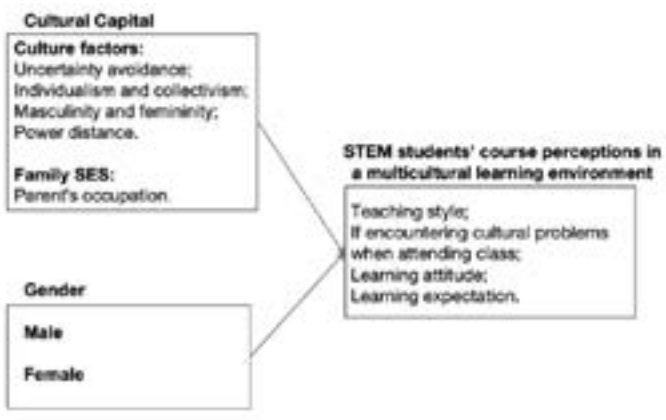

Fig. 1. Theoretical Framework

2 LITERATURE REVIEW

2.1 Course Perception Differences by Gender

Controversial claims exist regarding the influence of gender on students' learning.

Previous research indicates that gender impacts students' cognitive strategy usage (Wolters and Pintrich 1998). Moreover, gender emerges as a significant predictor

of learners' perceived learning, with female students often reporting higher perceived learning compared to their male counterparts (Rovai et al. 2005;Lee and Choi 2011; McCroskey et al. 1996). However, other researchers have found that female students perceive lower learning outcomes(Li 2019) and assert that gender does not affect the learners' levels of motivation and engagement in the classrooms (Almusharraf et al. 2023).

2.2 Course Perception Differences by Culture Factors

Previous studies affirm that cultural background does indeed influence students' perceptions about learning(Heath and Miller 2012; Munardji et al. 2020). While definitive conclusions about whether cultural differences lead to varying levels of satisfaction cannot be drawn, researchers have suggested that culture influences participants' perceptions of education and learning styles through communication, values, and educational systems (Morse 2003).

Furthermore, culture has been found to impact students' perceptions of the value of different forms of feedback (Evans et al. 2016). For instance, Kim et al. (2014) discovered within their cohort of first-generation Mexican immigrants that self-esteem was adversely affected by acculturative stress. They also noted that ethnic identity exacerbated the detrimental effects of the two identified types of acculturative stress (American-based and Mexican-based) on psychological well-being. The influence of stress and experiences of discrimination can lead individuals to become disengaged from the dominant culture. Zhang (2007) pointed out that Eastern cultural tradition, together with other social factors, has shaped a group-based, teacher-dominated, and centrally organized pedagogical culture. However, cultural identities are not fixed attributes; rather, they are adaptable and subject to change based on circumstances and situations (Deaux 2006; Oyserman et al. 2006).

Nevertheless, despite the importance of understanding the real differences in STEM students' course perceptions among different cultures, there is limited research on this topic.

2.3 Course Perception Differences by Family SES

Students' learning is influenced by their family's socioeconomic status (SES). Previous research indicates that individuals from different social backgrounds exhibit

variations in preferences, behavioral tendencies, and social norms (Liberatos et al. 1988). Contributing factors to these differences include parental educational background (Stephens et al. 2007), personal income, and personal educational attainment (Liberatos et al. 1988).

Research has shown that students from higher SES families often have higher expectations for their courses and might experience different learning outcomes compared to their peers from lower SES backgrounds (Sirin 2005; Reardon 2018). For instance, these students may be less engaged or challenged by the course material if it does not meet their elevated expectations (Bowen et al. 2005). However, it remains uncertain whether these trends hold true for students in STEM fields.

Given the distinct demands and characteristics of STEM education, further investigation is required to determine how family SES impacts STEM students' course perceptions and learning experiences (Musu-Gillette et al. 2016).

3 METHODOLOGY

3.1 Semi-structured Interview

The interviews comprised one-on-one in-depth sessions conducted in English for both the participants and the interviewer in August 2023. Each interview lasted around 10-30 minutes. The six participants were all undergraduates who attended and enrolled in the summer class held at a public university. Participants received a participant information sheet and a consent form. All interviews were recorded, kept confidential and anonymous, and the data were analyzed by using thematic analysis. This process involved familiarization, coding, and classification (Braun et al. 2006).

Initially, the interviews were transcribed and independently reviewed by the authors to record initial ideas and emerging themes. Subsequently, the transcripts were reread several times to refine the coded themes. The codes were then organized into discrete categories or themes, which are reflected in the structure of the findings section. For example, we combined and categorized all the interview data into different themes, such as positive worldviews, pessimistic worldviews, facing cultural problems, and not facing cultural problems, among others. The themes generated during the analysis were corroborated by data collected from all students who enrolled in the same class, thereby enhancing the credibility of the findings. All participants were STEM majors, with most aged between eighteen and twenty-five, totaling six students who attended the class and willingly participated in the interviews.

The following are the interview questions used in this study, which encompass students’ family backgrounds, their cultural values, and their attitudes towards the course. Additionally, they delve into their evaluation of the STEM course and the teaching style.

Interview Questions

1. Which country are you from? Are you an immigrant? What age range are you in? What are your parents' occupations?

2. What is your major? Which academic year are you currently in?

3. What are the most important values and beliefs in your culture, particularly regarding education? How do these influence your worldview?

4. Why did you choose to take this course? What is your perspective on the importance of mathematics and science? How do you typically approach studying these subjects?

5. Overall, what is your opinion of this class? How would you describe the teaching style? Can you identify three positive aspects and three negative aspects of the class?

6. Can you recall any other courses that left a strong impression on you? If so, why?

7. Have you ever encountered any cultural challenges while attending your courses? How did these challenges impact your comprehension of the material or your academic performance?

8. When students' cultural backgrounds, teachers' cultural backgrounds, and the culture of mathematics/science intersect in the classroom, what occurs?

9. How did this course enhance your problem-solving skills? What specific problem-solving techniques did you acquire from the course?

3.2 Participants

Table 1. Demographic information

No.	**Sex**	**Age**	**Parent's occupation**		**Immigrant or not**	**Major**	**Grade**	**If meet cultural problem in class**
			Father	**Mother**				
P1	Male	18-25	Engineering	Accounting	No	Physics	3	Y
P2	Female	18-25	/	Manager at laundromat	Yes, from central American	Bio-engineering	3	Y
P3	Male	30	Construction worker	Stay at home	Yes, from Mexico at 8 years old	Math	3	N
P4	Female	21	Retired	Design clothes at a clothing company	Yes, from South Korean, born in US	Applied mathematics with a concentration in economics	3	N
P5	Male	18-25	Unemployed	Retired	Yes, from Mexico, born in US	Double majors in physics and astronaut	5	Y
P6	Female	18-25	Worker	Worker	No	Education in Chemistry	4	Y

Table 1 shows the background information of all the participants. Among the participants, three are female students. P1 is a local American student. P2-P5 are second-generation immigrant students, hailing from Central America, Mexico, and South Korea respectively. P6 is an international student from China. The local American student has the highest family SES background, and the students from Mexico have the lowest family SES.

4 RESEARCH FINDINGS

4.1 Gender Differences

There are no apparent gender differences in encountering cultural problems when attending class and course learning expectations

When comparing P2 (Central American female) and P5 (Mexican American male), both have immigrant experiences and similar family SES backgrounds; their parents are both working class, and they share similar cultural values. P2 mentioned being "f*amily-oriented, kind, and honest*" while P5 emphasized "*treating others as you want to be treated*". Moreover, they both expressed discomfort in their STEM classes. For instance, P2 stated, "*Sometimes I'm the only woman there, and sometimes I'm the only person of color. It's intimidating. I was kind of afraid to speak*." P5 shared similar sentiments: "*I definitely feel it a lot with the physics courses I've taken here. All of my physics classes are very white-dominant, full of white students and professors. I don't really have much motivation to go to lectures. For the past few classes, we strictly learned from the book, not from the lectures. Some of the white professors have a very specific teaching style or tone, which I find unengaging.*"

These shared experiences suggest that factors other than gender, such as cultural background might play a more significant role in shaping students' course perceptions. Both participants displayed a positive attitude towards the course despite their challenges. P2 stated, "*The content is good but lacks placements*," while P5 mentioned, "*The concepts are all very interesting but lack placement*." Therefore, we assume that gender may not be an influential factor in encountering cultural problems and course learning expectations

4.2 Culture Factors Differences

Culture might be an influential factor in teaching style perceptions and in encountering cultural problems when attending class

When asked about the most impactful course in the past, P6 (Chinese international student) mentioned that she "*would like to express thanks to high school physics teacher, who was very strict with us. In this way, I could form a good habit and learned it well*."

The immigrant students (P2-P5) all expressed appreciation for teachers who were patient and enthusiastic. The local student (P1) mentioned a teaching style that combines practice and lecture, emphasizing hands-on activities.

When comparing P2 (Central American female) and P4 (Korean American female), both are immigrants with similar family SES backgrounds, their parents are working class. P4 emphasized self-effort in her family, saying, "*Everything is gonna be fine as long as you put in effort*." She also shared that she did not encounter any cultural problems when attending class. In contrast, P2 expressed a different experience: "*It's like navigating a game. It's kind of scary; you should find your support systems, like family. There are many challenges in life.*" She also noted, "*Sometimes I'm the only woman there, and sometimes I'm the only person of color. So it's intimidating. I was kind of afraid to speak.*"

Therefore, we assume that culture might be an influential factor in students' teaching style perceptions and in encountering cultural problems when attending class.

4.3 Family SES Differences

Family SES is an influential factor for students' course learning expectations and encountering cultural problems when attending class

During the interview, P1, a local white male student from a middle-class family, exhibited the most negative attitudes towards the course. His family background is the most affluent among all the participants. He expressed dissatisfaction, stating that he "*did not learn much from the course since it did not meet his standards, and the anticipated teaching method was not clearly expressed.*" In contrast, immigrant students and international students had a more positive appraisal of the perceived learning from the course, sharing that they learned a lot and benefited from it.

When comparing P3 (Mexican American male) and P5 (Mexican American male), P3 immigrated from Mexico at eight years old. The family SES of P3 is slightly lower than that of P5. P3 emphasized the unfairness of the educational resources available to them and insisted that only those with money could access a good education, highlighting "*unfairness*". They both shared a positive attitude towards the course. P3 reported not encountering any cultural problems in the class, while P5 held the opposite opinion.

Therefore, we assume that family SES might influence students' course learning expectations and encountering cultural problems when attending class.

5 SUMMARY AND DISCUSSION

The findings derived from the interview data highlight the influence of diverse cultural, gender, and family SES backgrounds on STEM students' perceptions of their courses. We found that there are no apparent gender differences in STEM students' encountering cultural problems when attending class and course learning expectations. However, culture and family SES could be influential factors for STEM students in encountering cultural problems when attending class. Also, culture might be an influential factor in students' teaching style perceptions and family SES might influence students' course learning expectations.

Specifically, Chinese and Korean students prefer strict teaching, while US and Mexican students prefer a patient and enthusiastic teaching style. Immigrant students from Mexico and Central America expressed struggles with assimilation into predominantly white mainstream society, affecting their willingness to participate in classroom activities led by white professors and their academic performance. All participants stressed the importance of learning STEM and the value of discussion-based teaching methods.

The research also has some limitations. Firstly, since the course is small, even though we interviewed all the students, the sample is still lacking. Secondly, the students who attended the class have diverse backgrounds, making it challenging to control for variables.

It's important to note that this study does not aim to determine which gender or culture has superior course perceptions or learning results. Rather, it seeks to analyze the differences among them. Although this study focused on course perception in only one summer course in the US due to resource limitations, it is hoped that the findings will contribute to understanding STEM students' course perception differences in multicultural environments. Ultimately, this article aims to offer suggestions and support to promote educational equity. Lastly, this research emphasizes the immigrant problem, especially for those from Central America or Mexico. Their children might encounter difficulties and obstacles in accessing educational resources and studying STEM majors.

REFERENCES

Almusharraf, Norah, Maha Aljasser, Hala Dalbani, and Dima Alsheikh. "Gender differences in utilizing a game-based approach within the EFL online classrooms." Heliyon 9, no. 2 (2023).

Bal, Aydin, and Aaron BT Perzigian. "Evidence-based interventions for immigrant students experiencing behavioral and academic problems: A systematic review of the literature." *Education and treatment of children* (2013): 5-28.

Bourdieu, Pierre. "The forms of capital (1986)." Cultural theory: An anthology 1, no. 81-93 (2011): 949.

Bowen, William G., Martin A. Kurzweil, Eugene M. Tobin, and Susanne C. Pichler. Equity and excellence in American higher education. University of Virginia Press, 2005.

Braun, Virginia, and Victoria Clarke. "Using thematic analysis in psychology." *Qualitative research in psychology* 3, no. 2 (2006): 77-101.

Collis, Betty. "Designing for differences: Cultural issues in the design of WWW-based course-support sites." *British journal of educational technology* 30, no. 3 (1999): 201-215.

Deaux, Kay. To be an immigrant. *Russell Sage Foundation*, 2006.

DiMaggio, Paul. "Cultural capital and school success: The impact of status culture participation on the grades of US high school students." *American sociological review* (1982): 189-20

Evans, Carol, and Michael Waring. "Exploring students' perceptions of feedback in relation to cognitive styles and culture." *In Styles of Practice in Higher Education*, pp. 39-58. Routledge, 2016.

Hofstede Insights, "Global Report 2024," 2024, accessed June 10, 2024, https://www.hofstede-insights.com/resources/report/global-report-2024.

Hofstede, Geert. "Cultural differences in teaching and learning." *International Journal of intercultural relations* 10, no. 3 (1986): 301-320.

Hofstede, Geert. Culture's consequences: International differences in work-related values. Vol. 5. sage, 1984.

Huang, Xiaowei. "Understanding Bourdieu-cultural capital and habitus." Rev. Eur. Stud. 11 (2019): 45.

Kholis, Nur, and Nuril Mufidah. "Community Multicultural Integration Pattern in Environment-Based Learning." *International Journal of Instruction* 13, no. 1 (2020): 101-124.

Kim, Eunha, Ingrid Hogge, and Camila Salvisberg. "Effects of self-esteem and ethnic identity: Acculturative stress and psychological well-being among Mexican immigrants." *Hispanic Journal of Behavioral Sciences* 36, no. 2 (2014): 144-163.

Lee, Youngju, and Jaeho Choi. "A review of online course dropout research: Implications for practice and future research." *Educational Technology Research and Development* 59 (2011): 593-618.

Li, Kun. "MOOC learners' demographics, self-regulated learning strategy, perceived learning and satisfaction: A structural equation modeling approach." *Computers & Education* 132 (2019): 16-30.

Liberatos, Penny, Bruce G. Link, and Jennifer L. Kelsey. "The measurement of social class in epidemiology." *Epidemiologic reviews* 10, no. 1 (1988): 87-121.

McCroskey, James C., Aino Sallinen, Joan M. Fayer, Virginia P. Richmond, and Robert A. Barraclough. "Nonverbal immediacy and cognitive learning: A cross-cultural investigation." *Communication Education* 45, no. 3 (1996): 200-211.

Morse, Ken. "Does one size fit all? Exploring asynchronous learning in a multicultural environment." *Journal of Asynchronous Learning Networks* 7, no. 1 (2003): 37-55.

Musu-Gillette, Lauren, Jennifer Robinson, Joel McFarland, Angelina KewalRamani, Anlan Zhang, and Sidney Wilkinson-Flicker. "Status and Trends in the Education of Racial and Ethnic Groups 2016. NCES 2016-007." *National Center for Education Statistics* (2016).

Oyserman, Daphna, Deborah Bybee, and Kathy Terry. "Possible selves and academic outcomes: How and when possible selves impel action." *Journal of personality and social psychology* 91, no. 1 (2006): 188.

Parrish, Patrick, and Jennifer Linder-VanBerschot. "Cultural dimensions of learning: Addressing the challenges of multicultural instruction." *The International Review of Research in Open and Distributed Learning* 11, no. 2 (2010): 1-19.

Reardon, Sean F. "The widening academic achievement gap between the rich and the poor." In Social stratification, pp. 536-550. Routledge, 2018.

Reeder, Kenneth, Leah P. Macfadyen, Joerg Roche, and Mackie Chase. "Negotiating cultures in cyberspace: Participation patterns and problematics." (2004).

Rovai, Alfred P., and Jason D. Baker. "Gender differences in online learning: Sense of community, perceived learning, and interpersonal interactions." *Quarterly Review of Distance Education* 6, no. 1 (2005): 31.

Sirin, Selcuk R. "Socioeconomic status and academic achievement: A meta-analytic review of research." *Review of educational research* 75, no. 3 (2005): 417-453.

Stephens, Nicole M., Hazel Rose Markus, and Sarah SM Townsend. "Choice as an act of meaning: the case of social class." *Journal of personality and social psychology* 93, no. 5 (2007): 814.

Zhang, Jianwei. "A cultural look at information and communication technologies in Eastern education." *Educational Technology Research and Development* 55 (2007): 301-314.

INTELLECTUAL HUMILITY, EMPATHY, AND RESISTANCE TO CHANGE AMONG SCIENCE AND ENGINEERING STUDENTS

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ABSTRACT

Humility is important for learning because it allows individuals to acknowledge their limits, accept feedback and be open to changing their ideas. This paper examines the relationship between intellectual humility, empathy, and resistance to change among science and engineering students. Intellectual humility is defined as the willingness to recognize one's own cognitive limitations and openness to diverse perspectives. Empathy involves the ability to understand and share the feelings of others. Resistance

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to change refers to the tendency to resist new ideas or ways of thinking. The study aimed to explore how these factors are interconnected. A survey was conducted among a sample of students from three universities in the USA to measure their levels of intellectual humility, empathy, and resistance to change. The results revealed that students with higher levels of intellectual humility tended to exhibit more empathy towards others and were more open to new ideas and change. Furthermore, the study found that humility played a significant positive role in mediating the relationship between empathy and resistance to change. These findings have important implications for educators and policymakers in promoting a culture of openness among science and engineering students. Suggestions for fostering intellectual humility and empathy in educational settings are also discussed.

1 INTRODUCTION

Learning requires an open mindset, yet research has shown that students seem to resist new ideas and have developed what Snelson (1992) calls an “ideological immune system”. In engineering education, prior research has shown that undergraduate engineering students carry a high level of cognitive rigidity and a high level of emotional attachment to their own ideas (Dyehouse et al., 2015), particularly regarding the nature of engineering as a human-oriented discipline. To better understand underlying mechanisms in students’ beliefs, cognition and their associated emotions, several lines of research have been pursued: A growing body of literature has researched empathy among undergraduate students (see e.g., Rasoal, Danielsson & Jungert, 2012) and within industry contexts (Strobel, Hess, Pan & Wachter Morris, 2013) showing particularly gender differences. Similarly, previous research has researched cognitive rigidity and emotional attachments to one’s own ideas (Dyehouse et al., 2015). Intellectual humility is briefly listed as possibly a virtue contributing to engineering students’ mindset and belief system (see Pierrakos et al., 2009), yet the connection to empathy and cognitive rigidity has not been explicitly studied. This paper represents a first step in a larger endeavor to understand the relationship between intellectual humility empathy, and resistance to change to contribute to a deeper understanding of existing worldviews, beliefs, and underlying mechanism at play when engineering students engage in the learning process. Longer term, this line of research could lead to rethinking learning outcomes, instructional and pedagogical approaches and understanding the complexity of individual learners.

The objectives of this research study are: (1) Researching how intellectual humility is related to perspective taking/empathy by identifying how the Intellectual Humility Scale (IH) is correlated with the Interpersonal Relativity Scale (a scale to measure perspective taking). (2) To identify the role of intellectual humility as a moderator between empathy and resistance to change. (3) To determine what sociodemographic variables presented any differences among the levels of intellectual humility and empathy in the engineering and science student sample and finally

2 PERSPECTIVE(S) OR THEORETICAL FRAMEWORK

The paper draws from three theoretical frameworks of which we argue are connected and benefit from being examined for their impact on student learning: Intellectual Humility, Empathy and Resistance to Change. Intellectual Humility is defined as "(a) having insights about the limits of one's knowledge, marked by an openness to alternative ideas, and (b) the ability to present one's ideas non-offensively and receive information non-defensively" (Wong & Wong, 2021, p.1) and falls in the broader category of emotion (Saroglou et al. 2008, p.168). Existing research shows that Intellectual Humility is positively associated with academic performance in post-secondary education (Wong & Wong, 2021) and has direct influence on how individuals process new information, remain open, change their conceptual understanding, and learn new competencies (Samuelson et al., 2015). In the context of engineering education, Intellectual Humility is briefly listed as intellectual virtue (Pierrakos et al., 2009) yet we have yet (a) to research to what extent Intellectual Humility is influencing engineering students' mindset and (b) to practically evaluate how Intellectual Humility as a quality can be taught (Leary, 2018). Empathy is broadly defined as "the reactions of one individual to the observed experiences of another" focusing both on the act of understanding and the capacity to enter the feelings of another and oneself (see Davis, 1980). The last two decades saw an increase in research on empathy and perspective taking (as part of empathy) in engineering education (Strobel et al., 2011; Strobel et al., 2013; Hess et al., 2016; Hess et al. 2017). Research shows strong connection to design thinking, communication, and other transversal skills (Sanz et al., 2023), ethical behavior (Hess & Fila, 2016), yet the connection to empathy and intellectual humility in engineering has not been explicitly studied.

This paper follows Oreg's (2003; 2018) model of resistance to change which conceptualizes resistance to change as "an individual's personality-based inclination to resist changes" (Oreg, 2018, p.89). We utilized particularly two dimensions: The emotional reaction to imposed change dimension captures the degree to which imposed change elicits anxiety and discomfort; and the cognitive rigidity dimension captures the degree of inflexibility in changing one's opinions or attitudes. Existing research shows that undergraduate engineering students carry a high level of cognitive rigidity and a high level of emotional attachment to their own ideas (Dyehouse et al., 2015) yet the connection between humility, empathy and resistance to change has not studied.

3 METHODS, TECHNIQUES, OR MODES OF INQUIRY

The research team constructed a survey using subconstructs of three independently developed validated survey instruments which each measured two sub constructs of our three main constructs: Intellectual Humility, Empathy (operationalized as interpersonal reactivity, see Davis, 1980), and Resistance to Change. The survey was administered in three universities in the U.S. Midwest and Southwest known for their STEM programs. We received 523 responses, and after data cleaning we had usable data from 369 respondents who had completed all items on at least three out of the six sub constructs we measured.

3.1 Sub constructs

We used the following sub constructs: from the Comprehensive Intellectual Humility Scale (CIHS; Krumrei-Mancuso & Rouse, 2016) we used two sub-constructs (a) Respect for Others' Viewpoints (IH-ROV: 6 items) and (b) Lack of Intellectual Overconfidence (IH-LIO: 6 items). The 12 items were rated on a scale from 1 (Does not apply to me at all) to 6 (Does apply to me very well). Sample items include 'I welcome different ways of thinking about important topics', and 'For the most part, others have more to learn from me than I have to learn from them'. A higher total score reflected a higher level of intellectual humility. In our study, the reliability of both subscales was good: α = 0.89 for Respect for Others' Viewpoints and α = 0.75 for Lack of Intellectual Overconfidence (Field, 2009).

To measure empathy, we used the Interpersonal Reactivity Index (Davis, 1980) from which we used two sub-constructs (a) perspective taking (IR-PT: 7 items) and (b) empathic concern scale (IR-EC: 7 items). The 14 items were rated on a scale of 1 (does not describe me very well) to 6 (describes me very well). Sample items include 'I try to look at everybody's side of a disagreement before I make a decision' and 'Other people's misfortunes do not usually disturb me a great deal.' A higher total score reflected a higher level of interpersonal reflectivity (empathy). In our study, the reliability of both subscales was good: α = 0.75 for Perspective-Taking and α = 0.74 for Empathic Concern.

To measure resistance to change, we used two sub-constructs of the Resistance to Change scale (Oreg, 2003) (a) Emotional Reaction to imposed change (RC-ER: 8 items) and (b) Cognitive Rigidity (RC-CR: 3 items). The 11 items were rated on a scale of 1 (Strongly disagree) to 6 (Strongly agree). Sample items include 'When things don't go according to plans, it stresses me out.' and 'My views are very consistent over time'. A higher total score reflected a higher level of resistance to change. In our study, the reliability of both subscales was good for Emotional Reaction to imposed change (α = 0.85) and borderline acceptable for Cognitive Rigidity (α = 0.63).

3.2 Data sources, evidence, objects, or materials

The research team administered an online survey to three institutes of higher education located in the Southwest and Midwest of the USA combining into one dataset. Recruitment happened through a network of colleagues supplemented with support from institutional offices such as associate dean of undergraduate studies. We deliberately recruited with a goal of reaching predominantly science and engineering (including computer science) undergraduate students. As recruitment followed a snowball principle, the study also includes graduate students, see the demographic information in Table 1.

Table 1: Demographics of Study Participants

		Gender			
		Female	Male	Other	Total
Major	Engineering	62	135	7	204
	Science	89	15	2	106

	Other	46	12	0	58
	Missing				1
Year in college	Freshman	46	28	1	75
	Sophomore	69	46	4	119
	Junior	49	34	2	85
	Senior	26	30	2	58
	Grad School	7	23	0	30
	Missing				2
Ethnicity	White	37	66	3	106
	Non-white	159	90	4	253
	Prefer not to say	1	6	2	9
	Missing				1

4 RESULTS

4.1 Relationships

A Pearson correlation analysis was conducted among IH-ROV, IR-EC, IH-LIO, RC-CR, IR-PT, and RC-ER. Cohen's standard was used to evaluate the strength of relationships (Field, 2009). The result of the correlations was examined based on an p value of .001. Table 2 presents the results of the correlation analysis.

Table 2 shows significant correlations between the two Intellectual Humility constructs, and the Interpersonal Reactivity constructs. The two Resistance to Change constructs have a weak, yet significant, correlation of .207, yet do not correlate with the other constructs. The only correlation we found between Resistance to Change constructs is between Cognitive Rigidity and Lack of Intellectual Overconfidence, and this correlation is negative, which means that if students score higher on Cognitive Rigidity, they score lower on Lack of Intellectual Overconfidence (LIO) and vice versa.

Table 2: Correlation Between Sub-constructs

		IH LIO	IR PT	IR EC	RC ER	RC CR
IH-ROV	Pearson r	.180**	.625**	.478**	.081	.069
	Sig. (2-tailed)	<.001	<.001	<.001	.128	.195
	N	352	348	339	354	354
IH-LIO	Pearson r		.238**	.351**	-.151	-.426**
	Sig. (2-tailed)		<.001	<.001	.004	<.001

	N		349	340	355	355
IR-PT	Pearson r			.604**	.068	.016
	Sig. (2-tailed)			<.001	.201	.763
	N			344	354	354
IR-EC	Pearson r				.134	-.085
	Sig. (2-tailed)				.013	.115
	N				345	345
RC-ER	Pearson r					.207**
	Sig. (2-tailed)					<.001
	N					361

**Probability level is <.05, ** Probability level is <= .001*

We ran a correlation analysis on the main constructs of the survey. We established a large correlation between IR and IH, and a small, negative correlation between IH and RC. This means that if participants score higher on Intellectual Humility, they score lower on Resistance to Change.

Table 3: Correlation Between Main Constructs

		IH	RC
IR	Pearson r	.611**	.022
	Sig. (2-tailed)	<.001	.691
	N	328	337
IH	Pearson r		-.145*
	Sig. (2-tailed)		.007
	N		347

**Probability level is <.05, ** Probability level is <= .001*

To test the mediating effect of humility on empathy and resistance to change, we performed a partial correlation test to determine the relationships between the variables, IH, IR, and IC. Partial correlation analysis is employed to control the effect that a variable has over the correlation of other variables. We conducted a Kolmorogov-Smirnov test for normality. This test yielded a non-significant result hence we assume the data is normally distributed meeting all conditions for partial correlation testing. The results of the partial correlation can be found in Table 4, which shows the correlations among the constructs and the partial correlations when we controlled for IH as an intermediating variable between IR and RC. When we did not control for IH, we found a nonsignificant ($p > 0.05$) relationship of .011 between IR and RC, which is negligeable. A positive correlation of .610 was observed between IR and IH, indicating a large effect size (p < .05). The correlation between RC and IH is negative and is weak yet significant at -.172 (p < .05). IH correlates with both other main constructs, while the other main constructs do not seem to correlate. When we control for IH the correlation between IR and RC increases to .149 (p < .05), which indicates that IH indeed is an intermediating variable between IR and RC. In other words, experiencing empathy for another person would not necessarily reduce the resistance to change one's perspective, yet people who score high on intellectual humility might be more willing to change their minds if they empathize with someone else's point of view.

Table 4: Partial correlations between main constructs

Control Variable			RC	IH
None	IR	Pearson r	.011	.610**
		Sig. (2-tailed)	.842	<.001
		N	321	321
None	RC	Pearson r		-.172
		Sig. (2-tailed)		.002
		N		321
IH	IR	Pearson r	.149*	
		Sig. (2-tailed)	.007	
		N	321	
Note: Partial correlations were calculated on data points without missing items.				

**Probability level is <.05, ** Probability level is <= .001*

4.2 Significant Differences between Groups

We tested for significant differences between *Year in College, Gender,* and *Fields of Study*. We did not find any significant differences for *Year in College*. The results for differences between gender are presented in Table 5. The differences between Male and Female students are striking, as we established moderate to large effect sizes for the sub constructs where we found differences. In all cases the Female students scored higher on the sub constructs.

Table 5: One Way ANOVA Differences based on Gender (only significant reported here)

		Mean	SD	F-value	p	Effect size*
IH ROV	Male	4.66	.963	5.655	.004	.33
	Female	4.96	.838			
IR EC	Male	4.09	.849	26.282	<.001	.79
	Female	4.71	.710			
IR PT	Male	4.14	.886	9.184	<.001	.44

	Female	4.51	.755			
RC ER	Male	3.52	1.09	14.761	<.001	.58
	Female	4.17	1.11			

**We used Hegdes' g for effect size calculations as the sample sizes differed strongly: Male: 106, Female: 193*

We tested for significant differences on our subconstructs between fields of study. We discern between Engineering (including Computer Science), Natural Sciences, and Other fields, e.g. kinesiology, neuroscience and nursing. For humility subconstructs, we did not find any statistically significance. We established significant differences for IR EC (F= 7.630, p= <.001), IR PT (F= 6.413, p= .002), RC ER (F= 5.955, p= .003) between Engineering, Science and Other fields (see Table 7 for details on the outcomes of this analysis) in so far that engineering students scored significantly lower on empathy subscales and the emotional reaction to imposed change subscale of the resistance to change construct.

Table 7: One Way ANOVA Differences based on major: Engineering, Science, Other (only significant reported here)

		Mean/ SD	Mean/ SD	F-value	p value*	Effect size**
IR EC	Engineering and Science	4.26 / .879	4.56 / .689	7.915	.005	.36
	Engineering and Other	4.26 / .879	4.75 / .727	10.145	.002	.57
IR PT	Engineering and Other	4.20 / .861	4.65 / .784	10.795	.001	.53
RC ER	Engineering and Science	3.71 / 1.14	4.12 / 1.15	9.028	.003	.35
	Engineering and Other	3.71 / 1.14	4.21 / 1.14	6.175	.014	.43

**We used a Bonferroni correction, which means that we consider p=.017 as the cut off score for significance.*
***We used Hedges' g for effect size, as the sample sizes between the fields differed in size: E= 196, S= 98, O= 56*

5 DISCUSSION

The aim of our study was to examine how intellectual humility is related to perspective taking/empathy and to determine what sociodemographic variables presented any differences among the levels of intellectual humility and empathy in the engineering and science student sample. Finally, to identify the role of intellectual humility as a moderator between empathy and resistance to change.

Our analysis has shown a positive and statistically significant relationship between sub-constructs of intellectual humility and empathy (interpersonal reactivity). We also established a small, negative correlation between Intellectual Humility (IH) and Resistance to Change (RC), meaning that students who score higher on empathy are also scoring higher on humility and that if participants score higher on Intellectual

Humility, they score lower on Resistance to Change. The finding does not come as a surprise as cognitive rigidity reflects a level of dogmatism and lack of overconfidence would rather indicate an intellectual doubt in one's own position – two juxtaposing positions. Findings here are consistent with existing literature on the inextricable relationship between cognitive rigidity and overconfidence (Cohen, 2017). The main outcome of this study pertains to IH as an intermediate variable between IR and RC.

As far as our significance testing between our constructs and Year in College, Gender, and Fields of Study it was surprising however that we did not find any significant differences for *Year in College* as it would indicate that humility and empathy are more stable traits. We also investigated gender differences and found that female students scored higher than males on all the interpersonal reactivity constructs (empathy, perspective-taking, and emotional reaction to imposed change) which is consistent with the literature on self-reported empathy data for students (Rueckert et al., 2011) yet not with results on engineers working in the profession (Hess et al., 2017).

For Fields of Study, we did not find any statistically significant differences when it came humility. We found, however, significant differences for Interpersonal Reactivity (empathy) subconstructs and the emotional reaction to imposed change (resistance to change) subconstruct based on fields of study. Engineering students scored statistically significantly lower on empathy subscales which is corroborated by research by Rasoal et al. (2012) and score lower on the emotional reaction to imposed change subscale of the resistance to change construct which confirms prior results by Dyehouse et al. (2017).

6 LIMITATIONS

The study has several limitations: The study surveyed students from three universities in the USA, which may limit the generalizability of the findings. The demographics, cultural backgrounds, and academic experiences of the participants might not represent the broader population of science and engineering students. In addition, the data collection relied on self-report measures to assess intellectual humility, empathy, and resistance to change. This approach is subject to social desirability bias, where participants may provide responses that align with perceived societal norms or expectations rather than their true attitudes or behaviors.

The study captured data at a single point in time, and the reliability of the CR construct could have been better. As a result, causal relationships cannot be inferred, and longitudinal studies are needed to examine how these constructs evolve over time and whether changes in one variable precede changes in another.

7 SCIENTIFIC OR SCHOLARLY SIGNIFICANCE OF THE STUDY OR WORK

Our research shows preliminary statistically significant correlations between multiple subconstructs and constructs of humility, empathy, and resistance to change. The results indicate differences based on gender and fields of study as well. In addition, our research shows that intellectual humility seems to be a mediator variable between empathy and resistance to change. Further research and the design of interventions are needed to improve intellectual humility of engineering students and change the cultural norms of engineering education.

REFERENCES

Campanario, J. M. (2002). The parallelism between scientists' and students' resistance to new scientific ideas. *International Journal of Science Education, 24*, 10, 1095-1110. http://dx.doi.org/10.1080/09500690210126702

Cohen, S. J. (2017). Cognitive rigidity, overgeneralization and fanaticism (pp.1-7), in *Encyclopedia of Personality and Individual Differences*, eds V. Zeigler-Hill and T. K. Shackelford (New York, NY: Springer). doi: 10.1007/978-3-319-28099-8_834-1

Davis, M. H.(1980). A multidimensional approach to individual differences in empathy. *JSAS Catalog of Selected Documents in Psychology,10*, 85.

Dyehouse, M., Weber, N., Fang, J., Harris, C., David, R., Hua, I., & Strobel, J. (2015). Examining the relationship between resistance to change and undergraduate engineering students' environmental knowledge and attitudes. *Studies in Higher Education*, 1-20. http://dx.doi.org/10.1080/03075079.2015.1052734

Field, A. (2009). Discovering statistics using SPSS (3rd Ed.), Sage Publishers.

Hess, J., Strobel, J., Pan, R. & Wachter Morris, C. (2017). Insights from industry: a quantitative analysis of engineers' perceptions of empathy and care within their practice. *European Journal of Engineering Education, 42*, 6, 1128-1153. http://dx.doi.org/10.1080/03043797.2016.1267717

Hess, J., Strobel, J. & Pan, R. (2016). Voices from the Workplace: Practitioners' Perspectives on the Role of Empathy and Care within Engineering. *Engineering Studies*.1-31. http://dx.doi.org/10.1080/19378629.2016.1241787

Hess, J. L., & Fila, N. D. (2016). The development and growth of empathy among engineering students. Proceedings of the American Society of Engineering Education Annual Conference and Exposition, New Orleans, LA, June 26–29. http://dx.doi.org/10.18260/p.26120

Krumrei-Mancuso, E. J., & Rouse, S. V. (2016). The development and validation of the comprehensive intellectual humility scale. *Journal of Personality Assessment, 98*, 2, 209-221. http://dx.doi.org/10.1080/00223891.2015.1068174

Leary, M. R. (2018). The psychology of intellectual humility. *John Templeton Foundation*, 3.

Oreg, S. (2003). Resistance to change: Developing an individual differences measure. *Journal of Applied Psychology, 88*, 4, 680. http://dx.doi.org/10.1037/0021-9010.88.4.680

Oreg, S. (2018). Resistance to change and performance: Toward a more even-handed view of dispositional resistance. *The Journal of Applied Behavioral Science, 54*, 1, 88-107. http://dx.doi.org/10.1177/0021886317741867

Ou, A. Y., Tsui, A. S., Kinicki, A. J., Waldman, D. A., Xiao, Z., & Song, L. J. (2014). Humble chief executive officers' connections to top management team integration and middle managers' responses. *Administrative Science Quarterly, 59*, 1, 34-72. http://dx.doi.org/10.1177/0001839213520131

Pierrakos, O., Prentice, M., Silverglate, C., Lamb, M., Demaske, A., & Smout, R. (2019, October). Reimagining engineering ethics: From ethics education to character education. In 2019 IEEE Frontiers in Education Conference (FIE) (pp. 1-9). IEEE. http://dx.doi.org/10.1109/FIE43999.2019.9028690

Rasoal, C., Danielsson, H., & Jungert, T. (2012). Empathy among students in engineering programmes. *European Journal of Engineering Education, 37*, 5, 427-435. http://dx.doi.org/10.1080/03043797.2012.708720

Rueckert, L., Branch, B., & Doan, T. (2011). Are gender differences in empathy due to differences in emotional reactivity? *Psychology, 2*(6), 574–578. https://doi.org/10.4236/ psych.2011.26088

Samuelson, P. L., Jarvinen, M. J., Paulus, T. B., Church, I. M., Hardy, S. A., & Barrett, J. L. (2015). Implicit theories of intellectual virtues and vices: A focus on intellectual humility. *The Journal of Positive Psychology, 10*, 5, 389-406. http://dx.doi.org/10.1080/17439760.2014.967802

Sanz, C., Coma-Roselló, T., Aguelo, A., Álvarez, P., & Baldassarri, S. (2023). Model and Methodology for Developing Empathy: An Experience in Computer Science Engineering. *IEEE Transactions on Education. 66*, 3, p.287-298. http://dx.doi.org/10.1109/TE.2022.3231559

Saroglou, V., Buxant, C., & Tilquin, J. (2008). Positive emotions as leading to religion and spirituality. *The journal of positive psychology, 3*(3), 165-173.

Snelson, J.S. (1992) The Ideological Immune System: Resistance of New Ideas in Science, *Skeptic Magazine, 1*, 4, p.1-20.

Strobel, J., Wachter Morris, C., Weber, N., Dyehouse, M., Klingler, L., & Pan, R. (2011). Full paper: Engineering as a caring and empathetic discipline: Conceptualizations and comparisons. Proceedings of the Research in Engineering Education Symposium, Madrid, October 3-7 (9 pages).

Strobel, J., Hess, J., Pan, R., & Wachter Morris, C. A. (2013). Empathy and care within engineering: Qualitative perspectives from engineering faculty and practicing engineers. *Engineering Studies, 5*, 2, 137-159. http://dx.doi.org/10.1080/19378629.2013.814136

Wong, I. H., & Wong, T. T. (2021). Exploring the relationship between intellectual humility and academic performance among post-secondary students: The mediating roles of learning motivation and receptivity to feedback. *Learning and Individual Differences, 88*, 102012. http://dx.doi.org/10.1016/j.lindif.2021.102012

DECODING THE SKILL PUZZLE: AN INVESTIGATION OF COMPETENCY PROFILES OF RECENT ENGINEERING GRADUATES

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ABSTRACT

As engineers play a central role in solutions for holistic sustainability, it is pivotal to ensure that our engineering graduates enter their careers with dynamic competency profiles - where core engineering skills are integrated with generic and value-based skills in a synergistic way. At present, the graduate competency discourse is driven by employers' and stakeholders' perspectives, thus overlooking those of recent graduates. In this study, we adopted a data-driven approach to study national survey data on recent graduates' (n=1976) perceptions on the importance thirty key competencies and the patterns underlying those perceptions. Our quantitative analysis revealed that while graduates perceive a variety of competencies as important within the first year of graduation, these competencies form five unique profiles where foundational and organizational skills are perceived as most

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important. Furthermore, we uncovered that graduates' perceptions on these competencies are shaped by two key dimensions: generic versus discipline-specific skills, and analytical versus holistic thinking. Our results provide foundational insights for both educators and employers to enhance their collaborative efforts in supporting students' transition from studies to working life. Particularly, by adopting experiential learning pedagogies and providing mentoring, there is an opportunity to leverage graduates' competencies and novel insights for the benefit of the industry and society.

1 INTRODUCTION

Today's engineers are operating in a rapidly evolving landscape that is shaped by technological advancements and demands for sustainable solutions. Early-career graduates could hold a pivotal role within this context through their education and novel insights, however, this is perhaps not well recognized yet in the working life, nor promoted sufficiently in the education (Karvinen 2024; Craps et al. 2021b). At the same time, both educators and working life actors are encouraged to collaboratively ensure that engineering graduates are sufficiently supported to develop competencies to respond to the on-going sustainability crisis (Kolmos et al., 2016; Karvinen, 2024). Therefore, gaining a broader understanding on how graduates perceive various working life competencies and how those competencies interact with one another can shed light on areas where current educational and professional practices could better support graduates' transition from studies to working life, and lifelong learning.

1.1 Early-career competencies of engineers

The discourse on what type of competencies engineers need in the early career is not new. There is a long tradition of surveying the general needs of engineering practice, particularly from the employers' perspectives. The key expectations towards engineering graduates often emphasize a broad range of skills, ranging from subject-specific know-how to various generic and interpersonal skills (Passow and Passow 2017; Khoo, Zegwaard, and Adam 2020). This pattern can be observed across different cultural and disciplinary contexts. For instance, a recent study surveying employers' expectations in the water and environmental engineering field in Finland found that a mix of subject-specific, social, and problem-solving skills are emphasized when recruiting graduates (Renko et al. 2020). Similarly, another study focused on mechanical engineering field in the United Kingdom found that personal working attitude, professional conduct, willingness to learn, as well as technical and subject-specific skills to be crucial for employability (Souppez 2023).

From graduates' perspective, the subject-specific or "hard" skills are more relevant in the early career, but when moving forward in the career, "softer" skills, such as leadership, ethics and value-based thinking, become more important (Winters et al. 2013; Vehmaa et al., 2018). The emphases on what skills become relevant also depend on which career paths the graduate ends up taking: for instance, those pursuing managerial positions require competencies such as business knowledge and leadership and are less likely to rely on engineering tools and techniques (Brunhaver et al., 2013). This diversity of career paths, coupled with high and changing demands of the working life, often leads to debates on misalignments between education and practice – particularly when engineering curricula tends to favour technical and theoretical foundation, whereas working life also seek for attitudinal factors and transferrable competencies (Trevelyan 2019; Pyrhönen et al., 2019).

1.2 Towards a shared vision of competency profiles

Recent soaring demands to enhance sustainability in education have created a strong need to incorporate not only workforce concerns but also agency and value-based skills in the engineering curriculum (UNESCO 2021; Malmqvist 2020). As a response, various competency profiles and frameworks have emerged in literature to be promoted through education. Frameworks such as key sustainability (Brundiers et al., 2021) and transformative competencies (OECD, 2019) emphasize that competencies should be viewed as a cohesive unit of interacting abilities rather than lists of isolated skills to be developed. Viewing competencies through the lens of interconnected and synergetic abilities is encapsulated, for instance, through the T-shaped competency profile (Uhlenbrook and Jong 2012; Conley et al. 2017) and a recently proposed hybrid competency profile (Karvinen 2024). Both models call for combining the core engineering expertise with broader competencies. In particular, the hybrid profile, highlights the need to integrate broader competencies—such as interdisciplinary, comprehensive, futures, and values thinking—into the core engineering expertise. These competencies are essential for engineers to support the transition towards more just and sustainable societies (Quelhas et al. 2019).

The responsibility of developing the needed competency profile should not fall solely on the graduates. Engineering education is confronted with the need to keep their curricula up to date with a variety of competencies aligning with employability and sustainability agendas, and what the graduates themselves perceive as important for their career and wellbeing. Simultaneously, employers play a crucial role in fostering environments that support professional growth and embrace graduates' contributions (Karvinen, 2024). However, to adequately support engineers' transition to working life, there is a need for a more in-depth understanding on the interplay of various competencies in the early career. Few studies have explored recent graduates' perceptions on the importance of these skills, and even fewer have examined the interrelations between them. This gap hinders a comprehensive understanding of how competency profiles develop in practice, and thereby also the efficacy of collaborative efforts to support graduates lifelong learning. To bridge this gap, the following questions directed our research:

1. What are recent graduates' perceptions of the importance of various skills for their careers?
2. What possible underlying patterns characterize these perceptions?

2 METHODOLOGY

We adopted a quantitative approach to address our research questions. For this study, we acquired and received permission to utilize survey data collected by a Finnish professional organization and labor union for engineers "Tekniikan Akateemiset" (TEK). TEK collaborates with seven Finnish universities to conduct an annual "Graduate Survey" for academic engineers and architects who have completed their degrees during the past year. Given the varying time spans associated with the term "early-career," we adopted "recent graduates" to specifically refer to those who graduated within the past year.

2.1 Data description

The survey data used in this study is from the most recent TEK Graduate Survey (N=1976; TEK 2022). The survey collected information on respondents' study experiences, developed competencies, well-being, and employment situation (response rate 61%). Respondents were mainly male (N=1332, 67%), and on average 29 years (range 21-64, median 27). A total of 83 % (N=1481) of respondents were Finnish and this share was similar among men and female. In this study, we used responses to questions related to the perceived importance of thirty pre-defined skills for respondents' careers that were ranked on a six-point Likert scale (1 = not at all, 2 = very little, 3 = little, 4 = somewhat, 5 = much, and 6 = very much important). Notably, 94% of the respondents gained work experience during their studies, indicating some level of understanding about the work life needs, despite been fresh graduates.

2.2 Data analysis

We used R programming language to conduct statistical analyses using *stats* and *factoextra* packages (Kassambara and Mundt 2020; R Core Team 2024). Due to limitations of the methods, we removed respondents that left at least one of the skills unrated and performed analysis on a total of 1502 respondents. We conducted basic descriptive analysis, correlation analysis, hierarchical clustering, and principle-component analysis (PCA) of the skill ratings. For hierarchical clustering, we used the Ward method to minimize variance when merging clusters. At each step, the two clusters that result in the smallest increase in total within-cluster variance are merged. This process continues iteratively until all data points form a single cluster. For PCA, we used a correlation matrix of the thirty skills as input data to account for variability.

3 RESULTS

3.1 Graduate perceptions of working life competencies

Our results indicate that generally, recent graduates perceived most of the surveyed skills as rather important for their career (Table 1). Particularly, problem-solving (M = 5.79), retrieval of information (M = 5.65), independent work (M = 5.65), and an attitude towards developing one's skills (M = 5.56) were ranked high. On the other hand, entrepreneurial capabilities (M = 3.95), and knowledge of history and development of own field (M = 4.14), although still considered "somewhat important", received lower scores compared to the rest of the skills. Surprisingly, mathematics and natural sciences (M = 4.57), and business knowledge (M = 4.62) were perceived in the same manner. The perceptions on the importance of entrepreneurial capabilities, business knowledge, digitalization and utilization of data, and knowledge of the history and development of the field were more variable compared to other skills. The correlation analysis reveals that most of the skills are significantly correlated, except for business knowledge, which showed less correlation with other skills.

Table 1. Descriptive statistics of the surveyed skills, ordered by mean values (n=1502).

	Mean	St. dev.	Median	Min	Max
Problem-solving	5.79	0.46	6	3	6
Information retrieval	5.65	0.60	6	2	6
Independent work	5.65	0.58	6	3	6
Developing own skills attitude	5.56	0.63	6	1	6
Time management and prioritization	5.52	0.68	6	2	6
Teamwork	5.50	0.69	6	1	6
Analytical thinking	5.47	0.67	6	2	6
Know-how own field	5.46	0.72	6	1	6
Self-confidence	5.42	0.70	6	1	6
Own well-being	5.37	0.79	6	1	6
Project management	5.36	0.77	6	2	6
Social skills	5.35	0.77	5	1	6
Critical thinking	5.32	0.71	5	2	6
Practical application of theories	5.31	0.79	5	2	6
Career management capacity	5.26	0.79	5	1	6
Self-knowledge	5.22	0.73	5	1	6
Oral communication	5.21	0.79	5	2	6
International environment	5.12	0.91	5	1	6
Creativity	5.01	0.89	5	1	6
Visual communication	4.95	0.92	5	1	6
Ethicality	4.91	1.02	5	1	6
Leadership	4.81	0.97	5	1	6
Written communication	4.80	0.98	5	1	6
Sustainable development knowledge	4.79	1.10	5	1	6
Digitalization and utilization of data	4.69	1.14	5	1	6
Research knowledge of field	4.63	1.06	5	1	6
Business knowledge	4.62	1.15	5	1	6
Mathematics and natural science	4.57	1.09	5	1	6
History and development of field	4.14	1.13	4	1	6
Entrepreneurial capabilities	3.95	1.21	4	1	6

3.2 Five competency profiles

Hierarchical clustering revealed five unique profiles of graduate competencies, which we named according to their contents (Figure 1). The largest cluster, “foundational and organizational skills”, contains a broad mix of organizational, intra- and interpersonal, cognitive, and field-specific know-how that are important to recent graduates. The second major cluster, “values and creativity”, contains knowledge and skills related to creativity, communication, and values-based skills, such as sustainability and ethicality. Knowledge and skills related to business, entrepreneurship, and leadership formed their own cluster, “strategic leadership”. Finally, “academic knowledge” and “scientific and data proficiency” clusters are formed based on two individual skills, but later together form a statistically significant cluster.

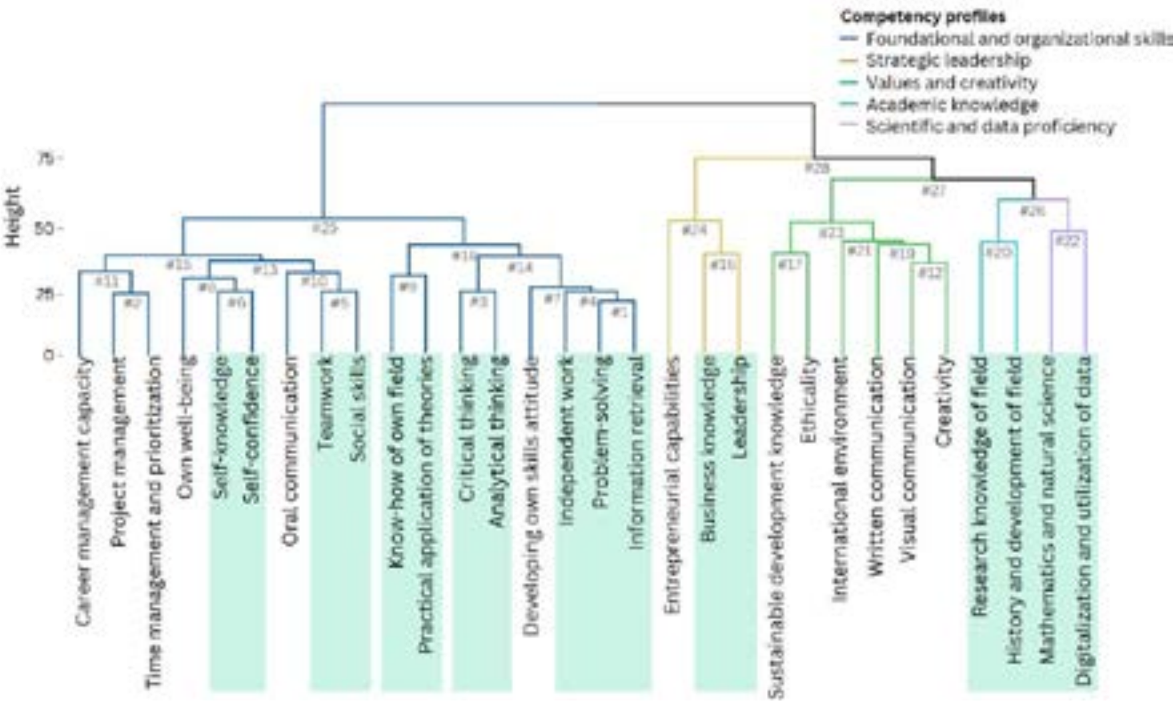

Figure 1. Hierarchical clustering of the surveyed skills, with statistically significant clusters (alpha ≥ 0.95) highlighted in teal, and the order of clusters formed indicated by running id.

3.3 Key dimensions of graduate perceptions

The principal component analysis (PCA) reveals the main dimensions of graduate perceptions and the loadings of each skill in these dimensions.The PCA highlighted the two most important dimensions, that explain 38 % of the total variation in the skill ratings (Figure 2). Based on the nature of the skills that had the most contribution to the variation, we intuitively named Dimension 1 “analytical vs. holistic thinking”, and Dimension 2 “subject-specific vs. generic skills”.

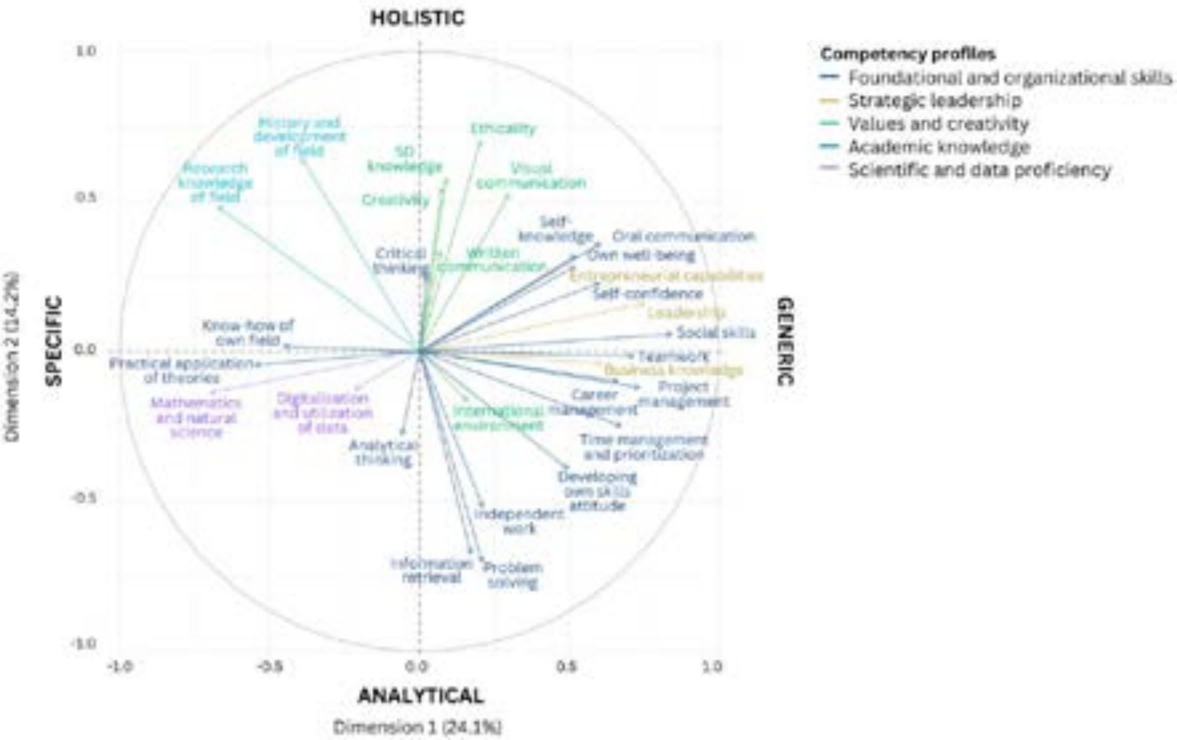

Figure 2. Principal component analysis biplot visualizing the loadings of the surveyed skills. The skills are grouped by the five competency profiles identified in hierarchical clustering.

The first dimension, “analytical vs. holistic thinking”, was strongly contributed by problem-solving and information retrieval on one end (analytical), and ethicality, knowledge on sustainability and history and development of the field in the opposite (holistic). The second dimension, “subject-specific vs. generic skills”, had a large contribution from social, leadership, and project management on one end (generic), and mathematics and natural science and practical application of theories on the opposite (specific). The positioning of these contributions indicates that recent graduates perceive a clear distinction in the importance between technical, discipline-specific abilities and broader, transferrable skills. Overall, it seems like the skills belonging to the five competency profiles previously identified tend to be positively correlated – in other words, rated similarly. Interestingly, it seems that some skills belonging to “foundational and organizational” group are oppositely correlated within the “specific vs. generic” spectrum.

4 DISCUSSION

To develop an engineering curriculum that delivers a competency profile aligning with industry needs and sustainability imperative, it is essential to understand graduate competencies from a holistic perspective. Although surveying learning outcomes of degree programmes is a prerequisite to identify what the graduates have learned in practice and possible competency gaps, this has been explored mainly through employer perspectives or stakeholder consultation. Graduate surveys are a common practice to monitor employment and satisfaction with education, but they can also be used to explore graduate perceptions on the importance and relevance of their working life competencies to inform educators, employers, and researchers. Our study therefore advanced the discourse on engineering competencies by incorporating the perspectives of recent graduates and patterns that underpin them by examining a national level survey.

Firstly, it seems that recent graduates value most competencies highly. Potential reasons for this could be that within the first year of graduation, graduates may feel uncertain about the professional roles as an engineer, the diversity of tasks in entry-level jobs and broad expectations of employers (Sheppard et al. 2015; Bennett and Male 2017; Jesiek et al., 2021; Craps et al. 2021a). Yet, given that problem-solving is a core competence for both employability and sustainability agendas of engineering education (Kolmos et al., 2016), our findings indicate that also recent graduates recognize its importance for their careers. **Secondly**, we identified five competency profiles that encapsulate the diverse skill combinations according to how recent graduates value them. While studying competency groups is not uncommon in engineering education research, it often lacks specificity regarding career stage or encompasses a broader timespan (Passow & Passow, 2017). Thus, our findings provide a unique perspective by highlighting groupings that are relevant within the first year of graduation – a crucial timeframe in transitioning to working life. **Finally,** our PCA revealed two distinct dimensions underlying graduate perceptions: the first dimension representing a spectrum from specific to generic skills, and the second dimension representing skills from analytical to holistic thinking. The explained variance (38%), along with the spread-out nature of the skills in the plot, suggests wide heterogeneity in how recent graduates prioritize and perceive them.

Understanding graduates' perceptions on competencies and their interrelations can provide a common grounding for educators and employers to support the development of a hybrid competency profile – integrating core engineering expertise with broad inter- and intrapersonal, thinking and value-based skills (Karvinen, 2024). Interestingly, it seems like recent graduates perceive the importance of few key competencies in an opposite manner, for example sustainability knowledge and problem-solving. While these perceptions could be explained through factors such as education background and career trajectory, it is important to not overlook the potential synergy among these skills within a competency profile. Thus, it is essential to recognize both the diversity in graduates' perceptions and the interconnectedness of these skills within a comprehensive competency framework. For example, engineering students' competence development and career readiness could be supported through experiential learning approaches resembling authentic engineering practice and its complexity (Mann et al. 2021). Employers can complement these efforts by providing training and mentoring aimed at supporting graduates' socialization and journey as lifelong learners (Davis et al., 2017; Korte et al., 2019).

Our primary limitation lies in analysing graduate perceptions in isolation from potential explanatory factors such as demographic, educational, and career characteristics. However, we believe that our findings offer foundational insights for moving forward: by incorporating additional variables and further exploring the variations of the identified patterns, future studies have an opportunity to yield a more holistic understanding on the development of graduate competency profiles across diverse engineering disciplines and cultural contexts within Europe and beyond.

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REFERENCES

Bennett, Dawn, and Sally A. Male. 2017. “An Australian Study of Possible Selves Perceived by Undergraduate Engineering Students.” *European Journal of Engineering Education* 42 (6): 603–17. https://doi.org/10.1080/03043797.2016.1208149.

Conley, Shannon Nicole, Rider W. Foley, Michael E. Gorman, Jessica Denham, and Kevin Coleman. 2017. “Acquisition of T-Shaped Expertise: An Exploratory Study.” *Social Epistemology* 31 (2): 165–83. https://doi.org/10.1080/02691728.2016.1249435.

Craps, Sofie, Maarten Pinxten, Heidi Knipprath, and Greet Langie. 2021a. “Different Roles, Different Demands. A Competency-Based Professional Roles Model for Early Career Engineers, Validated in Industry and Higher Education.” *European Journal of Engineering Education* 47 (February):1–20. https://doi.org/10.1080/03043797.2021.1889468.

Craps, Sofie, Maarten Pinxten, Heidi Knipprath, and Greet Langie. 2021b. “Exploring Professional Roles for Early Career Engineers: A Systematic Literature Review.” *European Journal of Engineering Education* 46 (2): 266–86. https://doi.org/10.1080/03043797.2020.1781062.

Davis, Pryce, Alexandra Vinson, and Reed Stevens. 2017. “Informal Mentorship of New Engineers in the Workplace,” June. https://nottingham-repository.worktribe.com/output/867857/informal-mentorship-of-new-engineers-in-the-workplace.

Jesiek, Brent K., Natascha T. Buswell, and Swetha Nittala. 2021. “Performing at the Boundaries: Narratives of Early Career Engineering Practice.” *Engineering Studies* 13 (2): 86–110. https://doi.org/10.1080/19378629.2021.1959596.

Karvinen, Meeri. 2024. *Supporting Agency for Sustainability - Exploring the Contributions of Universities and Workplaces to the Sustainability Competencies and Agency of Engineering Graduates*. Aalto University. https://aaltodoc.aalto.fi/handle/123456789/126617.

Kassambara, A, and F Mundt. 2020. *Factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R Package Version 1.0.7* (version 1.0.7.). https://CRAN.R-project.org/package=factoextra.

Khoo, E., K Zegwaard, and A Adam. 2020. “Employer and Academic Staff Perceptions of Science and Engineering Graduate Competencies.” *Australasian Journal of Engineering Education* 25 (1): 103–18. https://doi.org/10.1080/22054952.2020.1801238.

Kolmos, Anette, Roger G. Hadgraft, and Jette Egelund Holgaard. 2016. “Response Strategies for Curriculum Change in Engineering.” *International Journal of*

Technology and Design Education 26 (3): 391–411. https://doi.org/10.1007/s10798-015-9319-y.

Korte, Russell, Samantha Brunhaver, and Sarah M. Zehr. 2019. "The Socialization of STEM Professionals Into STEM Careers: A Study of Newly Hired Engineers." *Advances in Developing Human Resources* 21 (1): 92–113. https://doi.org/10.1177/1523422318814550.

Malmqvist, J., K. Edström, and A. Rosén. 2020. "CDIO Standards 3.0 - Updates to the Core CDIO Standards." In , 1:60–76. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85150729471&partnerID=40&md5=af9d0936cc9c91fc7c2ab517c5438bcb.

Mann, Llewellyn, Rosemary Chang, Siva Chandrasekaran, Alicen Coddington, Scott Daniel, Emily Cook, Enda Crossin, et al. 2021. "From Problem-Based Learning to Practice-Based Education: A Framework for Shaping Future Engineers." *European Journal of Engineering Education* 46 (1): 27–47. https://doi.org/10.1080/03043797.2019.1708867.

Passow, Honor J., and Christian H. Passow. 2017. "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review." *Journal of Engineering Education* 106 (3): 475–526. https://doi.org/10.1002/jee.20171.

Pyrhönen, V. P., S. Niiranen, and E. Pajarre. 2019. *Engineering Graduates' Development of Competencies - Views from Academic Stakeholders*. European Society for Engineering Education SEFI. https://doi.org/10/SEFI2019_Proceedings.pdf.

Quelhas, Osvaldo Luiz Gonçalves, Gilson Brito Alves Lima, Nicholas Van-Erven Ludolf, Marcelo Jasmim Meiriño, Chrystyane Abreu, Rosley Anholon, Julio Vieira Neto, and Leandro Silva Goulart Rodrigues. 2019. "Engineering Education and the Development of Competencies for Sustainability." *International Journal of Sustainability in Higher Education* 20 (4): 614–29. https://doi.org/10.1108/IJSHE-07-2018-0125.

R Core Team. 2024. *R: A Language and Environment for Statistical Computing.* (version 4.3.2.). Vienna, Austria: R Foundation for Statistical Computing. https://www.r-project.org/.

Renko, Julia, Anni Kaikko, Meeri Karvinen, and Marko Keskinen. 2020. *Aalto-yliopiston Vesi- ja ympäristötekniikan maisteriohjelman sidosryhmäselvitys 2019-2020 : yhteenvetoraportti: Alan tulevaisuus, osaamistarpeet ja vastavalmistuneiden rooli*. Aalto-yliopisto. https://research.aalto.fi/en/publications/aalto-yliopiston-vesi-ja-ymp%C3%A4rist%C3%B6tekniikan-maisteriohjelman-sido.

Sheppard, Sheri D., Anthony Lising Antonio, Samantha R. Brunhaver, and Shannon K. Gilmartin. 2015. "Studying the Career Pathways of Engineers: An Illustration with Two Data Sets." In *Cambridge Handbook of Engineering Education Research*, 283–310. Cambridge University Press. https://doi.org/10.1017/CBO9781139013451.020.

Souppez, Jean-Baptiste. 2023. "Engineering Employability Skills: Students, Academics, and Industry Professionals Perception." *International Journal of*

Mechanical Engineering Education, November, 1–18. https://doi.org/10.1177/03064190231214178.

TEK. 2022. “TEK Graduate Survey 2022.” https://www.tek.fi/fi/tietoa-tekista/tutkimus/tek-tutkii-opiskelijat/tek-graduate-survey-2022.

Trevelyan, J. 2019. “Transitioning to Engineering Practice.” *European Journal of Engineering Education* 44 (6): 821–37. https://doi.org/10.1080/03043797.2019.1681631.

Uhlenbrook, Stefan, and E. Jong. 2012. “T-Shaped Competency Profile for Water Professionals of the Future.” *Hydrology and Earth System Sciences Discussions* 9 (March):22. https://doi.org/10.5194/hess-16-3475-2012.

UNESCO. 2021. *Engineering for Sustainable Development. Delivering on the Sustainable Development Goals*. the United Nations Educational, Scientific and Cultural Organization, 7, place de Fontenoy, 75352 Paris 07 SP, Franceand International Center for Engineering Education (ICEE) under the auspices of UNESCO, Room 417, Wennan Building, Tshinghua University, Haidian District, Beijing 100084,P.R.China and Central Compilation and Translation Press (CCTP), Part B Hongru Building, #B-5 Chegongzhuang Street, Xicheng District, Beijing 100044, P.R.China. https://unesdoc.unesco.org/ark:/48223/pf0000375644/PDF/375644eng.pdf.mu lti.

Vehmaa, Anu, Meeri Karvinen, and Marko Keskinen. 2018. “Building a More Sustainable Society? A Case Study on the Role of Sustainable Development in the Education and Early Career of Water and Environmental Engineers,” July. https://aaltodoc.aalto.fi/handle/123456789/33098.

Winters, K.E., H.M. Matusovich, S. Brunhaver, H.L. Chen, K. Yasuhara, and S. Sheppard. 2013. “From Freshman Engineering Students to Practicing Professionals: Changes in Beliefs about Important Skills over Time.” In .

EQUITY AND EXAMINATION TIME PRESSURE IN FIRST YEAR MATHEMATICS FOR ENGINEERS

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ABSTRACT

The 'gender mathematics gap' which persists in many countries means that women students may, on average, have less high school preparation in mathematics than men students entering engineering education. This in turn could impact their performance in first-year exams and thus reduce women's participation in engineering programs. One factor that has been a focus of some interest in addressing equity issues in education is time-limited exams, which have been found

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to give rise to unfairness with respect to underrepresented students in a number of domains. In mathematics, time pressure has been found to be linked to increased student stress and to the use of less effective problem-solving strategies in assessment conditions. We sought to explore, therefore, the impact of reducing time pressure in a first-year engineering Linear Algebra course. We had 275 participants, of which 192 (69.8%) were men and 83 (30.2%) were women. Using a pseudo-experimental design in real-word conditions which controlled for teacher effects and assessment effects, we found that, when there was reduced time pressure, students with less prior mathematics performed better than when in a more time-pressured exam. Our results show that these students can learn the required Linear Algebra and can demonstrate their learning under appropriate conditions. This leads us to conclude that reducing time pressure in first year mathematics exams may contribute to improving the retention of women students in engineering education, particularly in cultural contexts in which a gender mathematics gap is prevalent.

1 INTRODUCTION

1.1 Exam length and equity in engineering education

Equity remains a persistent issue to be addressed in engineering education. Lichtenstein et al. note that in the US, for example, while the proportion of women enrolled in higher education has grown substantially since the 1980s, ‘‘minimal progress has been made in recruiting and retaining …women and minorities, into engineering programs’’ (Lichtenstein et al. 2014, 314). Similar patterns are evident in European engineering education (Barnard et al. 2012; Powell et al. 2012).

One factor which plays a role in this is the place of mathematics in the initial education of engineers. Lower prior performance in math has been found to be a factor in non-retention of students in engineering education (Takahira et al. 1998; Falkner et al. 2010; Falkner et al. 2014). This in turn is linked to gender since, despite a narrowing of the gap, boys continue to have, on average, higher mathematics achievement at upper secondary school level in many countries (OECD 2019). Indeed, the comparatively better performance of boys in mathematical attainment is actually higher than the OECD average in many European countries including Switzerland, Luxembourg, Austria, Germany, France, Italy, Portugal, Belgium, Ireland, Spain and the United Kingdom. This ‘gender mathematics gap’ is not something that should be taken for granted or accepted, however: girls actually outperform boys in mathematics in other nearby European countries including Sweden, Norway and Iceland (OECD 2019, 25-26). Rather than linked essentially to sex, gendered differences in attainment are linked to persistent cultural beliefs about gender and mathematics, as well as to educational practices (OECD 2023). The issue is, therefore, not a biological one, but one linked to culture and social and educational structures.

If there are differences in average high school performance in mathematics, this in turn impacts on those same students when they enter university. Differences in prior knowledge like this can be understood in two different ways: either as a ‘deficit’ in some students that needs to be addressed through the students changing what they learn before coming to university, or as a ‘difference’ between students that needs to be taken into account in pedagogical choices of institutions. There is evidence that framing equity issues as one of ‘difference’ is productive insofar as changing the way we teach and assess in university can have an impact on equity in student success without simply transferring the burden for change onto the student themselves. For example, specific pedagogical choices such as the use of flipped classes (Hardebolle et al. 2022) or interactive teaching (Theobald et al. 2020) have been identified as having an impact on reducing attainment gaps for women and other underrepresented students in undergraduate science, technology and mathematics courses. It makes sense, therefore, to look at other aspects of teaching and assessment that may be contributing to attainment gaps for women and other under-represented groups.

One such factor that is worthy of consideration is examination time pressure. Although time-limitations in assessment are widely accepted as a normal practice, there is evidence that time-limited tests discriminate unfairly against students who are learning in a second language (e.g. immigrant students), those who are older than average, and those from other underrepresented backgrounds (see Gernsbacher et al. [2020] for a review of evidence). Caviola et al. (2019) found that there is a substantial body of literature that suggests that the imposition of time limits can increase stress associated with challenging tasks. Specifically looking at mathematics problem solving, there is also evidence that, as is expected from stress reactions, shorter time limits can lead to a shift to using suboptimal (heuristic rather than analytical) solution strategies (Gillard 2009). Since there is a known association between mathematics anxiety and gender (e.g. Hart and Ganley, 2019; Vos et al. 2023) this suggests that examination time pressure may well play a role in contributing to gender differences in performance.

In light of such findings, it is surprising to see that there are few studies which have explored the impact of time pressure on equity in mathematics learning. Caviola et al.'s review, for example, found only a handful of studies looking at university students, most of which were relatively small, and which typically did not use the kinds of mathematical problems being solved by engineering students in first year courses. Furthermore, while experimental studies have the benefit of being designed for internal validity, their findings often do not transfer into real world settings. Kim (2019) for example, found that in one review of trials aimed at transferring a previously validated educational intervention into real-life settings, only 11 of 90 trials yielded positive results. This suggests a need to test such ideas beyond experimental settings, under real-world conditions.

This, then, gives rise to our research question: does reducing time pressure in first year university mathematics exams have an impact in reducing the gender gap in attainment for engineering students?

1.2 Context of this study

As noted above, gendered patterns of mathematical performance differ depending on the education system and culture of the wider society. This study took place in Switzerland, where almost all students come from France and Switzerland, two countries in which the 'gender-mathematics gap' (i.e. boys having higher mathematics scores than girls on average) in high school is a little bigger than the average for the OECD as a whole (OECD 2019, 25-26).

In the technical university in question, women make up circa 29% of the first-year intake. While the students coming from France all had a scientific baccalaureate (French BAC) (and therefore substantial prior studies in mathematics), not all Swiss students have substantial mathematics in their high school. Of the students entering this university who had a Swiss high school diploma, over the years 2014-20, 56% of the men had taken the physics and mathematics option in high school (Swiss PAM), as compared to 33% of the women. In the same time period, counting all students (i.e. including both Swiss and others) 70% of first year men passed exams to allow them to enter second year, as compared to 65% of women.

2 METHODOLOGY

The purpose of this study was to explore if reducing time pressure in first year university mathematics exams would have an impact in reducing the gender gap in attainment for engineering students. This was done through a pseudo-experimental study. In the academic year 2019-20, the number of questions in the Linear Algebra exam for first year students was reduced, without reducing the time allocated to the exam, the difficulty of the questions or the amount of material covered in the course. This, therefore reduced the time pressure on students in the exam, while retaining other factors as constant. Students who took the exam in 2018-19 were identified as a control group (normal time pressure condition), while those who took the exam in 2019-20 were identified as the experimental group (reduced time pressure condition).

2.1 Participants

Table 1. Student participants, the examination condition and their high school diploma type

	French BAC	Swiss PAM	Swiss Other	Total
2018-19 (Control condition)				
Men	34	17	11	62
Women	19	7	9	35
2019-20 (Reduced time pressure condition)				
Men	57	45	28	130
Women	25	8	15	48
Total	135	77	63	275

As the university was interested in researching aspects of mathematics pedagogy at that time, students were invited to volunteer to be part of a study on pedagogical innovations. A total of 660 students volunteered to participate in the years 2018-19 and 2019-20. In the university at that time, the Linear Algebra course in the first semester of first year was taught by nine different teachers. Since one of the classes had a different pedagogical condition than others (a flipped class) it was excluded from this study. This study is then based on data from classes with eight different teachers (effectively ensuring that any findings are not simply the result of a factor related to a single instructor). We therefore retained for this study (a) students who were not involved in the flipped class condition, (b) students who had not previously taken first year (i.e. repeating students were excluded) and (c) students whose high school experience we could meaningfully categorise (i.e. those who studied for a high school diploma in France or Switzerland). This gave us 275 students, of which 192 were registered as men and 83 were registered as women (the university registration system did not allow students at that time to identify with a gender other than these two). The breakdown of students in terms of their registered gender and high school diploma type (i.e. French scientific BAC, Swiss PAM, Swiss Other) is in table 1.

2.2 Measures

The Linear Algebra exam was 80% multiple choice questions (common to all teachers) and 20% developed response questions (different across different teachers). The multiple choice questions were set by the teachers collectively and validated to ensure that the difficulty level was the same from year to year (this effectively controlled for assessment-related factors). Students who did not achieve a grade of 3.5 out of 6 on their mathematics and physics subjects in the first semester are not permitted to proceed to semester two and are instead redirected into a 'foundations reboot program' which must be passed before they can be readmitted to first year (it should be noted 3.5 is not a 'passing' grade – students need 4 out of 6 on average over two semesters to pass first year). Since our focus was on retention of students in the first year we focused on two measures. The first is grade, scored on a scale of 1 to 6, with 6 being the highest. The second is achieving a grade of 3.5 or higher (since lower grades mean not being allowed continue in the first year unless the 'foundations reboot' is passed).

In the control condition there were 24 multiple choice questions. In the reduced time pressure condition there were 22 multiple choice questions. The exam time in both cases was 3 hours and the 20% of developed response questions did not change.

2.3 Ethics

Students had all volunteered to take part in research on pedagogical innovation in mathematics education and had given their informed consent for their data to be used in research. The decision to reduce the time pressure in the exam was taken by the teachers and was done for all students to ensure fairness and equity of treatment for all. Thus, while the mathematics test condition was the same for all students (those who volunteered to participate in the research on pedagogical innovation and those who did not), only data from students who volunteered to have their data used in research was included in this study.

3 RESULTS

Table 2 presents the overall average grades for students on the Linear Algebra exam including both the 80% common part and the 20% questions individual to each teacher. As table 2 shows, the average grade went being below the level which barred students from entering the second semester (3.5) to a grade above that level in the reduced time pressure condition. This difference is statistically significant ($t = -2.11$, $df = 193.98$, $p = .03$).

Interestingly, the additional time made effectively no difference to the performance of those who had substantial mathematics in their high school experience (French BAC and Swiss PAM diplomas), for whom the final grade in the control condition was very similar to under the control condition (see the dashed grey line in Figure 1, below). There is however a clear difference in those who had a non-mathematical Swiss high school diploma, who had a higher grade average in the reduced time pressure condition (t = -3.18 df = 41.16, p <.01). In the control condition only 4 out of 20 participants with a non-mathematical Swiss high school diploma scored 3.5 out of 6 and were thus allowed proceed to the second semester (20%); in the reduced time pressure condition this rose to 22 out of 43 (51%).

Table 2. Grades of participating students in control and reduced time pressure conditions

	N	Mean Grade	Median Grade	Grade St. Dev.
Control (2018-19)	97	3.38	3.5	1.25
Reduced Time Pressure (2019-20)	178	3.71	3.75	1.22

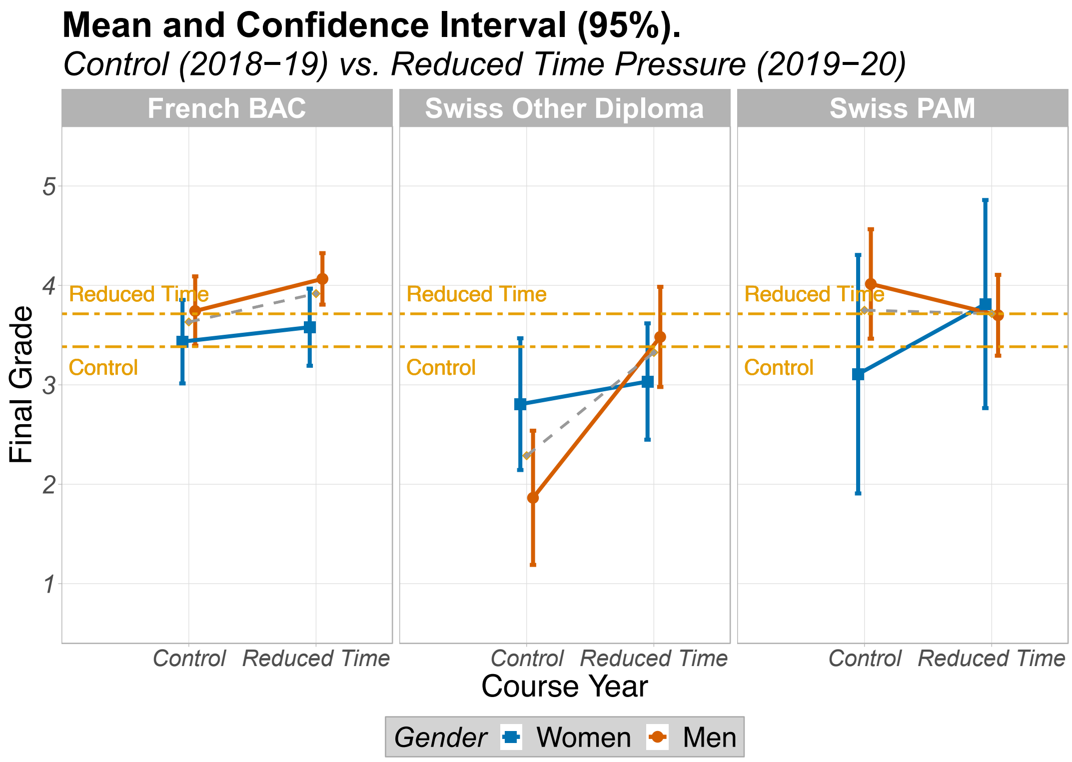

Fig. 1. Grades by gender, condition and high school diploma (including 95% confidence interval). The mean grade across groups is represented by dash-dotted horizontal lines. Dashed grey lines represented the weighted means for each condition and group.

Figure 1 (above) shows how the interaction between gender and prior mathematical experience in high school impacts upon this change. The improved performance of those who do not have substantial mathematics in their high school diploma (Swiss Other) is experienced by both men and women. This is reflected in the overall performance of women on the exam: their mean average grade rose from 3.21 (st. dev. = 1.11) in the control condition to 3.45 (st. dev. = 1.15) in the reduced time pressure condition (t = -0.96, df = 74.76, p = .34). This is reflected in an increase in the rate of women having a grade (3.5) that would allow them to enter the second semester: the rate in the time pressured condition was 15 out of 35 (42.9%). In the reduced time pressure condition this rose to 26 out of 48 (54.2%). Although Figure 1 shows a slight decline in grade for men with Swiss PAM backgrounds in the reduced time condition, and shows different levels of increased attainment between conditions for men and women with Swiss Other backgrounds, these differences are small enough that they are neither notable nor statistically significant.

4 ANALYSIS

The data shows that the difference in time pressure in the exam does appear to make some difference in student success in the exam. As Figure 1 shows, however, this improvement is not evenly distributed across all groups: the benefit is felt most acutely by those who have less mathematics in their high school diploma (Swiss Other Diplomas), a group in which women are over-represented. Unlike those who had more prior mathematics in high school, the grades obtained by this group are significantly higher in the reduced time pressure condition ($t = -3.18$, $df = 41.15$, $p < .01$). The specific psychological processes that explain this was not the subject of this study. It may be that students who have less prior mathematical practice have less fluency and therefore need more time to demonstrate their mathematical skills and knowledge. It may be (as studies cited by Caviola et al. [2019] found) that the time pressure increases stress and therefore leads to the use of less efficient solution methods for those students.

Whatever the actual psychological processes involved, the findings do seem to show that students with less prior mathematics (such as those with a Swiss Other diploma) can learn the required linear algebra knowledge and skills and can demonstrate that learning under the right conditions (such as a reduced time pressure exam). This in turn can be seen in a notable increase in grade by women students in our study, and an increase in women having the grades required to progress to the second semester. Unfortunately, the average grade for women in the reduced time pressure condition is still only 3.45, below the passing grade (4) and below the grade at which students are allowed to progress to the second semester (3.5). So a change in exam time, on its own, will not constitute a magic bullet to solve the 'gender mathematics gap'. However, it seems likely that there is no magic bullet to address this and rather there are only a range of strategies which each have an incremental effect and which together can have a meaningful impact. This data does suggest that time pressured exams may be one factor leading to the exclusion of both women and men students who did not have a strong background upon entry to university, and addressing this may be part of the solution.

This has clear implications for equity issues and the retention of women students in engineering education. As noted above, in the context of our study, the wider culture and the structure of high school education means that women, on average, come to engineering education with less prior mathematical experience than men. Creating assessments that allow those with less mathematical prior knowledge to show the mathematical knowledge and skills they have learned during the course is, therefore, one potentially important factor in improving equity. Reducing time pressure may well be one way of doing this.

As with any study, ours has some limitations. Our study is a real-world pseudo-experiment, which means we do not randomly assign students to control and reduced time pressure conditions. While the study effectively controls for multiple factors (teacher effects, assessment effects, prior mathematical background and gender), we cannot rule out some other factor impacting on the data. We would note however, that while this is a limitation, it is also a strength: the findings of the majority experimental studies do not survive transfer to real-world conditions (Kim, 2019) and what we have found is an impact in real-world conditions. A second limitation is that the number of women present in our study is relatively small, which means that we do not have enough power to find statistically significant differences. This is a function of the lower enrolment rates of women in our programmes: in fact we began with 660 participating students but once we controlled for prior study, gender, pedagogical differences and having repeated first year we were left with 24 women with a non-mathematical high school diploma. This highlights, once again, the challenges of doing real-world studies on gender and attainment in engineering education. Our study focused on the experience of women students. We are unable to say if this experience is shared by other under-represented groups, and thus this should be a focus of further research. A third limitation to be aware of is that gender differences in mathematics performance are not uniform across education systems and cultures, and so the findings from one place should not simply be applied in a different cultural context. A fourth limitation is that only one method of reducing time pressure in assessment (having fewer questions in the same time period) was studied here. There are other strategies for reducing time pressure, such as having more time and the same number of questions. These other strategies may also merit consideration.

5 CONCLUSION

Equity remains a persistent issue to be addressed in engineering education, including the retention of women students. Since, in many cultures and contexts, women come to engineering education with, on average, lower prior levels of mathematics education than men, one dimension of how we retain more women in engineering education is by ensuring that the impact of prior knowledge on their attainment in first year examinations in mathematics is minimised. In this study we sought to explore how we could adapt assessment to ensure more equitable outcomes for our diverse student intake.

Although time-limited assessments are a widely unquestioned part of the ritual of university mathematics, there is some evidence that these kinds of assessments can be unfair (Gernsbacher et al. 2020). There are also specific reasons for thinking that they might contribute to gender inequities in mathematical attainment (Caviola et al., 2019). Using a real-world pseudo-experiment, we explored the impact of time pressure on students' attainment in a first year Linear Algebra exam. We found that in a less time pressured condition, students with less prior mathematics can demonstrate the required linear algebra knowledge and skills while similar students in a more time pressured situation did not demonstrate the same learning. Students with a strong mathematical background do not benefit nor suffer from such a measure.

Creating assessments that allow those who had less mathematical experience in high school to show the mathematical knowledge and skills they have learned in university is, therefore, a potentially important contribution to improving women's retention in engineering education.

REFERENCES

Barnard, S., T. Hassan, B. Bagilhole and A. Dainty, 'They're not girly girls': an exploration of quantitative and qualitative data on engineering and gender in higher education, *European Journal of Engineering Education*, 37,2 (2012), pp. 193–204.

Caviola S, E. Carey, I.C. Mammarella, and D. Szucs "Stress, Time Pressure, Strategy Selection and Math Anxiety in Mathematics: A Review of the Literature". *Frontiers in Psychology* . 1;8 (2017):1488. doi: 10.3389/fpsyg.2017.01488

Faulkner, F., A. Hannigan, and O. Gill. "Trends in the Mathematical Competency of University Entrants in Ireland by Leaving Certificate Mathematics Grade." *Teaching Mathematics and Its Applications* 29, 2 (2010): 76–93.

Faulkner, F., A. Hannigan, and O. Fitzmaurice. "The role of prior mathematical experience in predicting mathematics performance in high education". *International Journal of Mathematical Education in Science and Technology*, 45, 5 (2014), 648-667. doi.org/10.1080/0020739X.2013.868539

Gernsbacher, M.A., R.N. Soicher, K.A. Becker-Blease. "Four Empirically Based Reasons Not to Administer Time-Limited Tests". *Translational Issues in Psychological Science*, 6, 2 (2020), 75-190. https://doi.org/10.1037/tps0000232

Gillard E, W. Van Dooren W. Schaeken L. Verschaffel. "Proportional reasoning as a heuristic-based process: time constraint and dual task considerations". *Experimental Psychology* 56, 2 (2009):92-9. doi: 10.1027/1618-3169.56.2.92.

Hardebolle, C., H. Verma, R. Tormey, and S. Deparis "Gender, prior knowledge, and the impact of a flipped linear algebra course for engineers over multiple years". *Journal of Engineering Education*, 111, 3 (2022), 554–574. https://doi.org/10.1002/jee.20467

Hart, S. A., and C.M. Ganley. "The Nature of Math Anxiety in Adults: Prevalence and Correlates". *Journal of Numerical Cognition*, 5, 2 (2019), 122-139. https://doi.org/10.5964/jnc.v5i2.195

Kim, J. S. "Making every study count: Learning from replication failure to improve intervention research". *Educational Researcher*, 48, 9 (2019), 599–607. https://doi.org/10.3102/0013189X19891428

Lichtenstein, G., H. L. Chen, K. A. Smith and T. A. Maldonado, "Retention and Persistence of Women and Minorities Along the Engineering Pathway in the United States", in A. Johri and B.M. Olds, (eds) *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, Cambridge, pp. 311–334, 2014.

McCloskey, A. "The promise of ritual: a lens for understanding persistent practices in mathematics classrooms". *Educational Studies in Mathematics*, 86 (2014), 19–38. https://doi.org/10.1007/s10649-013-9520-4

McNeil, N.M. B. Rittle-Johnson, S. Hattikudur and L.A. Petersen "Continuity in Representation Between Children and Adults: Arithmetic Knowledge Hinders

Undergraduates' Algebraic Problem Solving", *Journal of Cognition and Development*, 11, 4 (2010), 437-457, DOI: 10.1080/15248372.2010.516421

OECD, *PISA 2018 Results (Volume II): Where All Students Can Succeed*, PISA, OECD Publishing, Paris, 2019. https://doi.org/10.1787/b5fd1b8f-en.

Powell, A., A. Dainty and B. Bagilhole, "Gender stereotypes among women engineering and technology students in the UK: lessons from career choice narratives", *European Journal of Engineering Education*, 37,6(2012), pp. 541–556.

Takahira, S., D.J. Goodings, and J.P. Byrnes, "Retention and Performance of Male and Female Engineering Students: An Examination of Academic and Environmental Variables". Journal of Engineering Education, 87 (1998): 297-304. https://doi.org/10.1002/j.2168-9830.1998.tb00357.x

Theobald, E. J., M. J. Hill, E. Tran, S. Agrawal, E.N. Arroyo, S. Behling, N. Chambwe, D.L. Cintrón, J.D. Cooper, G. Dunster, J.A. Grummer, K. Hennessey, J. Hsiao, N. Iranon, L. Jones, H. Jordt, M. Keller, M.E. Lacey, C.E. Littlefield, … S. Freeman. "Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math". *Proceedings of the National Academy of Sciences*, 117, 12 (2020), 6476–6483. https://doi.org/10.1073/pnas.1916903117

Vos, H; M. Marinova, S.C. De Léon, D. Sasanguie, B. Reynvoet, "Gender differences in young adults' mathematical performance: Examining the contribution of working memory, math anxiety and gender-related stereotypes" *Learning and Individual Differences*, 102 (2023) 102255 https://doi.org/10.1016/j.lindif.2022.102255

Using Inquiry Based Learning to Teach Inclusive Engineering

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ABSTRACT

That inclusion is fundamental to sustainable engineering is reflected in the professional standards engineers work to, and the educational frameworks that underpin them. However, educational frameworks do not state how the skills, knowledge and aptitude related to inclusive engineering should be taught and assessed. For educators of engineers this poses the question, how can students learn about inclusivity and inclusive engineering, and what activities can be used to teach these? We asked the question: will a discipline specific inquiry based learning (IBL) group task to investigate inclusive engineering improve student's confidence, knowledge and understanding in relation to inclusion and inclusive engineering? To answer it, an inquiry based learning approach was used to develop an inclusive engineering workshop for undergraduate students to facilitate learning in a discipline relevant way. Survey results showed the workshop successfully improved student's knowledge, understanding and confidence in relation to inclusive engineering. Further use of a case study based IBL approach will allow for effective teaching and

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provide a means of assessment of inclusive engineering across undergraduate curriculums in engineering.

1 INTRODUCTION

1.1 Professional Attributes for Engineers

Engineers are trained to solve problems using new or existing technology. It is widely acknowledged that to do so successfully engineering and technology must be developed in a sustainable manner, and inclusivity is fundamental to sustainable outcomes. Professional engineers are expected to work to standards that embody principles of sustainability and inclusion. Specifically, in the UK, these are provided by the UK Standard for Professional Engineering Competence (UK-SPEC) (Engineering Council 2020b).

UK-SPEC specifies that engineers should understand and take into account societal and cultural structures outside of their own, and actively contribute to the development of sustainable communities. It states they should minimise adverse sustainability impacts during the design stage of engineering solutions, they must be aware of the conflicting unmeasurable elements of sustainability, and be prepared to challenge the status quo that often is not inclusive. They must seek multiple opinions by proactively engaging with those who will be affected by engineering solutions and involve those who have not traditionally been considered during development and design stages. They must seek and value the perspective of others, and should utilise multi-disciplinary perspectives (Engineering Council 2024).

The values and commitments of UK-SPEC underpin the Accreditation of Higher Education Programmes (AHEP 4), the framework of Learning Objectives for engineering education. In the accreditation framework it is explicitly stated that students “Adopt an inclusive approach to engineering practice and recognise the responsibilities, benefits and importance of supporting equality, diversity and inclusion” (learning outcome C/M11) (Engineering Council 2020a) and it is a requirement that this is assessed. Similar values and standards are embodied by professional engineering bodies across the world (International Engineering Alliance 2021) or are implied with reference to sustainability (European Network for Accreditation of Engineering Education, 2022.), and are integral to the UN sustainable development goals (The United Nations 2015). What is not provided by these documents are guidance as to how the skills, knowledge and aptitude related to inclusion and diversity should be taught and assessed. For educators of engineers this poses the question, how can students learn about inclusivity and Inclusive Engineering, and what activities can we use to teach these?

1.2 Inclusion and Inclusive Engineering

In this work, inclusion is taken to mean the extent to which people feel valued for who they are (their personal and professional background, experience, and skills) and the extent to which people feel they belong or ‘fit’ in the engineering profession and their organisation (Royal Academy of Engineering 2023). Inclusive engineering is taken to align with the British Standards Institute definition of inclusive design as “the design of mainstream products and/or services that are accessible to, and usable by, people with the widest range of abilities within the widest range of situations without the need for special adaptation or design” (British Standards Institute 2005).

Issues related to inclusion are a persistent problem in engineering and higher education. For example, women have been under represented in the engineering profession (Walker 2001), and the problem persists, as illustrated by relatively low numbers of female engineering graduates in the US (National Center for Science and Engineering Statistics. 2021). In 2023, a 9.4% attainment gap was reported between black and minority ethic students compared to their white counterparts for first class or 2:1 degree classifications in Science, Engineering and Technology degrees in English and Welsh Higher Education Institutions (Advance HE 2023). Improving inclusion and diversity in those who study, teach and work in engineering has long been a priority for educators (Baillie et al. 2011; Borrego and Bernhard 2011). By explicitly introducing inclusive engineering teaching into the curriculum, it is likely the profile of inclusion will be elevated and it could become a topic of debate and discussion among more engineering educators.

In this work, inclusive engineering is used as a concept to aid students and teachers in the development of their knowledge and understanding of issues relating to inclusion. Inclusive engineering can best be understood through examples, and oftentimes, these are where engineering solutions have turned out to not be inclusive. For example, the use of pulse oximeters to measure saturated oxygen levels in blood. Pulse oximeters are convenient, non-invasive, medical devices that are placed on a patient's finger or ear lobe, however, the accuracy of the measurement is reduced in non-white patients. During the Covid-19 pandemic, this led to worse clinical outcomes for non-white patients infected with SARS-CoV 2 (Fawzy et al. 2022; Sudat et al. 2023). This is a high profile case study that is relatable to current students who have lived experience of the Covid-19 pandemic. Although it is easy to understand the problems with this case, it is complex and multi-faceted, making it a good to learn about, discuss and critique.

1.3 Inquiry Based Learning

In Inquiry Based Learning (IBL) the learner is guided through an activity in which they address an open ended question or problem. It is a learner centred approach that requires them to take responsibility for directing the learning and for the construction of new knowledge and understanding (Spronken-Smith and Walker 2010; Aditomo et al. 2013). By setting learners the challenge of addressing open questions and giving them agency in the questions they answer, learners are required to critique knowledge and information, and to reflect on how these intersect experience and context. This process fosters independent thinking, and through practice, self-belief and confidence in learners is improved (Levy et al. 2010). The educational attributes of IBL are well aligned with the training needs required for individuals to meet the professional requirements specified by the Engineering Council in relation to Sustainability (Engineering Council 2024). Given that there are conflicting unmeasurable elements of sustainability, and that feeling included and the sense of inclusion are subjective and personal, the person centred and open ended mode of IBL (Spronken-Smith 2012) is well suited for learning about inclusion and inclusive engineering.

In engineering inclusive design principles can be seamlessly integrated into teaching related to the design of a product or system, as highlighted by the case studies investigated in the Cambridge Inclusive Design Toolkit (University of Cambridge, 2017.). The use of case studies allows learners to develop a better understanding of how their theoretical disciplinary knowledge links to real world problems, and thus support learners to develop an identity and sense of place within their discipline. Use of case studies for teaching engineers are well established and exemplified in the high quality, structured tool kits available to support teaching of Engineering Ethics and Sustainability (Engineering Professors Council, 2024a; 2024b). Similar toolkits do not exist for inclusive engineering; we aim to provide structured educational activities that utilise case studies.

1.4 Research Question

In order to develop methods for teaching the skills, knowledge and aptitude related to inclusive engineering, we asked the question: Will a discipline specific inquiry based learning group task to investigate inclusive engineering improve student's confidence, knowledge and understanding in relation to inclusion and inclusive engineering?

2 METHODOLOGY

2.1 Participants

A cohort of Materials Science and Engineering (MSE) students from the Faculty of Engineering at the University of Sheffield took part in the case studies workshop developed in this work during the Autumn semester of 2023. These students were sitting their first semester of graduate level study and they undertook the workshop during a non-credit bearing 'Skills Week' during which they took classes related to study skills, professional skills and employability.

23 students took part in the workshop, 13 of whom completed the start and end survey and consented to be included in this study. These responses are the data that underlie the results of this work. The other students were excluded from the analysis because they did not provide consent to be included in this research, they did not complete the survey fully, or they have a timestamp that disqualifies the response they gave because they completed the start survey after the workshop.

2.2 Ethics Approval

This work was carried out following The University of Sheffield Good Research and Innovation Practices policy, with ethical approval obtained (application number 049730).

2.3 Development of case studies workshop

The workshop activity and session plan were developed over a couple of years by the lead researcher in collaboration with students. The proposed approach was reviewed and critiqued by MSE undergraduate students who were members of a Task and Finish group, during the 21-22 academic session. Case studies of inclusive engineering (Table 1) and the structure of a IBL workshop was developed based on the discussions and feedback from that group, and were finalised by an undergraduate project student employed by the Faculty of Engineering Diversity Confidence in Engineering (DiCE) project (University of Sheffield 2022).

Table 1: Case studies offered in the workshop

Name of Case Study	Keywords
Non-inclusive aeroplane seats	Design, Corporate Policy, Body Shape
Discriminatory car safety testing	Legislation, Safety Testing, Society, Body Shape
The case for inclusive hip implants	Materials, Medical Regulation, Corporate Governance
Discriminatory automatic soap dispenser	Design, Skin Colour, Testing and Calibration, Corporate Policy
Vaccine hesitancy and racism in healthcare	Vaccines, Racism, Healthcare, Clinical Trials
Facial recognition bias	Racial Bias, AI, Facial Recognition, Procedural Failure

The facilitated workshop (Figure 1) included an introductory talk, in which the reasons for the workshop and research were described, key terminology explained and ground rules set. Key terminology included definitions of terms used during the workshop, descriptions of professional attributes of engineers, and about the Equality Act 2010 (United Kingdom Legislation, 2015.), as well as the concept of inclusive engineering with supporting examples. The students were assigned to groups, each of which was given the task of choosing a case study. The groups were given time for discussion and debate, guided by the questions in a pro forma (Appendix 1). The questions asked them to consider the who, how when and wider implications of the case study, and the group was expected to complete the pro forma. Each group then presented their critique of the case study to the other groups, with the assistance of the facilitator, an academic in the MSE department.

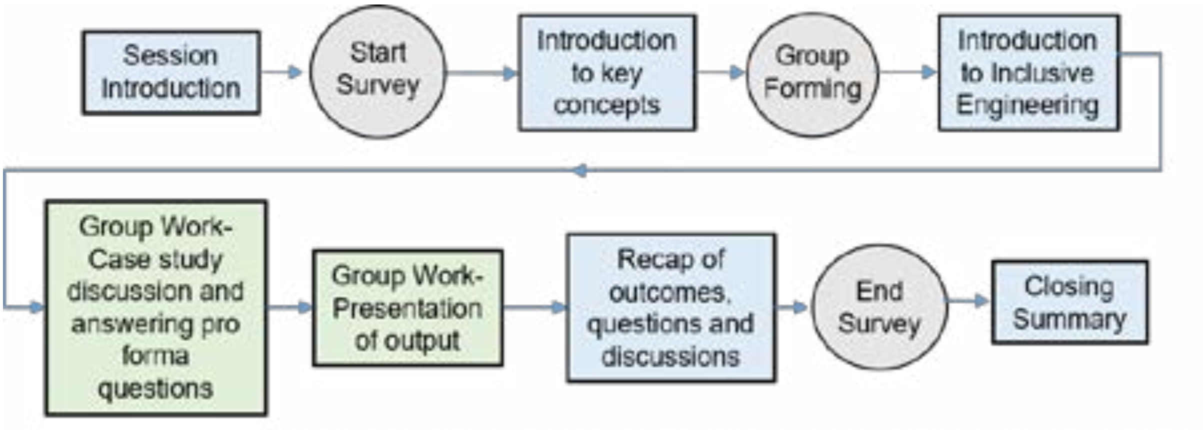

Figure 1: Inclusive engineering workshop structure. Background colour indicates different activity during the two hour long workshop. Blue: led by the facilitator; grey: activity or action; green: group work. The output of the group work was a completed collaborative Google Doc pro forma containing prompt questions completed by each group (Appendix 1).

2.4 Data collection, presentation and analysis

The students were surveyed using Google Forms at the beginning of the workshop, and again immediately after the workshop (Appendix 2). The form was designed to be quick and easy to complete to maximise the probability that participants would complete the survey. Informed consent was sought, and any student who declined consent in either of the surveys was excluded from the analysis. Numerical data collected from the survey was tabulated and analysed in GraphPad Prism (version 10.2.1). The survey included optional text responses. These were not systematically analysed due to the low number of responses but have been summarised in the Results section.

3 RESULTS

3.1 Quantitative outcome of the workshop

Comparison of the survey results before and after the workshop provided evidence that the workshop had a positive influence on student knowledge, understanding, confidence and opinions in relation to inclusive engineering.

When the students were asked to report their confidence in their Engineering (Figure 2A), Maths (Figure 2B) and Materials Science (Figure 2C) skills, there was no significant change in the numbers reported before and after the workshop. These questions were included to allow for comparison, given that there was no expectation that they would change because of the workshop.

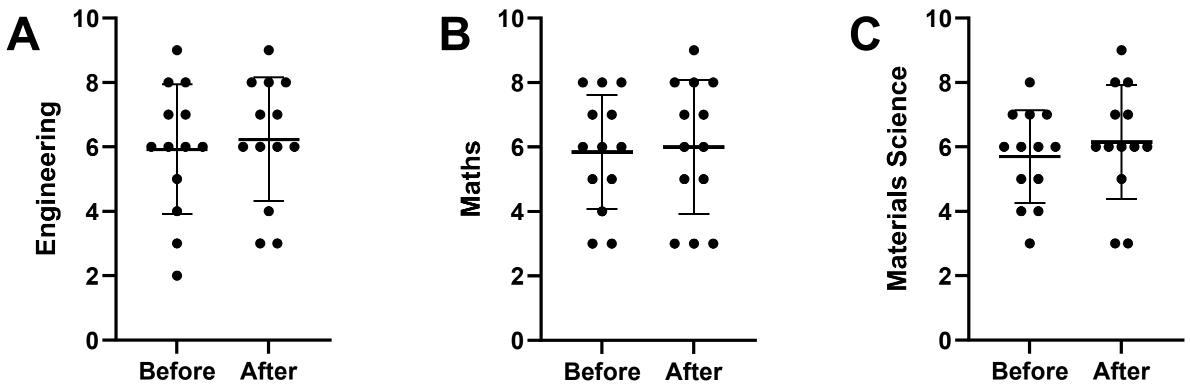

Figure 2: Self reported confidence in subject specifc skills. Students were asked to report their confidence of **A** Engineering, **B** Maths and **C** Materials Science skills before and after the workshop. Each point is an individual participant response, with the mean value and standard deviation indicated by lines and whiskers respectively. Two-tailed, paired t-tests performed for each question revealed no statistically significant differences, N=13 (A: p= 0.0395, t= 2.309, df= 12; B: p= 0.6130 t= 0.5193, df=12; C p= 0.1902 t= 1.389, df= 12).

When student scores were compared for attributes related to inclusive engineering, all measures increased (Figure 3). The largest change was in relation to student's reported knowledge of inclusive engineering which increased by an average of 1.8 (Figure 3A). The next largest change was in student's understanding of inclusive engineering (Figure 3B), which increased by an average of 1.4, followed by student's confidence to discuss inclusive engineering (Figure 3C) which increased by an average of 1. Student's opinion of how important inclusive engineering is (Figure 3D) increased by an average of 0.7.

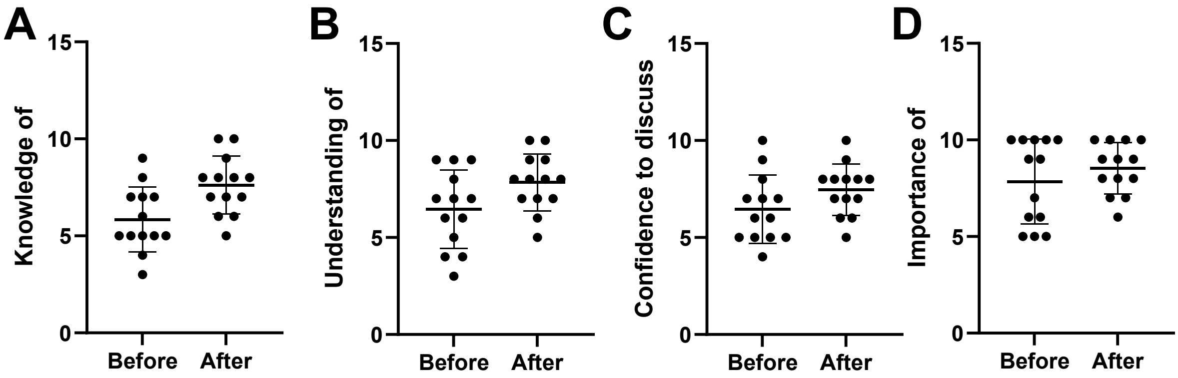

Figure 3: Self reported attributes in relation to inclusive engineering. Students were asked to report their **A** knowledge of inclusive engineering, **B** understanding of inclusive engineering, **C** confidence to discuss inclusive engineering, and **D** opinion of how important inclusive engineering was, before and after the workshop. Each point is an individual participant response, with the mean value and standard deviation indicated by lines and whiskers respectively. Two-tailed, paired t-tests performed for each question revealed statistically significant differences between the before and after responses for A-C with p values of <0.0001 (A, $t=6.299$, $df=12$), 0.0088 (B, $t=3.207$, $df=12$) and 0.0075 (C, $t=3.122$, $df=12$). There was no significant difference for (D, $p=0.1079$, $t=1.737$, $df=12$).

Despite the absolute low numbers of responses, the relatively high proportional number of completed responses (74%) is evidence that the survey design was effective for encouraging these. In future work using this survey method, an anonymised survey design, and other action or reassurance may encourage more students to consent to being included in the work. Repeating this work with bigger and different engineering disciplines would provide evidence of the wider applicability of the approach. Furthermore, the workshop could be carried out with cohorts that have differing proportions of home and overseas students, or studying at different levels to determine when inclusive engineering teaching is most impactful.

3.2 Qualitative feedback for the workshop

24 text responses were given, most of which were constructive. The salient points in response to question one were that two respondents liked the workshop, and four expressed a desire for inclusive engineering case studies to be embedded across the curriculum. One respondent indicated a desire for more ethnic diversity in professors.

When asked what was good about the workshop, five respondents gave reasons that they liked learning about the real world examples, and four that they liked discussion and the people in the workshop. These responses are further evidence of the strengths of using a case study IBL method, indicating that the students had to develop and discuss their ideas with others (Aditomo et al. 2013). To improve the workshop, one respondent desired more case studies, and another that they would like to develop case studies of their choosing, an idea that could be developed in future work.

It is important to consider these comments in context of the research design, because they were not anonymous, and the cohort was small. These factors may have resulted in respondents not wanting to give negative comments, and so the feedback here may not be fully representative. Regardless of these limitations, the comments provide useful insight and ideas for improving teaching of inclusive engineering. Specifically, by embedding it across the curriculum, which would ensure inclusive engineering is not regarded as secondary to theoretical or technical knowledge, although that approach would require teachers to develop skills, knowledge and understanding of inclusive engineering. Giving students the opportunity to develop their own case studies would allow for development of more skills and knowledge, as well as ownership of knowledge and an identity in the discipline, although would require more time and support for the learners.

An important consideration for using this approach is to ensure that students have the requisite skills to work inclusively in groups. Although it is related to inclusive engineering, inclusive group work, and the skills required to support this are a completely different topic, but should be acknowledged by the facilitator. This is particularly important where there might be a lack of diversity in the classroom, and where there is a danger that individuals might feel isolated or excessively burdened because they feel excluded by their group.

The workshop provides an activity and outputs that enable assessment of student skills, knowledge and understanding of inclusive engineering, although this was not manifest in this work. The inclusive engineering workshop was used to support learning in a separate group of 114 Automatic Control and Systems Engineering undergraduate students, prior to them performing a stakeholder analysis for a module in which they utilised the Engineering V- model (Walden and International Council on Systems Engineering 2023) to design and build a burglar alarm. The design process loosely followed the ‘Discover’ phase detailed in the Cambridge Inclusive Design Toolkit (University of Cambridge, 2017.), and the workshop helped students to consider an inclusive approach towards user and stakeholder requirements. In contrast to the assessment in previous years, inclusive engineering was evident in work submitted by the groups. Future work could investigate the link between the workshop and other activities to support student learning of inclusive engineering and assessment, by comparing submitted work between current and previous cohorts. This approach would identify the most impactful teaching to support learning of inclusive engineering.

3.3 Future developments

To build upon this work and to better integrate inclusive engineering into disciplinary curriculum, the ideas detailed here could be taken forward into new activities. The case study IBL approach is suitable for integration throughout the curriculum, and could be directly assessed, or used to support assessment of Learning Objectives. Supported learning tasks could be developed in which students make their own case studies, further helping them find their place and identity in their discipline. These approaches have the potential added benefit of being a vehicle for development of skills, knowledge and confidence in teaching staff, and would potentially improve awareness of and actions towards inclusivity in the academy (Liyanage 2020; Dale-Rivas 2019). The work also provides a template from which more extensive toolkits to support the learning of inclusive engineering could be developed, to compliment those that already exist (Engineering Professors Council, 2024a; 2024b).

4 SUMMARY AND ACKNOWLEDGEMENTS

We have demonstrated a successful educational intervention for teaching inclusive engineering, that gained positive written and verbal feedback from students who took part. The approach could be used to support assessment of Learning Objectives related to inclusion. Embedding inclusive engineering in disciplinary teaching requires development of new skills and knowledge by engineering specialists and a long term strategic approach. Practical and actionable teaching methods are a means to support this in engineering education.

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REFERENCES

Aditomo, Anindito, Peter Goodyear, Ana-Maria Bliuc, and Robert A. Ellis. 2013. 'Inquiry-Based Learning in Higher Education: Principal Forms, Educational Objectives, and Disciplinary Variations'. *Studies in Higher Education* 38 (9): 1239–58. https://doi.org/10.1080/03075079.2011.616584.

British Standards Institute. 2005. 'BS 7000-6:2005'. BSI Knowledge. 2 April 2005. https://knowledge.bsigroup.com/products/design-management-systems-managing-inclusive-design-guide?version=standard&tab=overview.

Dale-Rivas, Hugo. 2019. 'The White Elephant in the Room: Ideas for Reducing Racial Inequalities in Higher Education'. HEPI. 18 September 2019. https://www.hepi.ac.uk/2019/09/19/the-white-elephant-in-the-room-ideas-of-reducing-racial-inequalities-in-higher-education/.

Engineering Council. 2020a. 'AHEP 4 Engineering Council'. 31 August 2020. https://www.engc.org.uk/standards-guidance/standards/accreditation-of-higher-education-programmes-ahep/fourth-edition-implemented-by-31-december-2021/.

Engineering Council. 2020b. 'UK Standard for Professional Engineering Competence and Commitment'. https://www.engc.org.uk/ukspec4th.

Engineering Council. 2024. 'Guidance on Sustainability'. 30 March 2024. https://www.engc.org.uk/sustainability.

Engineering Professors Council. 2024.-a. 'Engineering Ethics Toolkit'. Engineering Professors Council. Accessed 1 April 2024. https://epc.ac.uk/resources/toolkit/ethics-toolkit/.

Engineering Professors Council. 2024.-b. 'Sustainability Toolkit'. Engineering Professors Council. Accessed 1 April 2024. https://epc.ac.uk/resources/toolkit/sustainability-toolkit/.

European Network for Accreditation of Engineering Education. 2022. 'EUR-ACE® Framework Standards and Guidelines'. ENAEE. Accessed 8 April 2024. https://www.enaee.eu/eur-ace-system/standards-and-guidelines/.

Fawzy, Ashraf, Tianshi David Wu, Kunbo Wang, Matthew L. Robinson, Jad Farha, Amanda Bradke, Sherita H. Golden, Yanxun Xu, and Brian T. Garibaldi. 2022. 'Racial and Ethnic Discrepancy in Pulse Oximetry and Delayed Identification of Treatment Eligibility Among Patients With COVID-19'. *JAMA Internal Medicine* 182 (7): 730. https://doi.org/10.1001/jamainternmed.2022.1906.

International Engineering Alliance. 2021. 'Graduate Attributes & Professional Competencies'. 21 June 2021. https://www.ieagreements.org/about-us/gapc/.

Levy, P., S. Little, P. McKinney, A. Nibbs, and J. Wood. 2010. *The Sheffield Companion to Inquiry-Based Learning*. Sheffield: CILASS: The Centre for Inquiry-based Learning in the Arts and Social Sciences. https://eprints.whiterose.ac.uk/192004/.

Liyanage, Mia. 2020. 'Miseducation: Decolonising Curricula, Culture and Pedagogy in UK Universities'. HEPI. 22 July 2020. https://www.hepi.ac.uk/2020/07/23/miseducation-decolonising-curricula-culture-and-pedagogy-in-uk-universities/.

Royal Academy of Engineering. 2023. 'Inclusive Cultures in Engineering'. 2023. https://raeng.org.uk/inclusive-cultures.

Spronken-Smith, Rachel. 2012. 'Experiencing the Process of Knowledge Creation: The Nature and Use of Inquiry-Based Learning in Higher Education'. In *International Colloquium on Practices for Academic Inquiry*, 1–17. University of Otago.

Spronken-Smith, Rachel, and Rebecca Walker. 2010. 'Can Inquiry-based Learning Strengthen the Links between Teaching and Disciplinary Research?' *Studies in Higher Education* 35 (6): 723–40. https://doi.org/10.1080/03075070903315502.

Sudat, Sylvia E K, Paul Wesson, Kim F Rhoads, Stephanie Brown, Noha Aboelata, Alice R Pressman, Aravind Mani, and Kristen M J Azar. 2023. 'Racial Disparities in Pulse Oximeter Device Inaccuracy and Estimated Clinical Impact on COVID-19 Treatment Course'. *American Journal of Epidemiology* 192 (5): 703–13. https://doi.org/10.1093/aje/kwac164.

The United Nations. 2015. 'THE 17 GOALS | Sustainable Development'. 2015. https://sdgs.un.org/goals.

United Kingdom Legislation. 2015. *Equality Act 2010*. Statute Law Database. Accessed 30 March 2024. https://www.legislation.gov.uk/ukpga/2010/15/contents.

University of Cambridge. 2017. 'Inclusive Design Toolkit'. Accessed 1 April 2024. https://www.inclusivedesigntoolkit.com/.

University of Sheffield. 2022. 'Diversity Confidence in Engineering Project Home Page'. 2022. https://sites.google.com/sheffield.ac.uk/dice/home.

Walden, David D. and International Council on Systems Engineering, eds. 2023. *INCOSE Systems Engineering Handbook*. Fifth edition. Hoboken, NJ: John Wiley & Sons Ltd.

Appendix

Appendix 1: Inclusive engineering workshop pro forma
https://docs.google.com/document/d/1QR8TELPzEE_Id2zp3r-WZHS6qI4Ei4id/edit?usp=sharing&ouid=110913931037164669198&rtpof=true&sd=true

Appendix 2: Google forms surveys

Start: https://drive.google.com/file/d/1oASK_IIWKTFp-GoEIHgQ2phHB1E_BIKM/view?usp=sharing

End: https://drive.google.com/file/d/1oEO-0A-cx1kzqZzX1Eg2dsBTnpEGBrwe/view?usp=sharing

HOW US POSTDOCTORAL OFFICES SUPPORT INTERNATIONAL STEM POSTDOCTORAL SCHOLARS (RESEARCH)

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Keywords: *case study, international STEM postdoctoral scholars, US postdoctoral office directors*

ABSTRACT

An intrinsic case study explores the personal and professional support provided to international science, technology, engineering, and math (STEM) postdoctoral scholars through postdoctoral offices at colleges and universities across the United States (US). Semi-structured interviews were conducted with 20 US postdoctoral office directors to explore this topic. Participant interviews were analyzed inductively and resulted in four themes: (1) Understaffed and underfunded; (2) Identification and communication challenges; (3) Social and professional development programming; and (4) Targeted support through specialized programs. The identified themes could be particularly instructive to US postdoctoral office directors and international faculty sending Ph.D. graduates to the US for postdoctoral training.

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1 INTRODUCTION

1.1 Overview

In the United States (US), over half of the science, technology, engineering, and math (STEM) postdoctoral scholars are international (Camacho and Rhoads 2015). Colleges and universities that host international postdoctoral scholars are uniquely positioned to support international scholars personally and professionally during their employment tenure in the US. However, little information is known regarding the ways in which university postdoctoral offices support international STEM postdoctoral scholars. An intrinsic case study design is employed to explore interviews conducted with 20 US postdoctoral office directors inductively. The research question guiding this study is: What personal and professional support do US university postdoctoral offices offer international STEM postdoctoral scholars?

1.2 Literature Review

International STEM postdoctoral scholars comprise a substantial part of the US academic labor force, and their presence not only diversifies American academia but also furthers high-quality, world-class research (Cantwell and Taylor 2013). However, international postdoctoral scholars have identified challenges they face when working in the US, such as immigration concerns, strains to find a community, pressure to publish and secure funding, and inadequate career counseling (Mendez et al. 2023). In addition, international postdoctoral scholars often report negative postdoctoral scholar-advisor relationships, complicating their postdoctoral experiences (Burt 2019; Van Benthem et al. 2020). Also, US institutional resources, such as postdoctoral offices, have been criticized for lacking adequate funding and personnel (Gunapala 2014) despite research indicating that a successful postdoctoral experience depends on whether a scholar has been provided with appropriate resources and support (Burke et al. 2018).

US postdoctoral and international offices are designed to combat these challenges and to provide academic, career, and personal support to international postdoctoral scholars (Ferguson et al. 2017). The National Postdoctoral Association (2019) publishes best practices for US postdoctoral offices, which includes offices providing an orientation to welcome new postdoctoral scholars; issuing a postdoctoral handbook outlining institutional benefits, policies, and opportunities; and providing career counseling and other professional development opportunities. However, research indicates a lack of universal orientation programs to help prepare postdoctoral scholars for their work responsibilities (Burke et al. 2019; Cutright et al. 2018). Moreover, few international postdoctoral scholars report familiarity or awareness of available resources (Ferguson et al. 2017). Thus, the extent to which these best practices are implemented is unclear, so more research on the personal and professional support available to international postdoctoral scholars in the US must be investigated.

2 METHODOLOGY

2.1 Research Design

An intrinsic case study (Stake 1995) was implemented to explore the personal and professional support provided to STEM international postdoctoral scholars by US college and university postdoctoral offices. Intrinsic case studies are valuable when seeking to provide insight into a particular issue in which the case is secondary. Interviews with 20 US postdoctoral office directors were analyzed inductively (Silverman 2019). The research question guiding this study was: What personal and professional support do US university postdoctoral offices offer international STEM postdoctoral scholars?

2.2 Participants

A diverse group of 20 postdoctoral office directors from public and private colleges and universities across the US was recruited via email. Most directors were in part-time positions, and some held dual faculty roles. The number of postdoctoral scholars working at the colleges and universities included in this study ranged from 400 to 1000. Nearly half of the postdoctoral scholars were categorized as international, and almost all of the international postdoctoral scholars were in STEM fields.

2.3 Data Collection

Following Institutional Review Board approval, all participants were provided with a consent form detailing the purpose of the study, interview procedures, and safeguards in place to protect their privacy and confidentiality. A semi-structured interview protocol was created to examine the personal and professional support offered to international postdoctoral offices by US postdoctoral offices and the extent to which they implemented best practices identified by the National Postdoctoral Association (2019). Open-ended probing questions were included so the researchers could seek clarification and meaning during the interview. Interviews averaged 60 minutes in length. All participants were given pseudonyms, and only de-identified interview transcripts were stored. Participation was incentivized with a $50 e-gift card.

2.4 Reflexivity and Positionality

Throughout the study, the research team engaged in individual and collective reflexivity by reflecting upon, bracketing out, and dialoguing about experiences and beliefs concerning the ways in which US colleges and universities support international STEM postdoctoral scholars. In qualitative research, reflexivity is a crucial component of inquiry, positioning researchers to consider their bias and its potential impact on meaning-making and interpretations during data analysis. Additionally, researchers must disclose their positionality so readers know the unique perspectives they bring to the study (Lincoln and Guba 1985). The research team comprised social science American women trained in qualitative research methods within educational settings. Two are professors, and the other is a doctoral student who is an international student. All are engaged in STEM education research, particularly in efforts to diversify the engineering professoriate and broaden success in academia. This study was approached as a matter of social justice; therefore, empathy and humility were integral to the data collection and analysis processes.

2.5 Data Analysis

Inductive thematic content analysis techniques (Silverman 2019) were employed to explore the personal and professional support provided to international STEM postdoctoral scholars by US postdoctoral offices. The transcripts were coded individually through three review rounds, leading to 25 unique codes. Next, the researchers collectively cross-referenced the codes and identified five initial themes through consensus. Following consensus-building, the themes were refined for parsimony and to ensure the themes captured the entirety of the data and could be applied broadly. This refinement led to four final themes: (1) Understaffed and underfunded; (2) Identification and communication challenges; (3) Social and professional development programming; and (4) Targeted support through specialized programs. Multiple verification strategies ensured the results were trustworthy by attending to credibility, transferability, dependability, and confirmability (Lincoln and Guba 1985). This occurred by including participant direct quotes, the researchers engaging in reflexivity and positionality, and involving multiple feedback loops in the data analysis process.

2.6 Limitations

As in all research inquiries, this study has several limitations. First, the researchers did not conduct member checks because arranging and conducting interviews was difficult due to participants' demanding schedules. Member checking might have provided more complex and nuanced depictions of their challenges. However, theoretical saturation was achieved by the sixth interview, so these results appear to adequately represent the viewpoints of postdoctoral office directors at large. This study attended to researcher bias through reflexivity and positionality, its potential to influence the results and interpretations cannot be guaranteed. Last, this inquiry is primarily approached from an outsider's vantage point, as none of the researchers hold a STEM academic background, but one has served as a postdoctoral scholar, and another holds an international student demographic.

3 RESULTS

3.1 Understaffed and Underfunded

All postdoctoral office directors shared that they lack the adequate personnel, resources, or financial means to support their international postdoctoral scholars. As Becca described, she has an "absurdly small budget," which limits her ability to provide the personal and professional support she desires and knows would benefit the international STEM postdoctoral scholars at her institution. Furthermore, they are often the only person managing the postdoctoral office for hundreds of postdoctoral scholars. With this personnel structure, the directors felt they were doing all they could but could not possibly reach nor help all postdoctoral scholars with such limited resources. Many of the postdoctoral office directors collaborate with others in their state or surrounding areas, such as the "Big 10" universities in the Midwest, to create postdoctoral coalitions that provide more professional development opportunities, advertise faculty and research positions, and offer connections for postdoctoral scholars across institutions.

3.2 Identification and Communication Challenges

All the participants stressed the importance of international STEM postdoctoral scholars finding connections and community within the university to ensure they were satisfied and productive in their positions. However, all expressed difficulty in identifying postdoctoral scholars at their institutions. As Travis said, "Defining what even constitutes a postdoc is a fraught question." Across US colleges and universities, there is no solid definition of a postdoctoral scholar, as it depends on the funding of their position, their research and teaching role, and their employment status. Some are classified as staff, some as faculty, and some as visiting professors. Therefore, it can be difficult for postdoctoral offices to identify and communicate with all the postdoctoral scholars employed at their institutions.

Most directors depend on their Human Resources departments to identify postdoctoral scholars, and then they reach out via email to welcome and connect with them. Some institutions offer a postdoctoral orientation, usually a virtual meeting; however, many depend on the "new hire" orientations provided by Human Resources due to their lack of funding and resources. Most postdoctoral offices post handbooks on their websites and send regular newsletters and emails with information regarding professional development offerings, grant opportunities, social events, and other university news. However, as Allison said, "It's passive," meaning they are not actively recruiting postdoctoral scholars to participate in these opportunities but rather providing information for consumption. If the postdoctoral scholars do not respond, they cannot connect with them. Furthermore, as Jessie expressed, "How can I know if I'm capturing everybody?"

3.3 Social and Professional Development Programming

All the postdoctoral office directors highlighted the importance of offering social and professional development programming for the international STEM postdoctoral scholars at their institutions. Because their resources are limited, almost all rely on postdoctoral associations to facilitate social events, such as monthly coffee hours; "field trips" to museums, art galleries, and local attractions; and international potlucks, where postdoctoral scholars bring food from their home country to share. The directors also indicated they partner with their institutional international office to ensure international postdoctoral scholars receive visa and immigration guidance, as well as language and cultural services. Also, many postdoctoral offices provide professional development opportunities with topics ranging from effective lab practices, finding funding, career preparation, enhancing professional communication skills, and health and wellness tips. Many of these professional development opportunities are also connected with the graduate school at their institutions, but some work with the National Postdoctoral Association or the National Institute of Health for programming. Many directors said they offer one-on-one career counseling and job material support to international postdoctoral scholars, but they do not publicize this service because they are understaffed. Thus, "word of mouth" often spreads this specific support activity.

3.4 Targeted Support through Specialized Programs

Some universities created unique grant-funded programs for postdoctoral scholars interested in entering the professoriate job market. These programs offer targeted personal and professional support, but only a handful of scholars participate in these programs, and only some are available to international postdoctoral scholars, as most are designed for minoritized US citizen populations. In these programs, postdoctoral scholars are provided mentoring, training, and coaching throughout their experience. As Tim described, the purpose is to diversify the professoriate, train excellent future faculty members, and "support the research scholarship and creative works as a larger intellectual community." The programs intentionally provide individualized support, so postdoctoral scholars can identify and meet their specific career goals, such as securing grant funding for their research or improving their instruction. Since these programs are grant-funded, there is limited funding to support the number of participants interested in these specialized programs. Directors indicated that these programs have successfully supported postdoctoral scholars in securing tenure-track positions at their institutions and beyond.

4 DISCUSSION AND CONCLUSION

4.1 Discussion

This intrinsic case study aimed to explore the personal and professional support provided to international STEM postdoctoral scholars by US postdoctoral offices. The participants in this study indicated that they are aware of the support, resources, and activities they want to provide, such as targeted professional development, community, and connection points, but their limited personnel and financial resources are a constraint. Furthermore, the difficulty in even identifying the postdoctoral scholars working at their institutions limits their ability to make initial contact and build relationships. All the directors indicated that they are doing what they can with their allotted resources, and they all communicate regularly with postdoctoral scholars via email and website postings.

Due to limited resources, they must rely on their postdoctoral association, the institutional international office, graduate school programming, and external opportunities to provide personal and professional support. As Allison described, international postdoctoral scholars "just need a sherpa…someone to help them navigate…and plug them into all the resources." However, as one director described, there is a severe lack of guidance and support for postdoctoral scholars when only a "skeleton crew" is in place. Specialized postdoctoral programming that provides personalized and targeted mentoring and coaching is successful, but it is impossible to scale without adequate funding. With more financial and personnel resources, US postdoctoral offices would be better positioned to support their international STEM postdoctoral scholars, but until greater advocacy for this large part of the academic workforce is more prevalent, support is unlikely to increase.

4.2 Implications

Implications abound for US postdoctoral office directors and international faculty sending Ph.D. graduates to the US for postdoctoral training. It is evident that postdoctoral office directors want to provide more support to their scholars; however, they are constrained by a lack of resources and personnel. The US depends on international postdoctoral scholars to diversify the academic workforce, produce world-class research, and staff universities and colleges nationwide, but their personal and professional needs are often going unmet. Every office director interviewed stressed the need for more financial and personnel resources to reach more scholars. For international postdoctoral scholars to have their personal and professional needs met, they must self-identify and advocate for themselves, which is an unfortunate undertaking for individuals to take on in the bureaucracy of American higher education.

4.3 Future Research

Future exploration is warranted to understand whether these personal and professional supports and connected challenges in offering them are unique to international STEM postdoctoral scholars or indicative of larger postdoctoral training trends. In order to do so, additional interviews with postdoctoral scholars, both international and domestic, could be administered to broaden and strengthen the results and implications of this study.

4.4 Conclusion

This intrinsic case study provides a deeper understanding of the personal and professional support international STEM postdoctoral scholars are provided by US postdoctoral offices. Data analysis of the interviews resulted in four main themes: (1) Understaffed and underfunded; (2) Identification and communication challenges; (3) Social and professional development programming; and (4) Targeted support through specialized programs. It is clear that more intentional support for international STEM postdoctoral scholars is needed, but this will only occur if more resources are directed to this large population within the academic workforce. This is an investment that is necessary if the US is going to support the careers of these scholars and advance diversity, equity, and inclusion in US academia.

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REFERENCES

Burke, L. E. C. A., J. Hall, W. A. de Paiva, A. Alberga, G. Mu, J. P. Leigh, and M.S. Vazquez. "Postdoctoral Scholars in a Faculty of Education: Navigating Liminal Spaces and Marginal Identities." *Arts and Humanities in Higher Education 18,* no. 4 (2019): 329–34. https://doi.org/10.1177/1474022217731697

Burt, B. A. "Toward a Theory of Engineering Professional Intentions: The Role of Research Group Experiences." *American Educational Research Journal 56* no. 2 (2019): 289–332. https://doi.org/10.3102/0002831218791467

Camacho, S., and R. A. Rhoads. "Breaking the Silence: The Unionization of Postdoctoral Workers at the University of California." *The Journal of Higher Education 86*, no. 2 (2015): 295-325. https://doi.org/10.1353/jhe.2015.0010

Cantwell, B., and B. J. Taylor. "Internationalization of the Postdoctorate in the United States: Analyzing the Demand for International Postdoc Labor." *Higher Education 66* (2013): 551-567. https://doi.org/10.1007/s10734-013-9621-0

Cutright, T. J., R. K. Willits, L. T. Coats, L. N. Williams, and D. R. Rodrigues. "Professional Preparation of Underrepresented Minority Ph.D.'s and Postdocs for a Career in Engineering Academia." Paper presented at *American Society for Engineering Education Annual Conference & Exposition, Crystal City, VA, USA, June 23 – 27, 2018*. https://peer.asee.org/29564

Ferguson, K., M. McTighe, B. Amlani, and T. Costello. 2017. *Supporting the Needs of Postdocs*. Bethesda, MD, USA: National Postdoctoral Association, 2017. https://www.sigmaxi.org/docs/default-source/Publications-Documents/2017_supporting_the_needs_of_postdocs.pdf

Gunapala, N. "Meeting the Needs of the 'Invisible University': Identifying Information Needs of Postdoctoral Scholars in the Sciences." *Issues in Science and Technology Librarianship 77* (2014). https://doi.org/10.5062/F4B8563P

Lincoln, Y. S., and E. G. Guba. *Naturalistic Inquiry*. Newbury Park, CA: Sage, 1985.

Mendez, S. L., J. A. Tygret, and K. Watson. "The challenge of postdoc'ing in the US: Perspectives from international engineering postdoctoral scholars." Paper presented at the European Society for Engineering Education (SEFI) Annual Conference, Dublin, Ireland, 2023.

National Postdoctoral Association. *Postdoc Office Toolkit*. Bethesda, MD, USA: Author, 2019. https://www.nationalpostdoc.org/page/npa_toolkits

Silverman, D. *Interpreting Qualitative Data.* 6th edition. London, UK: Sage, 2019.

Stake, R. E. *The Art of Case Study Research*. Thousand Oaks, CA: Sage, 1995.

Van Benthem, K., N. A. Mohamad, C. T. Corkery, J. Inoue, and N. M. Jadavji, N. M. "The Changing Postdoc and Key Predictors of Satisfaction with Professional Training." *Studies in Graduate and Postdoctoral Education 11,* no 1 (2020):123–142. https://doi.org/10.1108/sgpe-06-2019-0055

APPROACH AND EXPERIENCES OF USING DIGITAL CREDENTIALS IN CONTINUING EDUCATION MOOCS

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Keywords*: microcredential, digital credential, microlearning, MOOC, continuing education*

ABSTRACT

Microcredentials (MCs) are gaining increasing interest in continuing education and life-long learning in higher education institutions. MCs are often used within informal

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learning context and are related to microlearning entities, but they can also be used within formal learning and when delivering degrees. Our goal was to develop an approach and model for micro-learning and DCs to be piloted in two 5 ECTS continuing education MOOCs. We aimed at supporting student engagement by a gamified approach to motivate learners, and to give feedback on the competence development as well as to show the gained competences. We developed an initial stackable three-level framework for DCs, starting from nanocredentials related to microlearning entities, and ending at highest level with metacredentials for successful course completion. We describe the designed framework and its connection to pilot course design and implementation. The number of applications for the open digital badges was relatively high (60-70%) for both the nanocredentials and the metacredentials. The results of an online questionnaire after the pilot show that most of the students that responded (N = 36) reported that the used assessment method for the competences related to micro-credentials gave feedback on their learning, DCs showed development of their skills and competences, and getting a DC was found to be motivating and encouraging. However, about one fifth of the respondents saw no value in DCs. Further studies are needed to understand the factors affecting the perceived value of DCs, and to develop and test DC models in CEE.

1 INTRODUCTION

1.1 Background

Microcredentials are gaining increasing interest in continuing education and lifelong learning in higher education institutions (Ahsan et al. 2023, Smith and Kalman, 2023). They can be used for separate microlearning entities, or more recently, integrated to be part of course offerings (Brauer, 2020). In the latter case, microcredentials can be used as a means for gamification as well as for acknowledging the assessed skills and competences in the learning process, for example (ibid.). Microcredentials, and digital credentials generally, are typically issued electronically as digital open badges (DOBs) to identify and promote excellence and mastery of competences (Abramovich, Schunn and Higashi 2013). DOBs include detailed knowledge, competence, and expertise criteria as well as a description of the evidence like assessments (Brauer, 2020; European Commission, 2020).

Designing and implementing digital credentials in higher education calls for pedagogical design, which takes into account the specifics related to microlearning and credentialing in the course design and implementation. There is no consensus on what size, volume and depth microlearning actually has, meaning that the amount of time used for learning and showing the competences, and therefore gaining the microcredentials may vary (Varadajanan et al. 2023). Besides MC being a micro-unit, it can also be a sub-unit of a credential or qualification (European Commission, 2020). Therefore, when planning the use of MCs, it is important to consider what are the motivations and goals of implementing microlearning and microcredentials, how they are connected to course, program or degree components, learning objectives and competences, as well as to other credentials and qualifications provided.

1.2 Prior research on learner interest and value for digital credentials in HE

One of the important motivations for developing microlearning approaches in Higher Education (HE) is to supplement traditional degree programmes (Varadajanan et al. 2023). Learners are interested in short, practical, and up-to-date courses to support their career paths (ibid.). Similarly to findings by Varadajanan et al. (2023), Kiiskilä et al. (2023) report based on 19 learner interviews that learners place utility value in short and long term to digital credentials in job searching, for example. Furthermore, the clear description of the skills and competences associated with the digital credentials was appreciated and described to help in credit transfer to a different institution (Kiiskilä et al., 2023). In addition, learners expressed enjoyment and interest in digital credentials, as expression of their intrinsic value (ibid.). The factors that weakened the value of digital credentials for learners were related to the low number of available digital credentials at the institution at the time of the study, as well as the low awareness of them by industry (ibid.).

2 DEVELOPMENT OF THE MICROLEARNING MODEL AND FRAMEWORK FOR DIGITAL CREDENTIALS

2.1 Goals of the development

Our goal was to develop, implement, and trial a model for microlearning and a framework for digital credentials in two master's level (EQF-7) continuing education MOOC courses. Our specific interest was to study, how students participating in the two pilot MOOC courses perceive DCs as part of the course implementations, and whether adult learners who are upskilling or reskilling themselves will find them interesting and motivating. Furthermore, one of the identified challenges in MOOCs is the high drop-out rate of students and therefore the low percentage of those who complete the courses (Semenova, 2022). We were therefore interested, whether we could develop a model for HE with microlearning content and a stacked framework for DCs that could engage students with smaller learning entities as an alternative to taking a 5 ECTS course.

2.2 Modular structure for MOOC courses

We designed the two pilot MOOC courses as follows. First, we identified the skills and competences relevant for working life to define the learning objectives for each work-life related course. We then used our prior knowledge on students' preferences for developing the MOOC implementation as self-paced individual learning, but including also some asynchronous social learning activities. To create a modular structure for the five (5) ECTS courses, we identified five main themes related to learning goals that we grouped to form the skill and competence goals for the two five (5) ECTS courses, aiming for five one (1) ECTS sized thematic units within each course (Fig. 1).

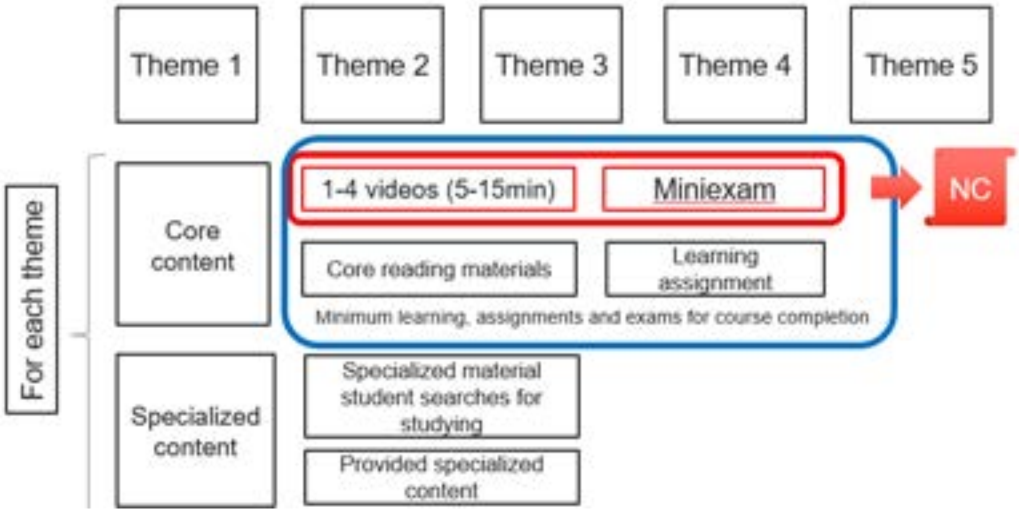

Fig. 1. Modular structure for a designed course with nano-credential (NC) application for successfully completing a microlearning entity.

For each of the five themes we created a modular structure, with short videos as core content, related mini exams that were automatically graded, as well as additional core reading materials and a larger learning assignment that was evaluated by the course instructors. In addition, specialized content was provided and/or searched by the student related to the theme that could be also used in doing the learning assignment. Application for a nanocredential (open digital badge) was possible with a successful mini-exam passing with at least 80% score of maximum points. The application for the DOB opened automatically for only those students that passed the minimum acceptance level for the mini-exam with a maximum of two attempts for passing.

2.3 Designing the initial framework for digital credentials

Designing the initial framework for the digital credentials was based on the following goals. We aimed to create a structure that supported the stacking of the credentials from thematic microlearning unit related nanocredentials (approximately 0.5-2 hours) to microcredentials equivalent to 1 ECTS. In addition, we aimed at creating course level metacredentials equivalent to 5 ECTS. In Finland, microcredentials are aimed to be used for 1-59 ECTS (Digivisio, 2022). Nanocredential is therefore suitable as a concept to be used for smaller microlearning related digital credential. We use here the notion of “metacredential” for the course level digital credential to differentiate between the levels and to clearly distinguish the three levels to nano-, micro- and metacredentials based on the amount of study time used on each level. The planned three levels of digital credentials are presented in Figure 2. In the pilot study, we focused on implementing and piloting levels 1 and 3 to test the idea and implementation, and to gain knowledge and experiences on the use, usefulness, and perceptions and preferences of students.

Fig. 2. Initial framework for digital credential levels.

Next, we present the pilot study, within which the digital credentials were available for the students to be applied for after successful completion of the thematic microlearning units and the completion of the courses. We report the findings on student interest based on the applications for the credentials in comparison to course completion statistics. This data is complemented by an online questionnaire covering the perceptions of students on microlearning, in terms of mini-exams used for competence development assessment, and related digital credentials.

3 METHODOLOGY

3.1 Participants of the pilot MOOCs

Altogether 100 students enrolled to the two pilot MOOC courses that were organized as open continuing education offering, and marketed in social media as well as on university web pages. Most of the students were enrolled to both courses, but some took part only to either of them. 57 students completed the first MOOC, and 46 students completed the second MOOC. MOOCs were open for anyone to enrol with no participation fee, as the MOOCs were developed and piloted within an educational project funded by an external funder. There were no entry requirements, including no requirements for prior knowledge on the course topics.

3.2 Implementation of the Open Badges in pilot MOOCs

The two pilot MOOC courses were implemented in Moodle learning management system. The digital credentials were offered as open digital badges through Open Badge Passport platform (https://openbadgepassport.com/). The digital badges created in the Open Badge Factory (https://openbadgefactory.com/en/) by the course instructors included the information on the name of the badge, issuing organization, date of issuing, name of the person the badge is issued to, short description of the skills and competences, the criteria for receiving the badge, including the learning objectives and how the skills have been demonstrated. Both Open Badge Factory and Open Badge Passport are certified to the Open Badges v2.0 standard.

The students could apply for the open badges as follows (see also Figure 1). The microlearning unit included watching short video(s) and passing a mini-exam related to the video content with a minimum of 80% correct answers. The mini-exam could be taken twice, but with a minimum of one hour between the first and second attempt. After successfully completing the mini-exam, the learner was opened a new section in Moodle, from which he/she could apply for the nanocredential. The learner could apply for the open badge issued for the nanocredential in question from Open Badge Passport. The issuing was done automatically based on the passed mini-exam. The learner then received an email on the issuing of the badge to his/her registered email address for the Open Badge Passport. Students, who had completed either of the courses, were also offered by an email an opportunity to apply for a metacredential for the course in question. The email included a link to the application form in Open Badge Passport.

3.3 Online questionnaire and respondents

We conducted an online questionnaire after the two pilot courses had ended. Questionnaire was implemented with Webropol survey tool and answering to it was voluntary. The link to the students was sent via an email in November 2023. The questionnaire included questions on student background, such as age, gender, and educational level.

There were 36 respondents to the questionnaire. 78% of the respondents were female, which may be due to fact that the courses were related to knowledge management in technology sector. The average age of the respondents was 46 years (min = 32, max 62). 94% of the respondents had a degree from tertiary education. All of the respondents expressed that they participated the courses to gain competences to be applied in work life. Only 6% of the respondents wanted to include the completed courses to their ongoing higher education studies, indicating that most of the respondents were adult learners in continuing education.

4 RESULTS

4.1 Interest towards digital credentials

First, we report the interest of students towards the nanocredentials for microlearning units and metacredentials issued for the whole course completion with a passed grade (see Table 1). We use as an indicator for the interest the number of applications compared to the number of course completions. In the first MOOC (MOOC1), the interest towards digital open badges decreased from slightly from 70% to about 60% for the nanocredentials after the first thematic microlearning unit with a nanocredential. However, the metacredential issued after the course for the 5 ECTS MOOC 1 completion increased again the number of applications to about 68% of the students who completed MOOC 1. For MOOC 2 the interest towards nanocredentials was about on the same level as for MOOC 1. The interest towards the metacredential for MOOC 2 course completion slightly decreased compared to MOOC 1. 60% of the students, who passed MOOC 2, applied for the metacredential.

Table 1. Number of students who applied for open badges based on completing successfully nano-credential sized microlearning units and course completion related meta-credentials.

Course	No. students, who passed MOOC	NC-1	NC-2	NC-3	NC-4	NC-5	meta-cred.
MOOC 1	57	40	34	35	34	34	39
MOOC 2	46	33	29	28	28	27	28

4.2 Student perceptions on digital credentials and mini-exams

In the online questionnaire we asked the respondents to rate their agreement on the following two topics: seven (7) questions on digital credentials and five (5) questions on mini-exams (see Table 2). Questions were formulated as statements, and respondents were asked to rate their agreement with a 6-point Likert scale (1 = strongly disagree, 6 = strongly agree). Table 2 shows the statements, with white cell background for statements related to digital credentials, and with grey cell background for mini-exam related statements. Besides the descriptive statistics, Table 2 also presents the percentages for scale values 1-6. For discussing the results, we discuss also sums of percentages for perceptions for agreeing (scale values 4-6), and with disagreeing (scale values 1-3) with the statements.

Over half of the respondents agreed with statements on the value of digital credentials perceiving them as encouraging and motivating as previous research suggests (statements 3, 5, 9). Digital credentials were perceived by over half of the respondents as showing increase of own competence, as well as generally showing the competence gained (statements 2, 4). In addition, getting a metacredential for the course completion was perceived as meaningful by over half of the respondents (statement 6). Over half of the respondents disagreed, that they were not interested in the digital credentials (statement 6). It should be noted that the agreement (disagreement for statement 7) varied between 58-72% depending on the statement. However, the results also show, that digital credentials divide opinions among the respondents. 17-25% of the respondents do not see value in digital credentials by completely disagreeing with the value statements 2-6 and 9, and completely agreeing with statement 7. Results are on one hand encouraging in terms of taking the digital credentials into use in HE, and even within master's level (EQF-7) MOOCs. This also encourages to develop and test options for micro-learning with digital credentialing in both degree and open learning in addition to their use in MOOC courses. One the other hand, as opinions are clearly divided on the value of digital credentials, further studies are needed to identify the appropriate application contexts and models for digital credentialing, and what factors affect the perceived value of digital credentials.

Passing a mini-exam was the prerequisite for applying for a related nanocredential. Mini-exams were felt to give feedback on own learning (78%, statement 1), testing own knowledge on the basics of a theme (78%, statement 11), as well as were perceived as meaningful on the basics of a theme (81%, statement 10). Over half of the respondents agreed, that the requirement level of the mini-exams was suitable (69%, statement 8). On the contrary, over half of the respondents agreed that the mini-exams were too easy (58%, statement 12). This clearly raises a development need for the future implementations – what is the suitable requirement level for a mini-exam and how to design the micro-learning entities with nanocredentials overall from the learning objectives to the ways of assessment and assessment criteria. On the other hand, the engagingness and motivational value of digital credentials, especially regarding nanocredentials, needs to be carefully considered.

Table 2. Perceptions on value of digital credentials and related mini-exams on 6-point Likert scale (1 = strongly disagree, 6 = strongly agree; N = 36). Statements with white background are on digital credentials, and with grey background on mini-exams.

	Mdn	min	max	1	2	3	4	5	6

1.Mini-exams give me feedback on my learning.	5	1	6	6%	8%	8%	20%	22%	36%
2.Digital credential shows increase of my competence.	4.5	1	6	17%	5%	14%	14%	22%	28%
3.Getting a digital credential encourages to continue learning.	4	1	6	17%	14%	11%	11%	22%	25%
4.Digital credential shows the competence I have gained.	4	1	6	22%	3%	17%	11%	28%	19%
5.Getting a digital credential is motivating.	4	1	6	22%	9%	8%	14%	25%	22%
6.Getting a digital credential for completing the course is meaningful to me.	4	1	6	25%	8%	8%	20%	8%	31%
7.I am not at all interested in the digital credentials.	2	1	6	28%	25%	5%	14%	11%	17%
8.Mini-exam to show the competence gained related to the basics of a theme was at a suitable requirement level.	4	1	6	6%	8%	17%	22%	33%	14%
9.Meta-credential given for the course completion is encouraging.	4	1	6	17%	8%	3%	25%	22%	25%
10.Mini-exam on the basics of a theme is meaningful.	5	1	6	11%	3%	5%	22%	31%	28%
11.Mini-exam tests my knowledge on the basics of a theme.	5	1	6	11%	3%	8%	22%	25%	31%
12.Mini-exam was too easy.	4	1	6	8%	14%	20%	31%	8%	19%

5 SUMMARY

We developed and tested an initial framework for digital credentials to be used within MOOC course implementations at a HEI. We aimed at a modular course structure within which the successful completion of thematic microlearning entities would result in nanocredentials that could be stacked to equal a microcredential, e.g., equivalent to a 1 ECTS entity. We also included an option for students to apply for a meta-credential on successful completion of the 5 ECTS course. The number of applications for open badges showed that students were interested in the badges both on the implemented nano- and metacredential levels. The results of the online questionnaire confirmed the interest. Furthermore, most questionnaire respondents found getting the digital credentials as open badges motivating and encouraging, and showing their competence. However, opinions were divided, and about one fifth of the respondents reported to see no value in digital credentials. The mini-exams were felt to be meaningful, give feedback on own learning, and testing basic knowledge on the theme, but they were perceived to be too easy.

The results indicate that including microlearning components with nanocredentials to a MOOC course is a promising approach in continuing education and life-long learning worth further development, testing, and studying, also to better understand the factors that affect the perceived value of digital credentials. Furthermore, microlearning seems to offer future potential as HEI offering. Microlearning units can, for example, be offered separately or as small entities to support adult learners own learning goals and objectives in up- and reskilling for new work-life competencies. The modularity in designing the course implementations in connection with microlearning and digital credentials offers an opportunity to increase the effectiveness and engagingness of providing different types of learner groups offerings that suit their needs.

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REFERENCES

Abramovich, S., Schunn, C. and Higashi, R.M. (2013). “Are badges useful in education? It depends upon the type of badge and expertise of learner”. *Educational Technology Research and Development*, 61(2), pp.217–232.

Brauer. S., (2020). “Digital open badge-driven learning - a doctoral thesis summary.” *Education in the North*, 27(1) pp. 148-156. https://doi.org/10.26203/gzee-4m08

Digivisio (2022). Modularity and curricular collaboration. Available at: https://digivisio2030.fi/wp-content/uploads/2023/04/2022-Digivisio-Modulaarisuus_ja_OPS-yhteistyo-raportti_en.pdf

European_Commission. (2020). Final Report: A European Approach to Micro-Credentials. Output of the Microcredentials Higher Education Consultation Group. Available at: https://education.ec.europa.eu/sites/default/files/document-library-docs/european-approach-micro-credentials-higher-education-consultation-group-output-final-report.pdf

Kiiskilä, P., Kukkonen, A. & Pirkkalainen, H. “Are Micro-Credentials Valuable for Students? Perspective on Verifiable Digital Credentials”. *SN COMPUT. SCI.* **4**, 366 (2023). https://doi.org/10.1007/s42979-023-01797-y

Smith, C., & Kalman, A. (2023). How Can Continuing Engineering Education Approaches Meet Societal And Industry Needs For Future-Focused, Lifelong Learning Skills And Competences? Proceedings of European Society for Engineering Education (SEFI). DOI: 10.21427/6VN5-HF41

Unesco (2018). Digital Credentialing – Implications for the recognition of learning across borders. Available at:

Varadarajan, S., Koh, J.H.L. and Daniel, B.K. (2023). A systematic review of the opportunities and challenges of micro-credentials for multiple stakeholders: learners, employers, higher education institutions and government. *International Journal of Educational Technology in Higher Education*, *20*(1), p.13. https://doi.org/10.1186/s41239-023-00381-x

Triggering students' lifelong learning competencies through a personal development process – case studies from Belgium, Ireland & Finland

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ABSTRACT

The workplace demands continuous learning to keep up with technological advancements and evolving labour market requirements, emphasizing the importance of lifelong learning (LLL) competencies for engineers. Preparing engineering students for their future career and for LLL is the responsibility of the engineering programmes. To support this, the TRAINengPDP project developed pilot interventions focusing on LLL while using a cyclical personal development process (PDP) based on literature reviews, a perception survey, and an analysis of learning outcomes in engineering programmes. Three diverse interventions were implemented, namely an e-portfolio, a self & peer assessment, and digital storytelling, with each intervention strategically emphasizing different LLL competencies and PDP steps. Student experiences were collected after the pilots using quantitative and qualitative feedback measures. While the e-portfolio fostered pragmatic quality, students desired less time-intensive reflection tasks. Peer & self-assessment interventions prompted behavioural changes and enhanced awareness. Digital storytelling interventions heightened awareness, understanding, and agency among participants. Finally, students' definitions of LLL post-intervention highlighted aspects of lifelong learning, including motivation. Challenges and adaptations for each intervention were identified, underscoring the importance of contextual understanding in implementation. Overall, the interventions showed promise in cultivating LLL competencies, with implications for engineering education's longitudinal integration of LLL and PDP across curricula.

1 INTRODUCTION

Today's workplace is characterized by continuous technological advancements and shifting requirements in the labour market, increasing the need for lifelong learning (LLL) competencies for engineers. By focusing on LLL in the curriculum, engineering students are made aware of the importance of LLL competencies, preparing them for their future as an engineer in the working field (Galanis et al. 2017; Sankaran and Rath 2021). LLL is, however, considered to be a container concept, consisting of a variety of competencies. In their systematic review, Cruz et al. (2019) lists the most frequently used criteria for LLL competencies in engineering: (1) self-reflection, (2) willingness, motivation and curiosity to learn, (3) self-monitoring, (4) locating and scrutinizing information, and (5) creating a learning plan. Lifelong learning is in this review defined as "the intentional and active personal and professional learning that should take place in all stages of life and in various contexts with the aim of improving knowledge, skills and attitudes" (Cruz et al., 2019, p.737).

Although there is clear agreement about the need for LLL and LLL competencies, a previous study showed that LLL competencies are currently not really embedded in the learning outcomes (Beagon et al., 2022, Dujardin et al., 2023). Self-reflection, Willingness, Motivation and Curiosity to learn, and Creating a Learning Plan were the least represented in the learning outcomes of the reviewed engineering programmes and are therefore the priority competencies to be developed. In addition, the presence of LLL competencies is mostly limited to the first and final year of the engineering study programme. Hence, there is value in developing separate pilot projects at Bachelor and Master level as the focus of competence development changes significantly within each programme.

Since learning outcomes are not always a perfect representation of what goes on in the lecture hall and in the minds of students (Armstrong and Niewoehner 2008; Maher 2004; Orón Semper and Blasco 2018), a survey to capture engineering students' and lecturers' perceptions about LLL competencies was distributed (Authors 2023). The results of the survey indicate that both students and lecturers find all the different competencies either important or very important. Additionally, the results show that students and lecturers perceived these LLL competencies only taught to a limited extent and evaluated even less (Van den Broeck et al., 2023). When asked about the educational practices in the context of LLL, lecturers believe that (1) Creating an inclusive, safe, and curious environment, (2) Reflective practice, and (3) Self-regulation tools will become crucial in the future. These practices are, therefore, included in the case studies of the current paper.

But how to support the development of students' LLL competencies? A scoping review distinguished four types of LLL interventions (Van den Broeck et al., 2022), namely (1) interventions focusing on self-regulation like (e)Portfolios, (2) reflective journals or reflective practice, (3) student-centred teaching methods like problem-based learning, and (4) the use of peer and self-assessment. Another approach is the use of personal development process as a method to stimulate LLL. The Personal Development Process (PDP) is a more dynamic and interactive adaptation of the popular Personal Development Plan. The latter is a tool in which students give an overview of the competencies they have been working on (looking back) and is planning to further develop (looking forward). Patel et al. (2013) distinguish five steps in this plan: Identify, prepare, act, monitor, and reflect. These five steps can be mapped on Zimmerman's (2000) cyclical self-regulation model: identify and prepare (forethought); act and monitor (performance/volitional control) and reflect (self-reflection). When reviewing the literature on PDP interventions (Van den Broeck et al., 2022), five PDP intervention types are described in the literature: (1) e-portfolios, (2) reflective writing, (3) digital storytelling, (4) progress file interviews – tutor or role play and (5) online resources about PDP. PDP and LLL interventions show considerable overlap, which was expected considering the theoretical overlap between the two concepts. Both literature reviews distinguished interventions with a focus on self-regulation such as e-portfolios and on self-reflection such as reflective journals. LLL interventions can also entail student-centred teaching methods and peer and self-assessment, which were not found in the literature on PDP interventions.

During the TRAINengPDP project, three pilot interventions were developed, implemented, and evaluated. The current paper focuses on (1) how the interventions were designed, specific attention is given to clearly reporting about the characteristics of the interventions, which are often neglected in papers, (2) students' experiences with the intervention, and (3) students' perception on LLL after the intervention. Effectiveness measurements and lecturer feedback are not covered in this current study, but will be analysed in the next phase of the project.

2 METHODOLOGY

The methodology part consists of a section to elaborate on the different intervention designs. A second section provides more information about how students' experiences with the interventions were captured and the final section describes how students' perception on LLL was analysed.

2.1 Intervention design

Based on the analysis of learning outcomes, survey results, and literature review, three pilot interventions for the different institutions were designed. Table 1 provides an overview of the different pilot characteristics and Table 2 gives a more detailed description of how the different LLL competencies and PDP steps are embedded in the pilots.

2.1.1 Pilot – Belgium (KU Leuven)

The pilot interventions are carried out on the first-year engineering students at Flemish University. The use of an e-portfolio is embedded in the course Engineering Experiences (9ECTS) in which challenging and authentic assignments are implemented thanks to the integration of the competencies acquired in other courses. Both technical and professional competencies need to be addressed as will be the case later on in professional practice. The portfolio focuses on students' professional competencies, their strengths, weaknesses, and interests.

2.1.2 Pilot – Ireland (TU Dublin)

The pilot interventions are carried out on the first year of a General Entry Engineering Level 8 (Ireland NFQ, EFQ=Level 6) programme at Irish University. The first year typically has 160 students who are separated into four groups of 40, to undertake a Design Project Module over semester 1 and 2. The Design Project module has 10 ECTS, but includes 3 projects, Electrical and Electronic Engineering (Robosumo = 5 ECTS), Mechanical Engineering Energy Cube (2.5 ECTS) and Civil and Structural Bridge Design (2.5 ECTS). The intervention will take place within the Civil and Structural Bridge Design project for each group of 40 students. The project already contains aspects of good practice in relation to LLL competencies, so the pilot projects will focus on bringing explicit attention to specific LLL competencies and embed this in the current student-centred teaching method. The pilot intervention also consists of the use of peer- and self-assessment with emphasis on specific LLL competencies.

2.1.3 Pilot – Finland (LUT University)

The pilot intervention was carried out on a master level engineering course module related to research planning and methods. The intervention was voluntary and students gained extra points which were counted towards their final course grade. The pilot was introduced in the last lecture of the module after which students had four weeks to produce and submit their digital stories. The pilot aimed at the improvement of students' reflection skills and students were instructed about digital storytelling with a collection of materials in the course module learning management platform.

Emphasis on LLL & PDPTable 2 gives a more detailed description of how the different LLL competencies and PDP steps are embedded in the pilots. To develop diverse interventions, it was decided to use different approaches for the three pilot interventions:

(1) The e-portfolio intervention aimed to encompass all the different PDP steps, as described by Patel et al. (2013), since the cyclical aspect was determined as a valuable advantage of an e-portfolio. Specifically, three LLL competencies: creating a learning plan, self-monitoring, and self-reflection, were intentionally incorporated to reinforce the cyclical aspect.
(2) In the self & peer assessment intervention explicit emphasis was placed on two specific LLL competencies (willingness, motivation, and curiosity to learn, and locating and scrutinizing information) by systematically going through the different PDP steps.
(3) The digital storytelling intervention prioritized the LLL competency of self-reflection and the PDP step of reflection. By focusing on the act of reflection itself, students were prompted to critically evaluate their experiences.

Table 1. Pilot characteristics

Characteristics	**Belgium**	**Ireland**	**Finland**
Intervention Type	e-portfolio	Peer and Self-assessment	Digital storytelling
LLL or PDP focus	LLL & PDP intervention	LLL intervention	PDP intervention
Target Group	First-year engineering students (n=80)	First-year engineering students (n=40)	2nd year M.Sc. (eng) students (electrical engineering & energy technology) (n=90)

Duration	12 weeks (explanation in a lecture, filling the portfolio in three times during the semester)	6 weeks (explanation in first lecture, self-assessment of two LLL competencies, including it in the team charter)	4 weeks (one-time intervention with 4 weeks to complete)
Extra/intra curricular	Intra curricular	Intra curricular	Intra curricular
Course/Cross curricular	Cross-curricular	Embedded in course	Embedded in course
Voluntary/Obligatory	Obligatory	Obligatory	Voluntary
Feedback from lecturer	Yes	No	No
Part of course assessment	Yes	Yes	Bonus point
Individual/Team task	Individual	Individual & team	Individual
Explicit/Implicit PDP	Explicit	Explicit	Explicit
LLL competencies	Creating a learning plan, Self-monitoring, Self-reflection	Willingness, Motivation and Curiosity to Learn; Locating and Scrutinising Information	Self-reflection

Table 2. Detailed description of PDP steps in pilot intervention

PDP steps	E-portfolio	Self & peer assessment	Digital storytelling
Identify	Self-assessment: first assess your own ability for the competencies below (communication, social competencies, self-management, innovative thinking). Then choose one to focus on during the project.	Self-assess individual ability for the two LLL competencies identified.	
Prepare	Creating a learning plan: Discuss the reason for your choice and a proposal of specific approach to develop this competency.	Develop team charter with group and identify individual roles. Think about how the two LLL competencies could be developed during the project.	
Act	Act on the learning plan	Work through project and assess how LLL competencies are being developed.	
Monitor	Self-monitoring; Peer and self-assessment	Peer and self-assessment	

Reflect	Self-reflection after peer feedback: Select one competency and discuss your response to the feedback received (this can be from your peers, coach, or technical expert), What specifically had you paid attention to regarding this competency? Did the others notice? Was there something you could have done differently? What specifically will you do to further develop this competency?	Complete Team Charter and assess how individual performed with respect to the competencies identified. - Willingness, Motivation and Curiosity to Learn (Are you motivated to learn new things by yourselves?) -Locating and Scrutinizing Information (How do you find and examine information to help progress the project?)	Self-reflection in the end of the course "How the course X has affected you as an engineering student and future engineering professional"

2.2 Students' experiences

In order to capture students' experiences with the interventions, a combination of quantitative and qualitative measurements was employed, tailored to the nature of each pilot. Given the necessity to maintain students' willingness to share their experiences, the questionnaire format was kept concise, considering that students also completed pre- and post-tests to gauge the effectiveness of the interventions (not included in this paper).

2.2.1 E-portfolio

The User Experience questionnaire (Laugwitz, Held, and Schrepp 2008) was used to make a quantitative assessment of students' experience with the e-portfolio. This questionnaire uses bipolar items ranging from -2 to 2 and consists of six factors. A subset of four factors was used because they respond the most to our concerns. Firstly, the items from the *attractiveness* factor are included to estimate the students' general feeling towards the e-portfolio. Secondly, the factors *perspicuity, efficiency* and *dependability* are included because they measure the pragmatic quality of the e-portfolio, which gives us insight in if the e-portfolio was easy to use. The factors *Novelty* and *Stimulation* were not used.

Additionally, students were given a list of possible changes to the e-portfolio and asked to select three and rank them. To analyse this data, each response was given a score (not chosen = 0; rank 3 = 1; rank 2 = 2; rank 1 = 3) and these were added up to a final score for each of the possible changes. How higher the final score, how stronger the students feel that this change should be made.

2.2.2 Peer & Self-assessment

Students were asked to answer one open-ended question regarding their experience with the intervention: *"We asked you to add two competencies to your team charter*

'Willingness, motivation and curiosity to learn' and 'Locating and scrutinizing information". How did you feel about this? Did it have an impact on how you engaged in the project?"

Their answers on this question are categorized in the following categories: awareness, understanding, agency, behaviour, or not applicable (NA).

2.2.3 Digital storytelling

Students were asked to answer one open-ended question regarding their experience with the intervention: *"Which benefits (besides the extra points towards the course grade) did you receive from doing the task?*

Their answers on this question are categorized in the following categories: awareness, understanding, agency, behaviour, or not applicable (NA).

2.3 Capturing students' perception on LLL

Students were also asked to give their definition of LLL after the interventions. The answers of the students are analysed according to the LLL competencies: (1) self-reflection, (2) willingness, motivation and curiosity to learn, (3) self-monitoring, (4) locating and scrutinizing information, and (5) creating a learning plan. The results were compared to determine if there are differences between the year of study (First year and Master students), and the intervention type (i.e. focus on specific competencies more present in students' definition).

3 RESULTS

3.1 User-feedback

3.1.1 Quantitative measures from e-portfolio pilot

Regarding the *attractiveness* of the e-portfolio the mean was lower than the midpoint of the scale of 3 (M = 2.41; SD = .71). However, the pragmatic quality is above the midpoint of the scale (M = 3.16; SD = .82). The students' ranking of possible changes of the e-portfolio can be found in Table 3. How higher the final score, how stronger the students feel that this change should be made (see 2.1.2. for score calculation details).

Table 3. Ranking of changes pilot

Change	Score
Less time intensive	22
Less reflection questions	19
More questions about professional competencies	17
Having to fill in less often	16
More feedback	15
Less frequently having to assess competencies	12
Faster feedback	10

More information about the grades	10

3.1.2 Qualitative measure from Peer & self-assessment and Digital storytelling pilot

A total of 15 students from the Finnish pilot and 13 of the Irish pilot answered the open-ended question regarding their experience with the intervention. The results of the analysis are in included in Table 4. The students in the Digital storytelling pilot report, equally distributed, an impact on their awareness (27%), understanding (27%), and agency (27%) after participation in the intervention. An impact on the students' awareness is the most present in the answers of the students in the peer & self-assessment intervention (31%). Notably, in the peer & self-assessment pilot, 23% of the respondents report an impact on their behaviour after participation in the intervention.

Table 4. Categorisation open-ended questions

Categorisation	Finland - Digital storytelling	Ireland - Peer & self-assessment	Total
Awareness	4 (27%)	4 (31%)	8 (29%)
Understanding	4 (27%)	2 (15%)	6 (21%)
Agency	4 (27%)	3 (23%)	7 (25%)
Behaviour	1 (7%)	3 (23%)	4 (14%)
NA	2 (13%)	1 (8%)	3 (11%)

3.2 Analysis of LLL definitions

All of the students who responded on the question what LLL means to them, provided at least a basic definition or understanding of LLL. When linking this to the earlier given definition "the intentional and active personal and professional learning that should take place in all stages of life, and in various contexts with the aim of improving knowledge, skills and attitudes" (Cruz et al., 2019, p.737), students indeed mentioned time related aspects in their definitions such as: "learning every day", "lasts for life", and "never stops". Some students also directly link it to the professional context (e.g. "for my career", "during my job") whereas others look at LLL in a broader way (e.g. "personal development", "learning from life experiences"). A vast majority of the Finnish students (73%) mentioned an aspect of willingness, motivation or curiosity in their definition, in comparison to only a smaller group of the other two pilots, both with first-year students (23% and 30%). In the Irish pilot, 15% of the students also defined self-monitoring as an aspect of LLL. The Belgian students mentioned the least LLL competencies, but two of them mentioned both self-monitoring and self-reflection in one definition, which are two of three elements of the cyclical approach of PDP.

Table 5. Students' LLL definitions

Analysis definitions	Total LLL definitions (N)	willingness motivation curiosity (N)	self-monitoring (N)	self-reflection (N)
Belgium	17	4 (23%)	2 (12%)	2 (12%)
Finland	15	11 (73%)	1 (7%)	1 (7%)
Ireland	27	8 (30%)	4 (15%)	0 (0%)

4 DISCUSSION

The pilot interventions are promising; however, an extensive approach is required to successfully support students in the development of LLL competencies and guide them through the PDP. This approach entails integrating various embedded interventions not only within a specific course but also across the curriculum. Students have to be reminded of the existence and importance of LLL and PDP in different contexts and at different times throughout their curriculum. An e-portfolio has the potential to be used as a longitudinal and cross-curricular intervention. However, along with these substantial and longitudinal interventions, LLL competencies can also be triggered by making small tweaks to the curriculum to make LLL and the LLL competencies more explicit.

Student-centred teaching methods such as problem-based learning are embedded in plenty of engineering programmes and are a perfect environment to make the LLL competencies more visible. Students tend to see the value of these methods for their further career, possibly making it easier to introduce the LLL competencies in this context. Additionally, student-centred teaching methods in the engineering context often include multiple assignments where LLL and PDP can be introduced (team charter, peer-assessment, …) and often span over multiple weeks allowing for a longitudinal implementation. For example, in the Irish pilot the LLL competencies were made more explicit in the already used peer and self-assessment.

When implementing an intervention, understanding the context is crucial. While all interventions offer substantial benefits, it is essential to also acknowledge their drawbacks. The e-portfolio requires support from educators in guiding the students and providing feedback. This can be a daunting task without experience with PDP and LLL. With the use of a feedback rubric, the time for giving feedback to an individual student was approximately 15 minutes for one semester. The e-portfolio, and other interventions such as a reflective essay, require students to write about their thoughts, behaviour and sometimes also their emotions. As can be seen in the results of the ranking question, engineering students are not always a fan of self-reflection and they can encounter difficulties in writing reflections. A possible adaptation to the e-portfolio could be to to submit their self-reflection in a different format, similarly to what was done in the Digital storytelling pilot. Although not applicable to the current pilot, a challenge with the digital storytelling intervention would be that the diverse formats make it challenging to assess. Nevertheless, using digital storytelling allows students to be creative, which is also an important trait for an engineer. Although peer & self-assessment is already commonly used, with having the advantages of being embedded in a course, of including all types of competencies, and of partly replacing lecturers' feedback, it also has the risk of being influenced by team dynamics or social desirability. Using the peer & self-assessment in the project-based course in Ireland resulted in a direct impact on students' behaviour (23%), according to their experiences.

When looking at how students define LLL, some differences were noted. The majority of students from Finland mentioned an aspect of willingness and motivation in their definition on LLL. This can be explained by the fact that the pilot was voluntary and that the students are master students. Consequently, it could be that the participants were already intrinsically more motivated, more prepared for LLL, or more aware of what it means. Two specific LLL competencies were not included in the students' definition, namely creating a learning plan and locating and scrutinizing information. This could be explained by the fact that these are the two most specific LLL competencies and that definitions are kept more general.

5 SUMMARY AND ACKNOWLEDGEMENTS

LLL is crucial in preparing engineering students for the dynamic demands of the contemporary workplace. PDP emerges as a promising way to foster LLL, offering a cyclical approach that aligns with the iterative nature of learning. Explicitly including LLL competencies in learning outcomes of engineering programmes enhances their visibility and importance. Selecting interventions tailored to specific contexts enables targeted competency development, addressing the unique needs of students and programmes. While longitudinal interventions are essential for sustained impact, smaller tweaks in curricula can also yield significant benefits and employing a combination of interventions allows for a multifaceted approach to LLL.

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REFERENCES

Armstrong, Perry, and Robert Niewoehner. 2008. “The CDIO Approach To the Development of Student Skills and Attributes.” *2008 4th International CDIO Conference, Hogeschool Gent, Belgium*.

Beagon, U., Byrne, A., Depaor, C., Van den Broeck, L., Dujardin, R., Craps, S., Naukkarinen, J.. “Lifelong Learning competencies in Engineering Programmes – Heat Map Report.” Available on the TRAINengPDP project website (2022).

Dujardin, R., Van den Broeck, L., Craps, S., Beagon, U., De Paor, C., Byrne, A., Langie, G. 2023. Lifelong Learning as Explicit Part of Engineering Programmes: A Case Study. In: Proceedings of the 19th International CDIO Conference, (Paper No. 181), (902-912). Presented at the CDIO, NTNU, Trondheim, Norway, 26 Jun 2023-29 Jun 2023. ISBN: 978-82-303-6186-3.

Cruz, M. L., Saunders-Smits, G. N., & Groen, P. “Evaluation of competency methods in engineering education: a systematic review.” *European Journal of Engineering Education* 45,5 (2019): 729-757.

Galanis, Nikolas, Enric Mayol, Maria José Casañ, and Marc Alier. 2017. “Towards the Organization of a Portfolio to Support Informal Learning.” *International Journal of Engineering Education* 33 (2): 887–97.

Laugwitz, Bettina, Theo Held, and Martin Schrepp. 2008. “Construction and Evaluation of a User Experience Questionnaire,” 63–76.

Maher, Angela. 2004. “Learning Outcomes in Higher Education: Implications for Curriculum Design and Student Learning.” *The Journal of Hospitality Leisure Sport and Tourism* 3 (2): 46–54. https://doi.org/10.3794/johlste.32.78.

Orón Semper, José Víctor, and Maribel Blasco. 2018. “Revealing the Hidden Curriculum in Higher Education.” *Studies in Philosophy and Education* 37 (5): 481–98. https://doi.org/10.1007/s11217-018-9608-5.

Sankaran, Meenakshi, and Amiya Kumar Rath. 2021. “Assessing Undergraduate Engineering Programmes Using Alumni Feedback.” *Journal of Engineering Education Transformations* 34 (Special Issue): 733–41. https://doi.org/10.16920/jeet/2021/v34i0/157174.

Van den Broeck, L., Dujardin, R., Craps, S., Beagon, U., de Paor, C., Byrne, A., Naukkarinen, J. (2023). Students' and lecturers' perceptions on the importance, training, and assessment of professional and lifelong learning competencies. In: 51st Annual Conference of The European Society for Engineering Education, (Paper No. 117). Presented at the SEFI, TU Dublin, Dublin Ireland. doi: 10.21427/0SKE-QJ24

Van den Broeck, L., Craps, S., Dujardin, R., Beagon, U., Byrne, A., dePaor, C., Naukkarinen, J. (2022). “Literature review on Personal Development Process (PDP) and Lifelong Learning (LLL) interventions”. TRAINeng- PDP project

PRELIMINARY INSIGHTS INTO AI AND ENGINEERING EDUCATION IN THE US AND UK: AN EXPLORATORY STUDY

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Conference Key Areas: *Digital tools and AI in engineering education, Building the capacity and strengthening the educational competencies of engineering educators.*
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ABSTRACT

This exploratory study investigates the integration of Artificial Intelligence (AI) in undergraduate engineering education in the US and UK by focusing on engineering academics' perceptions from two prominent universities in each country. Responses were collected from three academics through semi-structured interviews, and these responses were organised into four key themes: AI curriculum integration, faculty perceptions of AI, ethics and biases in AI education, and interdisciplinary AI topics.

The preliminary findings, which were compared to those from prior research, suggest a mix of caution and optimism towards AI regarding pedagogical innovation, highlighting the need for responsible AI usage. The study highlights various pedagogical practices for AI in engineering, from explicit AI-focused material to the use of AI tools in assessments and projects. In addition, some of the academics interviewed mentioned the significance of project-based learning (PBL) in teaching AI topics to engineering students due to its ability to foster hands-on learning and real-world problem-solving skills. Furthermore, the study found that there is a growing demand by students for AI-related engineering topics or 'AI-engineering' to be incorporated into traditional engineering classrooms, implying a need for curricula development to meet future industry needs.

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These insights provide a foundation for further research and aim to inform current engineering educators on how they can generate strategies for incorporating AI into undergraduate engineering curricula. This study lays the groundwork for future research to explore how AI can be integrated into engineering education so that educators can bridge the gap between current demand and future practices.

1 INTRODUCTION

1.1 Overview

The research described in the paper delves into the perceptions of undergraduate engineering faculty members and students in the US and UK regarding Artificial Intelligence (AI) in their curricula. Specifically, the project explores how these perceptions impact their career choices post-graduation and if students are aware of biases in AI. It focuses on current undergraduate or Generation Z students, as this generation is currently entering a workforce heavily influenced by AI technology. Most current undergraduate students belong to Generation Z or Gen-Z, defined as those born after 1995 (Seemiller and Grace, 2016). The definition of AI that will be utilised throughout the project comes from Russell, Stuart, and Norvig (2016), as it captures the interdisciplinary nature of the AI technologies discussed.

As engineering programmes incorporate AI modules into their curricula (AI-engineering), it is crucial to understand how these topics are being taught to Gen-Z engineering students, whether they recognise the biases embedded in AI technologies, and whether these students are interested in pursuing a career in AI. For the first phase of my thesis, I interviewed six faculty members from two universities, one in the US and the other in the UK.

For this exploratory paper, I will discuss the responses of three of the six academics interviewed. My preliminary findings indicated that faculty members' attitudes toward integrating AI into the curriculum varied significantly across all six academics. However, the three academics chosen for this paper had particularly unique positionings based on how much they interacted with AI within engineering education.

1.2 US and UK: Motivations for Innovation

The intersection between global economic competition, technological innovation, and the rise of AI, particularly within the fields of Science, Technology, Engineering, and Mathematics (STEM), positions AI-related engineering or ‘AI-engineering’ education in the US and UK at a critical time for maintaining the two countries’ historical leads when it comes to technological advancement. This calls for exploring national policies that promote innovation for economic growth and societal advancement (Kennedy and Odell 2014; Liu 2022) to improve both countries' current engineering and AI contexts.

At the same time, as highlighted by (Chu, Tu, and Yang 2022), the use of AI in higher education has also become more prevalent in recent years– specifically among undergraduate, engineering, and Gen-Z students across a variety of subjects– calling for the importance of understanding how current engineering faculty are even more imperative

In the US, the science, technology, and innovation (STI) policy, under which AI would fall, has been intricately linked with political decisions that often dictate the direction of funding for technological advancements (Liu 2022). This has revealed a historical trend where the funding for large-scale projects has been influenced by governmental interests– reflecting the country's consistent challenge of aligning scientific progress with political interest.

In 2020, in the UK, the government published its 'Research and Development Roadmap' highlighting the various issues and policies the country aimed to tackle by 2025 (UK Government 2020), for example, the lack of long-term funding, which has hindered essential projects due to the government not allowing researchers enough time to complete their projects. As opposed to countries like the US, where the majority of technological funding is privately sourced, the UK government has noticed that British businesses presently invest less in STEM when compared to other Western nations and hopes to console this by seeking international investment.

1.3 AI in Undergraduate Engineering Education

The above-mentioned motivations for AI innovation, in the US and UK, led me to decide that the prevalence of AI in engineering curricula was an important topic for exploration. A review of AI in higher education conducted by (Crompton and Song 2021) identified undergraduate computer science and engineering students as having significant exposure to AI compared to other degree subjects. Another systematic review conducted by (Crompton and Burke 2023) showed the growing interest in AI applications for teaching, specifically in computer science and engineering, and outlined the diverse roles AI plays in assessment, prediction, and personalised learning.

It could be argued that the AI profiles and motivations for AI innovation for both countries can be summarised as such: the US's desire to maintain the lead in technological innovations and the UK's goal to be on par with the advancements of similar countries serve as the two countries' main incentives to rise in order compete with Asia's– specifically China's (Lee 2018)– massive AI investments for both national prestige and increasing AI human capital. These drivers have resulted in AI being more prominent in engineering and computer science education, as literature has supported. As a result, this paper will focus on the perceptions of academics currently working in the US and UK contexts to learn more about how they navigate AI-engineering education with their Gen-Z students.

2 METHODOLOGY

2.1 Positioning Within Project

To understand how the integration of AI in engineering curricula is perceived by AI-engineering academics, with the US and UK AI-engineering contexts in mind, individual interviews were conducted with engineering faculty before interacting with the student participants. This was done to gain a better idea of the current state of AI and engineering at both universities, in addition to learning which programmes are viable for recruiting student participants. The faculty interviews also provided further insight into current student perceptions about AI and whether their students have expressed confidence in working with AI after undertaking the proposed recruitment modules.

2.2 Participant Recruitment

The academics were initially contacted through email to conduct the interviews and they were discovered using online university engineering department directories which summarised their teaching and research interests. The faculty members who expressed interest were sent scheduling links through Microsoft (MS) Teams along with the decided date and time, the consent form, and participant key information sheets for them to complete before the interview. Before starting the interview, participants were also informed that the interview would be audio-recorded and transcribed.

2.3 Interview Structure and Analysis

As this phase of the data collection was an opportunity to develop questions for the forthcoming survey and individual student interviews, semi-structured interviews were conducted with academics to allow for new topics and themes to be addressed in the next phases of the study. Kallio et al. describe the semi-structured interviews as “... conducted conversationally with one respondent at a time, the semi-structured interview employs a blend of closed- and open-ended questions, often accompanied by follow-up why or how questions" (Kallio et al. 2016, 493). The authors also mention how this style of interviewing allows the interview to meander around various topics as opposed to a standardised open-ended interview where a set number of questions are asked to the participants in the same order. Semi-structured questions also allowed for exploring ideas that were not previously considered for the thesis– allowing it to have a greater breadth.

A pool of 32 open-ended questions was developed and conversationally delivered to the faculty members at both universities. The six academics interviewed were anonymised by labelling them Academic A, Academic B, Academic C, Academic D, Academic E and Academic F. The interviews were structured in three sections and the participants were debriefed on how the interview would be conducted. The first section (1) related to general thoughts on AI before going on to AI and teaching (2) and concluding with AI and students (3).

I reviewed the transcripts generated from MS Teams and marked the recurring topics and issues that were discussed by the academics during the interviews. Then, I created mind maps to identify the possible relationships and connections between these topics. As a result of this analysis, I developed six themes based on the responses of the six academics, out of which four will be discussed in this paper.: **Theme One:** *AI Curriculum Integration and Pedagogical Approaches*, **Theme Two:** *Faculty Perceptions and Interactions with AI in Higher Education*, **Theme Three:** *Ethics and Biases in AI Education*, and **Theme Four:** *Interdisciplinary AI Topics and Demand for AI Education*

As mentioned in the introduction, six academics were interviewed for the thesis. The three participants chosen for this paper are Academic A, Academic C, and Academic E. The three academics were chosen for analysis due to their unique roles in AI-engineering education due to the different ways they interacted with AI. Table 1 describes the three academics who were chosen and their roles:

Table 1. Faculty Participants Overview

Academic	Country	Discipline	Role in AI Engineering Education

A	US	Robotics Engineering	Explicitly teaches AI modules, at both an introductory and advanced level for undergraduate students
C	UK	Chemical Engineering	Does not teach AI explicitly but utilizes AI for grading assessments and for showing students how to use AI tools
E	UK	Mechanical Engineering	Supervises AI-related student projects and is currently developing an AI module for engineering students

The main messages that emerged from these interviews for each theme were also shown in Table 2, so that major findings could be visually represented and summarised in a table for ease of interpretation.

2.4 Theme One: AI Curriculum Integration and Pedagogical Approaches

Academic A:

"... the courses I teach are AI courses—not necessarily robotics courses. There are two courses I teach…one is an introductory course… it is kind of a ... broad overview of AI, and the other is a senior-level course that is…more advanced AI tools for autonomous agents."

"The advanced course is a project-based course, a group-based, project-based course... the introductory course is... individual programming and written assignments. Both of them have final exams, but the bulk of the learning is done through assignments… programming-based assignments."

Academic C:

"No, I don't teach AI explicitly... it comes in at least for me mainly when it comes to assessment... I bring that (AI) in to show students how they might use certain AI tools to help them... that's really probably as far as it goes."

Academic E:

"In the projects that I propose for the third year… students are mainly data analysis and machine learning. So, I supervise students on projects that they use machine learning... I don't teach modules that are machine learning if that makes sense."

"For the AI topics that I interact with at the moment, they are projects. So, you have third year projects which is an individual year-long project...students do this project all year long and at the end they need to submit a report... have a presentation... it's not like lecture, lecture, exam... it's about regular meetings and their responsibility to pull off the project."

Findings:

The context for the deployment of AI in all three of the academics' cases was project-based learning (PBL). CDIO defines PBL in engineering education as "…an instructional method in which students learn a range of skills and subject matter in the process of creating their own projects. Sometimes, these projects are solutions to a real-world problem. But what is most important in project-based learning is that students learn in the process of making something. They work in groups and bring their own experiences, abilities, learning styles and perspectives to the project” (CDIO Initiative, “What is CDIO?”).

Academic A explicitly used PBL in their advanced AI module through project-based group projects, e.g. requiring students to complete large, programming-based projects in groups. Academic E oversaw projects that encouraged students to use AI in a practical way– similarly to how it would be used in an engineering workplace– by incorporating machine learning and data analysis. However, Academic C’s use of AI tools is rather different from the other two. Academic C shared a more implicit use of PBL by demonstrating how AI tools could be used for some assignments, e.g. showing students how to use an AI chat engine to generate an outline for an essay. This aligns with how Díaz Lantada discusses how PBL should evolve with technology– namely AI– within a modern engineering education framework, stating, “the employment of artificial intelligence tools for supporting educational practice” is just one of the ways engineering educators can use technology to support student understanding (Díaz Lantada 2022, 5).

These findings of the academics implementing AI in different ways also align with those found by (Zawacki-Richter et al. 2019), who explored the various ways AI is currently being implemented across higher education and emphasised the need for flexibility when it came to catering to AI in different educational contexts. However, as (Adeyeye and Akanbi 2024) found, as useful as diversification is to ensure AI engineering can be implemented in different contexts, without the collaborative efforts of educational institutions, AI developers, and policymakers, the full potential of AI in engineering may never be reached.

2.5 Theme Two: Faculty Perceptions and Interactions with AI in Higher Education

Academic A:

"...I think it (AI) is going to have a very large impact on education, both in terms of the tools that people can use, such as CoPilot for computer science…ChatGPT… in terms of personalising education... things like smart tutors and being able to personalise the types of education that you get in terms of… personalised exams or personalised assignments that can be automatically generated.”

Academic C:

“Yeah, so recently what I've gone and done is I've gone and... kind of made a draft of a coursework using AI to show the students the quality that they get out of it. If they did choose to go down that road..."

“It's, I think, as with a lot of things it is useful. Dangerous if misused. I think I perceive it one way as an educator or as... for my personal use, and I perceive it another way when applied to how I teach students.”

Academic E:

"It's a tool that should ease a lot of our tasks... we need to benefit from it. We need to learn how to use it... especially in higher education... we need new guidelines… we can’t ignore these tools... these tools are a part of our lives whether in academia or… industry… or even our personal lives. So, we need to embrace them. But we need to know how to control them, or we need to know how to use them.”

Findings:

The academics agreed that AI will significantly impact engineering education, and Academic C and Academic E emphasised its responsible use. Furthermore, they highlighted the dual nature of AI's role: as a personalised tool to teach students engineering topics and as a pedagogical tool for providing feedback. In addition, their perspectives differed in tone regarding the different applications of AI in engineering education. Academic A suggested AI could lead to personalised learning experiences– sharing an optimistic viewpoint for future students. Conversely,

Academic C and Academic E suggested a more cautious approach and even highlighted how AI is still at an experimental or introductory stage in engineering education– similar responses were also found in several previous studies. For example, (Mandal and Mete 2023) found that while educators understood the benefits of AI in the higher education workplace– such as simplifying administration tasks– they were also aware of issues concerning data privacy. Similarly, (Slimi 2022) found that while faculty members appreciate the efficiency AI can offer, they are still concerned about what over-reliance on AI can bring and the 'human' elements in teaching that can be lost due to its implementation in the classroom.

2.6 Theme Three: Ethics and Biases in AI Education

Academic A:

"…so, in a machine learning course, we'll talk about…bias and privacy...the course I have in autonomous agents, we focus on human autonomy and liability of the autonomous system… so yeah, the different courses take different aspects of… ethical dilemmas that... AI engenders and tries to look at things in that specific lens…"

Academic C:

"…we also show them or give them examples of… where there are biases with information that is generated…especially because a lot of the information generated is from, say Western society. And that they may be missing out perspectives of, you know, the wider world…so we do touch on that as well."

Academic E:

"… it's technical for sure; students need to know what each algorithm does and the math behind each algorithm… I think the technicalities are important…"

Findings:

Evidently, the academics had very different views about AI and ethics issues. Two broad views were identified– AI and ethics as a module topic and AI and ethics as a passing issue in a module. This is evident in the responses, with Academic A being the only faculty member who mentioned that they explicitly teach ethics and biases surrounding AI alongside technical topics, Academic C teaching how AI-generated information can be biased, and Academic E not discussing AI biases at all. Even though Academic A and Academic C do discuss AI biases in their modules, they differed on how they taught these topics– with Academic A discussing bias and ethics issues directly related to the technical topics of the module and Academic C highlighting the importance of recognising biases in AI-generated content in general.

Though the academics interviewed had mixed approaches to incorporating AI ethics and biases into the engineering classroom, the need for these topics to be introduced has been understood by professional and governing bodies in both the US and the UK. In their recent statement of how professional engineers should approach AI ethics, a key policymaking body in the US, the National Society of Professional Engineers (NSPE) stated that engineers should prioritise ethical standards in the development and deployment of AI-engineering technologies (NSPE 2023). Similarly, (UK Government 2020) shared a similar sentiment, more so focusing on the need for AI technologies to benefit society as a whole– which calls those developing it, potentially current engineering students, to be aware of the technology's shortcomings and inherent biases.

2.7 Theme Four: Interdisciplinary AI Topics and Demand for AI Education

Academic A:

"Yeah, definitely (there is student demand for AI topics within engineering)."

Academic C:

"…the demand is there, but the demand is also being met because they have optional modules that they can take…where if they wanted to focus more on AI and other digital tools, they can do that... so yeah… the demand is definitely there and being met as well."

Academic E:

"…because there... have been numerous requests from students…that they are interested in this topic…we thought that it's time now to propose this module…later on we can have an advanced or an intermediate level module…but this module is like an introductory module for machine learning and how to use it… and… the math behind it…maybe later on we …can improve this."

"…very important remark here is that we are a mechanical engineering department…not a computer science department, so… we need to be more focused on the applicability of these algorithms rather than… how complicated these algorithms are."

Findings:

All the academics recognise student demand for AI topics to be taught to them during their engineering degrees, with Academic A having a short response due to them already teaching AI-engineering modules. Academic C mentioned that the demand is also being met by highlighting that students could take optional AI modules outside their degree programmes. Although Academic A and Academic E did not discuss their plans for expanding AI- engineering within their departments, Academic E specifically highlighted how they are introducing a new AI module, which directly responded to students' interest in AI. This academic also mentioned how this new module is engineering-based and focuses on the practical applications of AI for solving engineering problems.

My findings align with a larger survey conducted by (Balabdaoui et al. 2024) to investigate the usage of AI by students at a technical university. Their study, similar to what the academics shared, found that the majority of students expressed a strong desire for AI topics to be further integrated into their technical curricula, calling for current AI tools to be more curated for technical subjects to better supplement STEM topics. Furthermore, the study, which surveyed 4,800 students, found significant demand across technical subjects- with computer science students and engineering students showing the most demand and natural sciences students showing the least, emphasising the interdisciplinary nature of AI student demand in not only engineering as the academics highlighted but a variety of technical subjects.

2.8 Summary of Findings Table

Table 2. Main messages from each theme summarised from the academics' interviews.

Theme One: *AI Curriculum Integration and Pedagogical Approaches*	**Theme Two:** *Faculty Perceptions and Interactions with AI in Higher Education*
• AI integration in engineering education is predominantly project-based. • Different approaches to AI education include structured group projects, individual projects, and the use of AI tools for specific assignments. • Project-based learning (PBL) frameworks are effectively used to teach AI, with students gaining practical skills applicable in real-world engineering contexts. • The findings align with Díaz Lantada's (2022) discussion on evolving PBL with AI and Zawacki-Richter et al.'s (2021) emphasis on flexibility in AI integration.	• AI is recognised as having significant potential to transform engineering education. • AI is seen as a tool for personalising learning experiences and increasing efficiency in educational tasks. Faculty members acknowledge the dual nature of AI's role: beneficial for providing pedagogical support yet requiring careful implementation to address ethical and practical challenges. • Mandal and Mete (2023) and Slimi (2022) found that educators appreciate AI's efficiency but are concerned about data privacy and the loss of human elements in teaching.
Theme Three: *Ethics and Biases in AI Education*	**Theme Four:** *Interdisciplinary AI Topics and Demand for AI Education*
• Academics had varying views on AI ethics, with some incorporating ethics and biases as a core part of their curriculum while others only touched on these issues briefly or not at all. • There is a need for a consistent approach to teaching AI ethics and biases, recognising the importance of these topics in engineering education. • Professional and governing bodies in the US and UK emphasise the importance of ethical standards in AI development and deployment.	• There is strong student demand for AI topics in engineering education. Different approaches to meeting this demand include optional AI modules and the introduction of new AI-focused courses. • Balabdaoui et al. (2024) found a significant desire among students for AI topics to be integrated into technical curricula, with the highest demand among computer science and engineering students. • The interdisciplinary nature of AI education is highlighted, with demand across various technical subjects.

3 CONCLUSION: EARLY FINDINGS AND FURTHER RESEARCH

This paper took an initial look into the perceptions of engineering faculty members in relation to AI curricula integration in the US and the UK. Though the thesis is primarily concerned with the perceptions of undergraduate engineering students, the phase of data collection explored allowed me to gain engineering academics' perceptions. It served as a way for me to gain access to the students later in the project. Through the conversations with the six faculty members– three of which were examined here– I was able to gain a foundational understanding of how academics from both the US and the UK are currently implementing AI into their engineering curricula and was able to generate six themes– four of which were highlighted– from their responses. From the interviews, I was also able to develop summaries of emerging messages related to each theme to allow for the main messages from the interviews to be apparent to readers in Table 2. The academics' insights, in addition to supporting findings found by previous researchers, pointed towards the various ways AI and engineering education are currently positioned– calling for further research and the need for student perceptions for a comprehensive understanding within the bounds of the thesis. In addition, some of the academics interviewed mentioned the significance of project-based learning (PBL) in teaching AI topics to engineering students due to its ability to foster hands-on learning and real-world problem-solving skills. Furthermore, the study found that there is a growing demand by students for AI-related engineering topics or 'AI-engineering' to be incorporated into traditional engineering classrooms, implying a need for curricula development to meet future industry needs.

My thesis is timely, as recent literature from the past three years has identified a general gap in knowledge regarding AI and engineering education, calling for further investigations (Xu and Ouyang 2022; Zhai et al. 2021). However, Aditya Johri's ongoing research (McDonald et al. 2024) and his webpage have been incredibly helpful resources in navigating the evolving discourse around this topic. They have allowed me to build a compelling case for my thesis objective, which is to understand the perceptions of academics and students in a cross-national context. Ultimately, the exploration discussed in this paper laid the groundwork for me to learn more about AI's nuanced and ever-transforming role in engineering education and how it is being introduced to the students who took part in my study.

REFERENCES

Adeyeye, O. J., and I. Akanbi. "The Future of Engineering Education: A Data Analytics Approach." Engineering Science & Technology Journal 5, no. 4 (2024): 1342-1356. https://doi.org/10.61854/esatj.v5i4.1930.

Balabdaoui, Fadoua, Nora Dittmann-Domenichini, Henry Grosse, Claudia Schlienger, and Gerd Kortemeyer. "A Survey on Students' Use of AI at a Technical University." *Discover Education* 3 (2024). https://doi.org/10.1007/s44217-024-00136-4.

CDIO Initiative. "What is CDIO?" Accessed June 11, 2024. http://www.cdio.org/.

Chu, H., Y. Tu, and K. Yang. "Roles and Research Trends of Artificial Intelligence in Higher Education: A Systematic Review of the Top 50 Most-Cited Articles." Australasian Journal of Educational Technology 38, no. 3 (2022): 22–42. https://doi.org/10.14742/ajet.7526.

Crompton, H., and D. Burke. "Artificial Intelligence in Higher Education: The State of the Field." International Journal of Educational Technology in Higher Education 20, no. 1 (2023): 22.

Crompton, H., and D. Song. "The Potential of Artificial Intelligence in Higher Education." Revista Virtual Universidad Católica Del Norte 62 (2021): 1–4. https://doi.org/10.35575/rvuen.n62a1.

Díaz Lantada, A. "Engineering Education 5.0: Strategies for a Successful Transformative Project-Based Learning." IntechOpen (2022). http://dx.doi.org/10.5772/intechopen.102844.

Kallio, H., et al. "Systematic Methodological Review: Developing a Framework for a Qualitative Semi-Structured Interview Guide." Journal of Advanced Nursing 72, no. 12 (2016): 2954-2965.

Kennedy, T., and M. Odell. "Engaging Students in STEM Education." Science Education International 25, no. 3 (2014): 246-258.

Lee, Kai-Fu. AI Superpowers: China, Silicon Valley, and the New World Order. Boston: Houghton Mifflin Harcourt, 2018.

Liu, S. "A Review of the Innovation Policy of the US Government." Paper presented at the 2022 7th International Conference on Social Sciences and Economic Development (ICSSED 2022). Atlantis Press, 2022. https://doi.org/10.2991/assehr.k.220301.001.

Mandal, R., and J. Mete. “Teachers’ and Students’ Perception Towards Integration of Artificial Intelligence in School Curriculum: A Survey.” International Journal of Multidisciplinary Educational Research 12, no. 7 (2023): 95-103. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4544750.

McDonald, N., A. Johri, A. Ali, and A. Hingle. "Generative Artificial Intelligence in Higher Education: Evidence from an Analysis of Institutional Policies and Guidelines." arXiv preprint arXiv:2402.01659 (2024).

National Society of Professional Engineers. Ethical Guidelines for AI Development and Deployment. 2023. Retrieved from NSPE website. https://www.nspe.org/resources/ethics/ethical-guidelines-ai-development-and-deployment.

Russell, S., and P. Norvig. Artificial Intelligence: A Modern Approach. 3rd ed. Upper Saddle River, NJ: Prentice Hall, 2016.

Seemiller, C., and M. Grace. Generation Z Goes to College. San Francisco, CA: Jossey-Bass, 2016.

Slimi, Z. “The Impact of Artificial Intelligence on Higher Education: An Empirical Study.” European Journal of Educational Sciences 10, no. 1 (2022): 17-33. https://files.eric.ed.gov/fulltext/EJ1384682.pdf.

UK Government. "UK Research and Development Roadmap." 2020. https://www.gov.uk/government/publications/uk-research-and-development-roadmap.

Xu, W., and F. Ouyang. "The Application of AI Technologies in STEM Education: A Systematic Review from 2011 to 2021." IJ STEM Ed 9, 59 (2022). https://doi.org/10.1186/s40594-022-00377-5.

Zawacki-Richter, O., V. I. Marín, M. Bond, and F. Gouverneur. "Systematic Review of Research on Artificial Intelligence Applications in Higher Education – Where Are the Educators?" International Journal of Educational Technology in Higher Education 16, no. 1 (2019): 1-27. https://doi.org/10.1186/s41239-019-0173-8.

Zhai, X., X. Chu, C. S. Chai, M. S. Y. Jong, A. Istenic, M. Spector, J.-B. Liu, J. Yuan, and Y. Li. "A Review of Artificial Intelligence (AI) in Education from 2010 to 2020." Complexity 2021: Article ID 8812542 (2021). https://doi.org/10.1155/2021/8812542.

CHOOSING INFORMATION TECHNOLOGY AS A MAJOR; ARE THERE GENDER DIFFERENCES?

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ABSTRACT

The popularity of studying computing disciplines has varied considerably over the last decades. The low share of female students, however, has remained constant. The issue extends beyond educational institutions to society as a whole, as the growing Information Technology (IT) industry requires more IT professionals, and IT faculties fail to supply enough proficient graduates with diverse backgrounds.

The aim of this study is to consider attraction to higher education IT studies from the perspective of IT majors. Students are regarded as experts by experience in the study. In developing pedagogical, administrative, and recruiting practices, their voices should be heard.

The online survey utilised a novel dialectical three-phase question method (D3P) combining open and closed questions to elicit initial, informed, and prioritised opinions of the respondents. Mixing qualitative and quantitative methods provides diverse perspectives to the phenomenon under study.

Students' opinions on factors attracting into IT studies underlined high employment rates, interest in IT, good salary, and versatile career options. The study revealed significant differences between genders. Women emphasised good salary and interest in problem solving while men were more interested in IT and technology in general.

The dialectical three-phase question method proved to be informative: It combined the benefits and limited the issues of both qualitative and quantitative approaches.

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1 INTRODUCTION

As the abundance of services, tools, entertainment, and gadgets is getting new digitalised forms, there is a growing demand for a workforce capable of designing and implementing creative and reliable software solutions. Information and Communication Technology (ICT) know-how is the prerequisite for digital and digital-enabled innovations and plays a key role in modern technology-fuelled economies.

In 2023, 9.7 million people in the EU worked as ICT specialists, representing 4.8% of the total EU workforce. From 2013 to 2023, the number of ICT specialists in the EU grew by 59.3%. (Eurostat 2024) In 2022, 5.3 million people in the US worked in 'Computer and mathematical occupations'. This occupational group is estimated to grow from 2022 to 2032 at the second fastest rate of 15.2%. (US Bureau of Labor Statistics 2023) The shortfall of computing graduates who could fill current and future computing jobs is a serious concern of industries, governments, and educational institutes (Nager & Atkinson, 2017; Stephenson et al., 2018).

The popularity of majoring in IT has varied widely over the decades. The number of IT students started to grow in the 1980s and even more so in the late 1990's along with the www boom. In the 2000s the popularity waned following the burst of the IT bubble, but begun to rise again in 2010s. (Zweben and Bizot 2016; Nager and Atkinson 2017; Zweben and Bizot 2023)

Today, IT is a profession of white males (Jaccheri, Pereira, and Fast 2020; Myers 2018). The profile of IT workforce reflects the profile of IT majoring students. In OECD countries less than 18% of ICT students are females. As seen in Figure 1, the share of new female entrants into higher education was the lowest in Information and Communication Technologies (ICT) compared to all other educational fields. Even other STEM fields are more attractive to women. (OECD 2021)

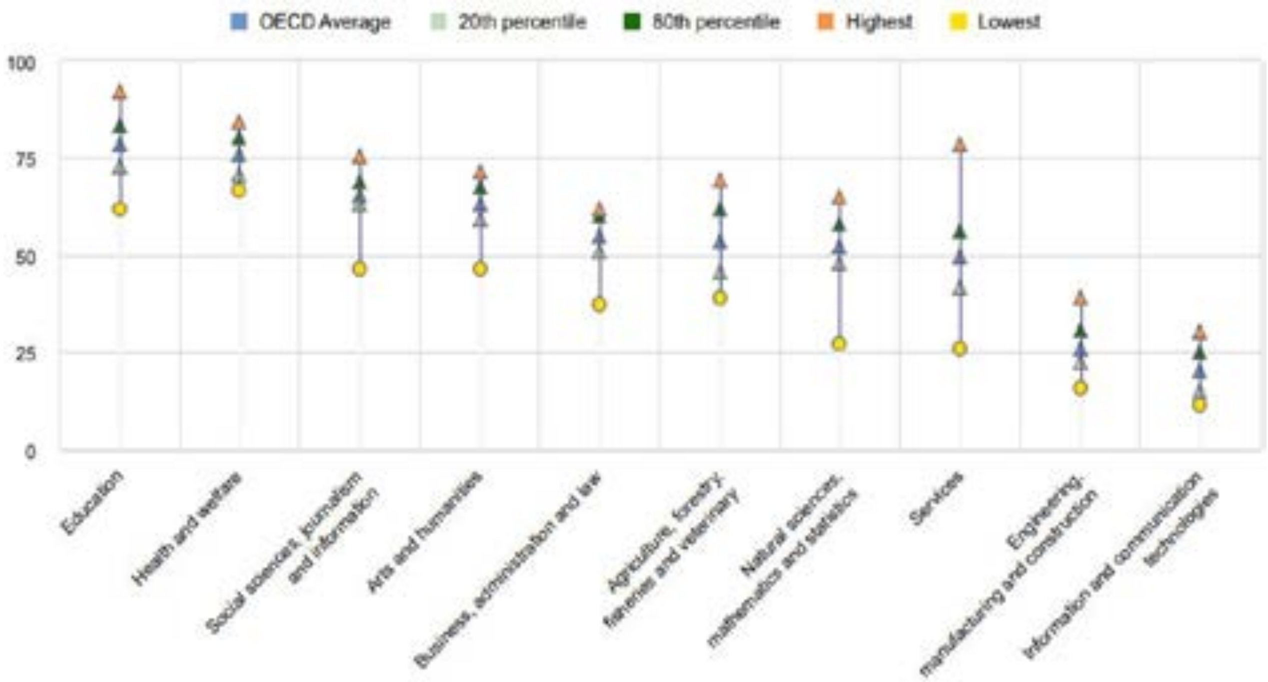

Fig. 1. Share of female new entrants into higher education by field of education in 2019 (OECD 2021)

Women earned the majority of all bachelor's degrees (58%), and nearly 50% of bachelor's degrees in science and engineering, but accounted only for 22% of bachelor's degrees in the computing disciplines in the US in 2021 (DuBow and Wu 2022) and 23% in the OECD (OECD 2023). The share of women in computing disciplines reached its peak in the US in 1985 with 37% of bachelor degree diplomas (DuBow and Wu 2022). The share declined steadily close to 15% in 2009. Since then only modest growth has been observed (Zweben and Bizot 2016). This unsettling imbalance has persisted for decades, and no significant progress has been observed, either in Europe (Informatics Europe, n.d.) or in the US (Zweben and Bizot 2023).

Increased diversity in computing would increase diverse voices and perspectives in research, development, and innovation, thus resulting in products and services that are usable and attractive to a diverse population. (Hunt et al. 2018; Fountain 2000) Attracting and retaining more diverse population to IT degree programmes is a persistent concern in IT institutes (Stephenson et al. 2018; Nager and Atkinson 2017). However, efficient measures to balance the distribution have not yet been established (Jaccheri, Pereira, and Fast 2020).

To shed additional light on the issue, the aim of this study is to elicit the opinion of IT-majoring higher education students on which factors attract youth to study computing. Students are regarded as experts by experience in the enquiry (Jasanoff 2016, Fisher, Margolis, and Miller 1997). The research question guiding this study is: Which factors attract students into bachelor-level computing education according to students majoring in Information Technology - and do these factors differ by gender?

The paper is organised as follows: Section 2 takes a look at factors identified as attracting to computing education. Section 3 describes the study design, and section 4 presents the results. Section 5 discusses the results and implications.

2 ATTRACTION TO STUDY IT

The Universities and Colleges Admissions Service (UCAS) in the United Kingdom conducted an impressive survey in 2020 covering more than 27,000 first and second year students aged 18 and 19 accepted to higher education in 2019 and 2020. According to the survey, students chose their major mainly based on the enjoyment of a subject (74%). High graduate employment rates were the second most important factor influencing the choice of the major (54%) (UCAS 2021).

Motivation refers to the psychological factors steering our actions. Intrinsic motivation refers to the internal drive to engage in an activity for its own sake, without the need for external rewards or incentives. Interest and enjoyment are typical manifestations of intrinsic motivation. Extrinsic motivation refers to the drive to engage in an activity in order to attain external rewards or to avoid negative consequences. Employment, status, and competitive salary are typical extrinsic motivators. (Järvelä and Renninger 2014) Both intrinsic and extrinsic motivation guide career choices.

In addition to motivational factors applicants' beliefs about their own skills shape their career choices (Savickas 2008). Success in studies and interest typically enhance each other. Students are generally interested in careers that allow them to utilise and develop their abilities. Youth with strong mathematical background are more likely to choose STEM fields as their major than ones with less competence. The problem with computing disciplines is that there is no undisputed consensus on what predicts performance, with math and verbal skills dominating the discussion. (Virkki 2021)

Values and perceptions behind career choices are susceptible to external influences. Societal and cultural influence from family, friends, career counsellors, media, social media, and role models may guide, support, or discourage career aspirations of the young. (Sanders 2005; Wang et al. 2015) In spite of decades of work towards gender equality, the world doesn't appear the same for women and men. Discourses in the gender-biased societies will likely teach youth to have gender-stereotyped interests. (Adam et al. 2006; Clayton, Hellens, and Nielsen 2009; Trauth 2002)

Factors that cause women not to choose IT as their career have been studied more than factors that attract women to IT. The stereotypical images of IT professions and culture do not appeal to women (Cheryan, Master, and Meltzoff 2015; Thomas and Allen 2006; Wolff, Knutas, and Savolainen 2020). Motivational factors for both men and women appear quite similar: high employment, interesting job opportunities, good salary, and interest in IT. (Corneliussen 2024)

Factors characterising women in computing fields were studied by Lehman, Sax and Zimmerman (2017). Women intending to major in computing in the US earned higher high school grades than their male counterparts. They outperformed men on the SAT verbal tests but scored less on the SAT math. Women in Computer Science (CS) self-rated themselves lower than male students on intellectual self-confidence, computing skills, math ability, competitiveness, leadership ability, public speaking ability, and social self-confidence. On the other hand, women rated themselves higher than men on writing ability, artistic ability, and creativity.

In comparison to women in other STEM fields, CS-pursuing women rated themselves highest on computing skills and artistic abilities. On the other end, women in CS rated themselves lowest on intellectual self-confidence, leadership ability, drive to achieve, and math. However, their actual scores on the SAT math were the same as in other STEM fields, and they scored better on the SAT verbal. (Lehman, Sax, and Zimmerman 2017)

Previous studies indicate that young women tend to rate their IT and math abilities lower than men, even if they had similar levels of academic achievement. Women's lack of confidence and low self-efficacy in their math and IT abilities may contribute to women's decision not to pursue an IT major or to drop out from the IT degree programme (Fisher, Margolis, and Miller 1997; Wilson 2002; Dempsey et al. 2015; Lishinski et al. 2016; Pappas, Giannakos, and Jaccheri 2016; Herbert et al. 2020). Interest and confidence in computing are key components in developing an identity as an IT professional and a sense of belonging in IT. (Dempsey et al. 2015)

Different career choice theories emphasise various factors in the career decision process. Parson's early talent-matching approach emphasised the skills and abilities of a person and the attributes required in particular jobs (Savickas 2008). Holland's theory highlights the congruence between vocational personality types and job environments (Holland 1985). The Social Cognitive Career Theory is based on Banduras concepts of self-regulation and self-efficacy according to which individuals' beliefs in their capabilities in a particular domain influence not only the choices they make, but even the goals they cherish (Bandura 1991). Our study was not committed to any single theory but sought a dialogue between theories and the survey data.

3 METHODOLOGY

The study was conducted as a survey. This chapter presents the sampling, question construction, execution, and analysis of the survey.

3.1 Sampling

The population under investigation consists of higher education students majoring in IT. Second year students were chosen as the sample. They already have experience of studying IT, but limited experience of working in IT. The survey was conducted in Haaga-Helia University of Applied Sciences in Finland in 2021.

In the academic year 2019-2020, 200 students began their studies in the Information Technology Degree Programme of Haaga-Helia University of Applied Sciences. After the first year of studies 20 of them (10%) had discontinued their studies. Thus, the sample size was 180 students (131 males and 49 females). The sample represents a cross-section of the IT majors at the university, which accommodates an average of 650 IT majors (75% males, 25% females). Sampling ratio was 28%.

3.2 Question Construction

A good question produces answers that are valid and reliable measures of what is under investigation. In this context, reliability means that the questions are consistently comprehended by both respondents and researchers. Validity means that answers correspond to the genuine opinion of the respondents. (Fowler and Cosenza 2009)

A novel questioning format, the dialectical three-phase question method (D3P), was applied in the survey. The study was interested in the experiential knowledge and conceptualisations of the respondents. On the other hand, generalisable results were sought as well. By collecting and analysing both quantitative and qualitative data, more comprehensive evidence can be gathered, and more robust and nuanced results achieved (Jick 1979).

In D3P the same question is presented three times with distinct formulations (Virkki 2023): The first question is an open question to elicit answers that express respondents' initial responses on the topic, unaffected by the conceptualisations of the researcher. Thus, answers to the open question have high validity (Sue and Ritter 2016). Respondents' own wordings involve rich information content, such as sincerity, feelings, and rationales. Answers to the first question are referred to as Initial Opinions.

The second question is a multiple-choice question with several response options allowing respondents to select as many options as they prefer. The response options were drawn from scientific literature by the researcher. The last response option was "Other", with a fill-in text-field, to offer a suitable response option for everyone. Answers to the second question are referred to as Informed Opinions.

In the third question, respondents were asked to identify the three to five most important factors, after being exposed to the multiple response options of the previous question and the thought process initiated by the first question. In other words, respondents were encouraged to reconsider and prioritise their views. Answers to the third question are referred to as Prioritised Opinions.

The rationale for the three-phase question method was to overcome the issues of one question type (open versus closed) with the counter-balancing strengths of the other. Open questions catch what crossed the respondent's mind when presented the question. However, respondents may not consider their answers thoroughly but utter the first thought entering their mind. The responses are influenced by the situation of the respondents, their knowledge, emotions, and mental states. Respondents' interpretations of open questions often vary, too (Peterson 2013).

On the other hand, a closed question with predefined response options may bias and restrict participants' answers (Fowler and Cosenza 2009). The choice and phrasing of the response options are done 'a priori' by the researchers and not by the respondents (Deetz 1996). Emerging and unanticipated answers are easily forgotten when faced with the battery of ready-made options. Furthermore, closed questions can only capture factors the researcher is already aware of, and nothing new may emerge.

Finally, prioritising opinions encourages respondents to reconsider and evaluate their views. Both researchers and respondents perceive the world from their own perspectives. Given the chance to even peak into the world of the other, both of them may encounter something new that allows them to learn and refine their views (Rock 2001). The D3P opens a dialogue between respondents and researchers.

Question quality and validity were ensured through a review and a field pre-test (Fowler and Cosenza 2009; Hardy and Ford 2014). Three university professionals in IT reviewed all questions and response options, and adjustment were made as needed. A pre-test involving 24 first-year students was also conducted. A group discussion with these students addressed the clarity, atomicity, and unambiguousness of the questions and response options, as well as the comprehensiveness and relevance of the response options. Insights from students' responses to open questions were utilised to add new response options to the questionnaire.

3.3 Survey Execution and Analysis

The questionnaire was deployed in 2021 using Webropol online survey tool. The survey was presented to the students by the researcher during online classes allotting 10 minutes for completion to encourage participation. Responding to the survey was voluntary and had no bearing on course assessment ("The European Code of Conduct for Research Intregrity" 2017). Two reminders were sent to non-responding students with one-week intervals.

There were 89 respondents, 61% males and 39% females. (In the target population, gender distribution is 75% males and 25% females.) The response rate was 49,4%. The median age of the respondents was 26 and mode 23, the youngest were 19 years, and the oldest 48 years old. Other diversity aspects of the respondents were not recorded. No responses were eliminated.

Responses to open questions expressing initial and prioritised opinions were catalogued and broken into atomic expressions with synonyms harmonised. The atomic expressions of initial opinions were synthesised under themes using inductive thematic content analysis (Braun and Clarke 2008). Prioritised opinions were analysed statistically as the format of the responses was list-like. Responses to multiple-choice questions, expressing informed opinions, were studied statistically.

4 RESULTS

4.1 Initial Opinions on Factors Attracting to IT

Both women and men emphasised interest in IT, high employment, and salary in Initial Opinions. External influences, personality types, or skill congruence were only rarely expressed. Responses brought up less diversity than expected, and no significant differences between genders emerged. Initial opinions are illustrated with representative quotes from the respondents (Eldh, Årestedt, and Berterö 2020).

"Interest in IT, reasonable salary, high employment."

"*Salary, employment, interest In IT and the nice combination of logic and creativity in software development."*

4.2 Informed Opinions on Factors Attracting to IT

In Informed Opinions, students selected as many of the response options as they pleased. High Employment was the most popular factor attracting youth to study IT. The multiple-choice questions of Informed Opinions added diversity in views and revealed differences between genders. The difference was considered significant when it was at least 10 percentage points. Men valued Interest in IT and Interest in Technology clearly more than women. Women appreciated Good Salary, IT as a Field of Future and Interest in Problem Solving more than men as seen in Fig. 2. Women also found that Media affected their career choice more than men perceived.

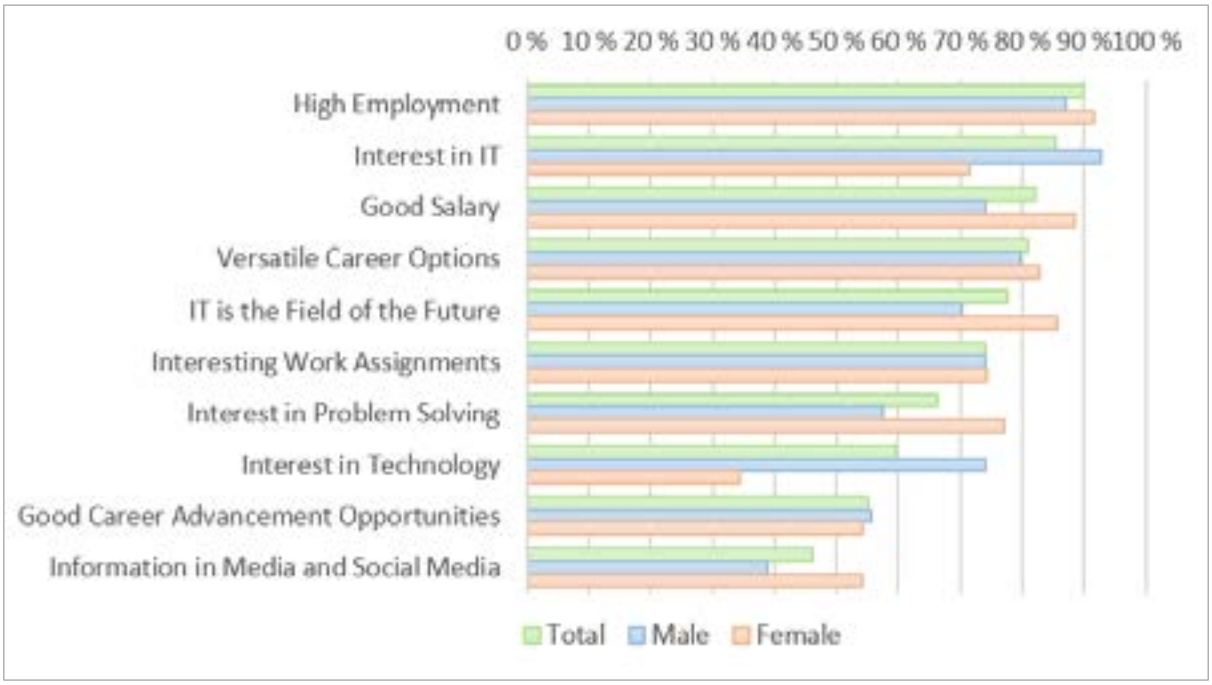

Fig. 2. Top 10 Informed Opinions on Factors Influencing the Choice of IT as a Major

For men the most popular intrinsic motivator was Interest in IT as for women the most popular intrinsic motivator was Interest in Problem Solving. In general, extrinsic motivators were more popular among women than men.

4.3 Prioritised Opinions on Factors Attracting to IT

When asked to prioritise and write down only three to five most important factors contributing their career choice, the first four factors stayed the same as in Informed

Opinions. However, three new factors appeared at the bottom of the list as seen in Fig. 3: Remote Work Possibilities, Interest in Design and Creativity, and Family and Friends. Women appreciated extrinsic motivators the most: High Employment, Good Salary, Versatile Career Options and Remote Work Possibilities. The most important intrinsic motivators for women were Interest in IT and Interest in Problem Solving.

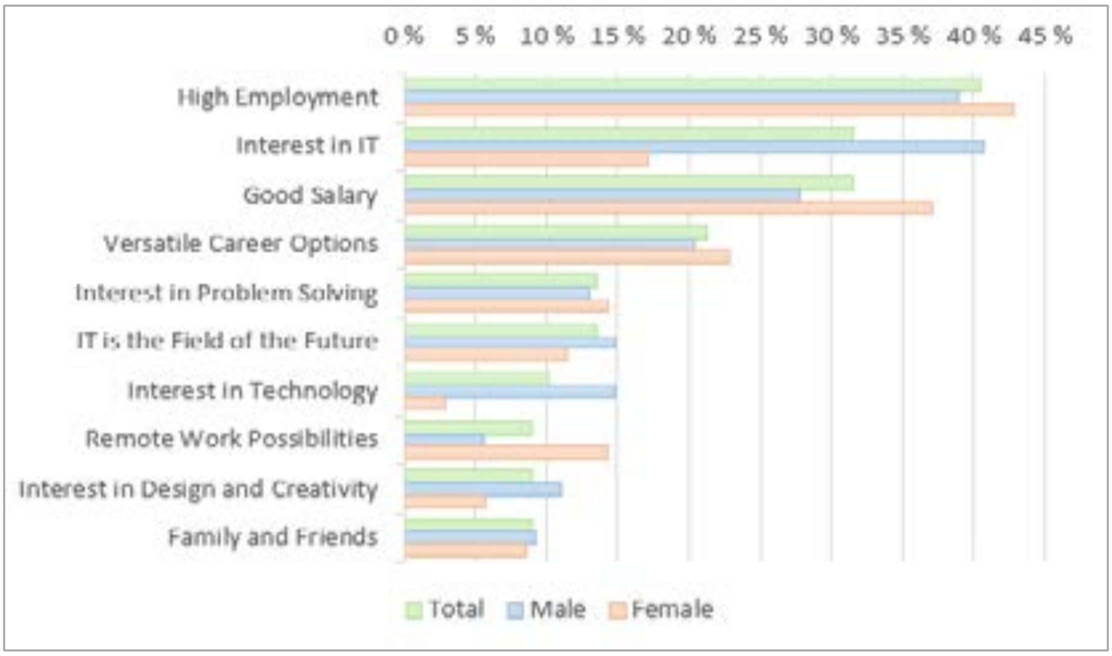

Fig. 3. Top 10 Prioritised Opinions on Factors Influencing the Choice of IT as a Major

5 DISCUSSION

The study gathered student opinions. However valid the opinions are, they may not capture the reality as it is, but opinions about it. Nonetheless, opinions matter as they affect the way people behave. All three question formulations of the D3P provided a slightly different perspective on the topic. Open questions enabled respondents' own conceptualisations. The multiple-choice question options broadened the response sphere. Prioritising brought forth the most important factors. By opening a dialogue with the experiential knowledge of the students and the science-based knowledge of the researchers, more sound and holistic evidence could be gathered. The sample sizes were modest for drawing definitive statistical inferences, but plentiful for qualitative analysis. Both theoretical and pragmatic implications are discussed succinctly.

Intrinsic and extrinsic motivators dominated students' responses. External influences, personality types, skill congruence, or self-efficacy were rarely expressed by students in this study. Bringing out one's personality features or issues may feel uncomfortable to students. On a general level, reasons to study IT are similar for women and men. But when the topic was elaborated further, considerable differences emerged. Interest in Problem Solving is the most popular intrinsic motivator for women. Men are more inclined to Technology Interest. These results are novel yet congruent with previous research. The difference may imply that women perceive IT more as a means to an end, while men are more intrigued by technology itself (Clayton, Hellens, and Nielsen 2009).

The study revealed that extrinsic motivators like high employment, good salary, and time- and location-independent work are essential to women. This may follow from the fact that women's financial independence is still not on par with that of men (UN Women 2024). Media has the potential to influence the stereotypical images of IT professions and work culture and thereby impact women's perceptions of IT as a career choice. Policies and practices to increase the attractiveness of IT studies and professions to young women could be refined with the outcomes of this study.

REFERENCES

Adam, Alison, Marie Griffiths, Claire Keogh, Karenza Moore, Helen Richardson, and Angela Tattersall. "Being an 'it' in IT: Gendered Identities in IT Work." *European Journal of Information Systems* 15, 4 (2006): 368–78. https://doi.org/10.1057/palgrave.ejis.3000631.

Bandura, Albert. "Social Cognitive Theory of Self-Reguation." *Organizational Behavior and Human Decision Processes* 50 (1991): 248–87.

Braun, Virginia, and Victoria Clarke. "Using Thematic Analysis in Psychology." *Qualitative Research in Psychology* 3, 2 (2008): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Cheryan, Sapna, Allison Master, and Andrew N. Meltzoff. "Cultural Stereotypes as Gatekeepers: Increasing Girls' Interest in Computer Science and Engineering by Diversifying Stereotypes." *Frontiers in Psychology* 6 (2015): Article 49, 1-8. https://doi.org/10.3389/fpsyg.2015.00049.

Clayton, Kaylene L., Liisa A.Von Hellens, and Sue H. Nielsen. "Gender Stereotypes Prevail in ICT; A Research Review." Paper presented at *SIGMIS CPR'09: The 2009 ACM SIGMIS Computer Personnel Research Conference*, Limerick, Ireland, May 28–30, 2009,. https://doi.org/10.1145/1542130.1542160.

Corneliussen, Hilde G. *Reconstructions of Gender and Information Technology; Women Doing IT for Themselves*. Singapore: Palgrave Macmillan. 2024. https://doi.org/10.1007/978-981-99-5187-1.

Deetz, Stanley. "Crossroads—Describing Differences in Approaches to Organization Science: Rethinking Burrell and Morgan and Their Legacy." *Organization Science* 7, 2 (1996): 191–207. https://doi.org/10.1287/orsc.7.2.191.

Dempsey, Jennifer, Richard T. Snodgrass, Isabel Kishi, and Allison Titcomb. "The Emerging Role of Self-Perception in Student Intentions." Paper presented at *SIGCSE 2015: The 46th ACM Technical Symposium on Computer Science Education*, Kansas City, MO, USA, March 4–7, 2015. https://doi.org/10.1145/2676723.2677305.

DuBow, W., and Zhen Wu. "NCWIT Scorecard: The Status of Women in Technology." 2022. https://ncwit.org/resource/scorecard/.

Eldh, Ann Catrine, Liselott Årestedt, and Carina Berterö. "Quotations in Qualitative Studies: Reflections on Constituents, Custom, and Purpose." *International Journal of Qualitative Methods* 19 (2020) 1–6. https://doi.org/10.1177/1609406920969268.

Eurostat. "ICT Specialists in Employment." Eurostat, 2024.

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment

Fisher, Allan, Jane Margolis, and Faye Miller. “Undergraduate Women in Computer Science: Experience, Motivation and Culture.” SIGCSE Bulletin 29, 1(1997): 106–10. https://doi.org/10.1145/268085.268127.

Fountain, Jane E. “Constructing the Information Society: Women, Information Technology, and Design.” *Technology in Society* 22 (2000): 45–62. https://doi.org/10.4324/9781003275961.

Fowler, Floyd J. Jr., and Carol Cosenza. “Design and Evaluation of Survay Questions.” In *The SAGE Handbook of Applied Social Research Methods*, edited by Leonard Bickman and Debra J. Rog, 2nd ed. SAGE. 2009.

Hardy, Ben, and Lucy R. Ford.. “It’s Not Me, It’s You: Miscomprehension in Surveys.” *Organizational Research Methods* 17, 2 (2014): 138–62. https://doi.org/10.1177/1094428113520185.

Herbert, Nicole, David Herbert, Erik Wapstra, Kristy de Salas, and Tina Acuña. “An Exploratory Study of Factors Affecting Attrition within an ICT Degree.” Paper presented at ACE 2020: *The Twenty-Second Australasian Computing Education Conference*, Melbourne, VIC, Astralia, February 3-6, 2020. https://doi.org/10.1145/3373165.3373174.

Holland, John L. *Making Vocational Choices: A Theory of Vocational Personalities and Work Environments*. 2nd ed. Prentice Hall. 1985.

Hunt, Vivian, Sara Prince, Sundiatu Dixon-Fyle, and Lareina Yee. “Delivering through Diversity.” *McKinsey & Company*. 2018.

Informatics Europe. n.d. “Higher Education Data Portal.” Informatics Europe. https://www.informatics-europe.org/data/higher-education/.

Jaccheri, Letizia, Cristina Pereira, and Swetlana Fast. “Gender Issues in Computer Science: Lessons Learnt and Reflections for the Future.” Paper presented at SYNASC *2020: 22nd International Symposium on Symbolic and Numeric Algorithms for Scientific Computing*, Online, September 1-4, 2020. https://doi.org/10.1109/SYNASC51798.2020.00014.

Järvelä, Sanna, and K. Ann Renninger. “Designing for Learning: Interest, Motivation, and Engagement.” In *Cambridge Handbook of the Learning Sciences*, 2nd ed., (2014): 668–85. https://doi.org/10.1017/CBO9781139519526.040.

Jasanoff, Sheila. *The Ethics of Invention: Technology and the Human Future*. W.W.Norton. 2016.

Jick, Todd D. “Mixing Qualitative and Quantitative Methods: Triangulation in Action.” *Administrative Science Quarterly* 24, 4 (1979): 602-611. https://doi.org/10.2307/2392366.

Lehman, Kathleen J., Linda J. Sax, and Hilary B. Zimmerman. “Women Planning to Major in Computer Science: Who Are They and What Makes Them Unique?” *Computer Science Education* 26, 4 (2017): 277–98. https://doi.org/10.1080/08993408.2016.1271536.

Lishinski, Alex, Aman Yadav, Jon Good, and Richard Enbody. “Learning to Program: Gender Differences and Interactive Effects of Students’ Motivation, Goals, and Self-Efficacy on Performance.” Paper presented at *ICER 2016: The 2016 ACM Conference on International Computing Education Research, Melbourne, VIC, Australia, September 08 - 12, 2016*. https://doi.org/10.1145/2960310.2960329.

Myers, Blanca. “Women and Minorities in Tech, By the Numbers.” *Wired*, Mar 27, 2018. https://www.wired.com/story/computer-science-graduates-diversity/.

Nager, Adams, and Robert D. Atkinson. “The Case for Improving U.S. Computer Science Education.” *Information Technology & Innovation Foundation* (2017): 1–38. https://doi.org/10.2139/ssrn.3066335.

OECD. *Education at a Glance 2021: OECD Indicators*. Paris: OECD, 2021. Publishing. https://doi.org/https://doi.org/10.1787/b35a14e5-en.

OECD. *Education at a Glance 2023: OECD Indicators*. Paris: OECD, 2023. https://doi.org/https://doi.org/10.1787/e13bef63-en.

Pappas, Ilias O., Michail N. Giannakos, and Letizia Jaccheri. “Investigating Factors Influencing Students’ Intention to Dropout Computer Science Studies.” Paper presented at *ITiCSE’ 16: Innovation and Technology in Computer Science Education 2016,* Arequipa, Peru, 11-13 July 2016: 198–203. https://doi.org/10.1145/2899415.2899455.

Peterson, Robert A. “Open- and Closed-End Questions.” In *Constructing Effective Questionnaires*. Thousand Oaks: SAGE Publications, 2013. https://doi.org/10.4135/9781483349022.

Rock, Paul. “Symbolic Interactionism and Ethnography.” In *Handbook of Ethnography*, edited by Paul Atkinson, Amanda Coffey, Sara Delamont, John Lofland, and Lyn Lofland, 477–92. London: SAGE, 2001. https://doi.org/https://doi.org/10.4135/9781848608337.

Sanders, Jo. “Gender and Technology in Education: What the Research Tells Us.” Paper presented at *CWIT ’05: The International Symposium on Women and ICT: Creating Global Transformation*. Baltimore, Maryland, USA, June 12-14, 2005. https://doi.org/10.1145/1117417.1117423.

Savickas, Mark L. “Helping People Choose Jobs: A History of the Guidance Profession.” In *International Handbook of Career Guidance*, edited by James A. Athanasou and Jan Van Esbroeck. Springer, 2008.

Stephenson, Chris, Alison Derbenwick Miller, Christine Alvarado, Lecia Barker, Valerie Barr, Tracy Camp, Carol Frieze, et al. *Retention in Computer Science Undergraduate Programs in the U.S.: Data Challenges and Promising Interventions.* New York, NY: ACM, 2018.

Sue, Valerie M., and Lois A. Ritter. *Conducting Online Surveys*. SAGE, 2016.

“The European Code of Conduct for Research Intregrity.” Berlin, Germany: ALLEA, 2017. https://doi.org/10.1142/9789814340984_0003.

Thomas, Theda, and Alesha Allen. “Gender Differences in Students’ Perceptions of Information Technology as a Career.” *Journal of Information Technology Education: Research* 5 (January 2006): 165–78. https://doi.org/10.28945/241.

Trauth, Eileen M. “Odd Girl out: An Individual Differences Perspective on Women in the IT Profession.” *Information Technology & People* 15, 2(2002): 98–118. https://doi.org/10.1108/09593840210430552.

UCAS. “Where next? What Influences the Choices School Leavers Make?” Cheltenham: UCAS, 2021. https://www.ucas.com/file/435551/download?token=VUdIDVFh.

UN Women. “Facts and Figures: Economic Empowerment.” UN, 2024. https://www.unwomen.org/en/what-we-do/economic-empowerment/facts-and-figures.

US Bureau of Labor Statistics. “Employment Projections: Employment by Major Occupational Group.” US Bureau of Labor Statistics. 2023. https://www.bls.gov/emp/tables/emp-by-major-occupational-group.htm.

Virkki, Outi T. “Computer Science Student Selection — A Scoping Review and a National Entrance Examination Reform.” Paper presented at *SIGCSE ’21: The 52nd ACM Technical Symposium on Computer Science Education, Virtual Event, March 13-20, 2021*, 654–59. https://doi.org/10.1145/3408877.3432371.

Virkki, Outi T. “Performance and Attrition in Information Technology Studies ; A Survey of Students’ Viewpoints.” Paper presented at *EDUCON'23: 2023 IEEE Global Engineering Education Conference*, Kuwait, Kuwait, May 1-4, 2023. https://doi.org/10.1109/EDUCON54358.2023.10125231.

Wang, Jennifer, Hai Hong, Jason Ravitz, and Marielena Ivory. “Gender Differences in Factors Influencing Pursuit of Computer Science and Related Fields.” Paper presented at *ITiCSE'15: ACM Conference on Innovation and Technology in Computer Science Education.* Vilnius, Lithuania, Jul 04-08, 2015. https://doi.org/10.1145/2729094.2742611.

Wilson, Brenda Cantwell. “A Study of Factors Promoting Success in Computer Science Including Gender Differences.” *Computer Science Education* 12, 1–2 (2002): 141–64. https://doi.org/10.1076/csed.12.1.141.8211.

Wolff, Annika, Antti Knutas, and Paula Savolainen. “What Prevents Finnish Women from Applying to Software Engineering Roles? A Preliminary Analysis of Survey Data.” Paper presented at *International Conference on Software Engineering*, Seoul, Republic of Korea, May 23–29, 2020. https://doi.org/10.1145/3377814.3381708.

Zweben, Stuart, and Betsy Bizot.. “2022 Taulbee Survey.” Computing Research Association, 2023. https://cra.org/crn/wp-content/uploads/sites/7/2023/05/2022-Taulbee-Survey-Final.pdf.

Zweben, Stuart H, and Elizabeth B Bizot. “Representation of Women in Postsecondary Computing:” *Computing in Science & Engineering* 18, 2 (2016): 40–56. https://doi.org/10.1109/MCSE.2016.21.

Advice for Success: Insights from Early Career Women on Vital Competencies Empowering Their Transition into the Civil Engineering Workforce

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Conference Key Areas*:* Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing, Engineering skills, professional skills, and transversal skills.
Keywords*: Women, Civil Engineering, Early Career, Professional Development, Workforce Sustainability*

ABSTRACT

Despite extensive research on women in engineering, the retention of women engineers in the workforce remains a persistent obstacle to diversifying the engineering workforce. To confront this issue, empowering women engineers with the requisite skills for seamless integration into the workforce is essential. This study utilized an asset-based framework to examine the competencies employed by early career women as they transitioned from school into their engineering careers. Through qualitative methods involving both inductive and deductive analyses, we conducted initial and follow-up interviews with seven early career women (1-2 years into engineering careers), enabling them to reflect on the skills needed and advice they wished they had received during their transition. Findings indicated that prioritizing a good work-life balance, seeking guidance or support, and cultivating self-assurance, confidence, assertiveness, and resilience were essential for successfully navigating the transition into the engineering workforce. This work offers

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insights into how to best prepare and empower women as they transition into the engineering workforce.

1 INTRODUCTION

In the United States, it has become a national imperative to include the ‘missing millions’ in science and engineering, referring to the absent voices and identities of underrepresented groups like women and Black engineers (“National Science Board: Vision 2030” 2020). This call resonates globally, as women constitute only 16.5% of engineers worldwide (“International Women in Engineering Day 2022” 2022). Research suggests that discrimination against women engineers persists in many workplaces, particularly within the construction and civil engineering industry (Enshassi et al. 2008). Workforce sustainability involves fostering an environment that prioritizes the safety and well-being of all individuals to generate optimal engineering solutions. Engineering careers often entail demanding work conditions and stressful environments (Loosemore and Waters 2004; Jensen and Cross 2021). Furthermore, there are calls for enhanced professional development for civil engineers, leading to increased global responsibility in reducing corruption and advancing sustainable development (Chance et al. 2020). The engineering workforce is in dire need of amplifying the voices that have been historically underrepresented. The transition into the workforce is a pivotal time in career decision making, and it is during this critical time that efforts must be concentrated to foster diversity and inclusion. Supporting the development of skills tailored to help women navigate this stressful period can significantly contribute to increasing diversity and creating a more inclusive engineering community. Empowering women engineers with a skill set for successful transition to the engineering workforce is key to establishing more sustainable careers in engineering.

1.1 Early Career Women Engineers

Early career experiences lay the groundwork for progression and significantly shape career choices and decisions (Francis and Michielsens 2021). In the field of engineering, positive early career experiences are associated with increased persistence and retention in the profession (Marinelli et al. 2022). The transition to the workplace requires early career engineers navigate how their existing skills and knowledge can seamlessly integrate into a workplace that presents new challenges for them to address (Smit 2023). The transition from academia to industry presents challenges to all engineers including high stress, demanding workloads, learning new information, and depending more on others (Beddoes 2019; Jensen and Cross 2021), and women often face additional challenges including isolation, harassment, stereotypes and stereotype threat, imposter syndrome, underrepresentation, exclusion, pressure to work harder to prove themselves, and negative interactions (Beddoes 2019; 2022; Chew et al. 2020; Buse et al. 2013).

1.2 Asset-Based Approaches and Empowerment

In studying underrepresented populations within engineering, it is important to avoid using deficit based approaches or situating the problem within the individuals themselves (Harper 2010). Therefore, our work implements an asset-based approach and seeks to empower these individuals by examining what skills and competencies they brought to this critical transitional time that helped empower them to be successful in navigating challenges in their career. Further, they identify advice they wished they had received as an early career woman entering the civil engineering workforce and additional skills they are working towards developing.

1.3 Professional Development in Engineering and Leadership Enabling Competencies

To excel in their professions, engineering students need an extensive array of competencies (i.e., knowledge, skills, and attributes) (Bae et al. 2022). Effective professional development, or preparedness for the workforce, is crucial for achieving successful and sustainable career growth (Bae et al. 2022). A study of construction industry leaders identified critical leadership-enabling competencies that engineering students should develop for successful transitions to construction and engineering careers (Simmons et al. 2020). These competencies include communication skills, professionalism, critical thinking/problem-solving, self-awareness, ambition/drive, time management, management, ethics/responsibility, big-picture thinking, humility, teamwork/collaboration/networking, quality control, adaptability, computer skills, safety/risk management, assertiveness, people focus, legal knowledge, and economic principles and trends (Simmons et al. 2020). These leadership-enabling competencies provided a framework to guide the analysis of the data to understand which competencies were most useful for women transitioning into careers in civil engineering.

1.4 Research Question

This study was guided by the following research question: What competencies and skills do early career women identify as empowering to navigate challenges as they transition to careers in civil engineering?

2 METHODOLOGY

2.1 Data Collection

Qualitative narrative techniques were employed to gather data, involving the comprehensive collection and synthesis of individual participant narratives. The data collection process consisted of bi-weekly reflection journals and initial and follow-up semi-structured interviews, each lasting between 40 to 90 minutes. Interviews were conducted in person or over Zoom, recorded, and transcribed verbatim. Participant narratives were then individually constructed using the process of restorying (i.e., reordering participants' stories chronologically) (Creswell 2020). The participants were then asked to review the final narratives as a form of member checking. Due to the nature of narrative inquiry, participants' individual identities, background and educational experiences, work experiences, and stories were allowed to emerge naturally, and interviews often shifted to follow up on participants' individual paths. As a part of the follow-up interview process, participants were prompted to describe responses to the following questions: “What advice would you give to your younger self before you embarked on a career in engineering?” and “How would you mentor or support other women navigating transitions into engineering careers?”.

2.2 Participants

Participants for this study were recruited by convenience sampling using the first author's network and industry connections. All participants identified themselves as women with engineering degrees in their first 1-2 years of work, working at highly reputable civil engineering firms across the southeastern United States. Five participants identified themselves as Black, one identified as White, and one participant chose not to identify their race. During this investigation, we acknowledge the principle of intersectionality, where the convergence of diverse identities can profoundly shape an individual's experience. It is important to recognize that an individual's experience cannot be exclusively attributed to a singular aspect of their identity. Participants selected pseudonyms to protect their identity.

2.3 Data Analysis

Thematic analysis was employed to analyze, examine, and present patterns from the data (Braun and Clarke 2006). Our analysis consisted of a combination of deductive coding, using the leadership-enabling competencies established by (Simmons et al. 2020), which was used as a conceptual model through which the data was analyzed. We also used inductive coding, which allowed emergent codes to arise from the narrative data. Thematic analysis of qualitative narrative data consisted of repeated readings (Saldaña 2013), restorying, and initial coding (Creswell 2020). Following a comprehensive examination of each participant's narrative, the researchers distanced themselves from the data and conducted a broader review across all participant narratives. This process aimed to construct a synthesis of competencies that empowered women to effectively navigate challenges during their transition into the engineering workforce. Codes were then complied into themes using the qualitative analysis technique and sorting and reviewed to assure they aligned with the participant data (Saldaña 2013; Creswell 2020; Braun and Clarke 2006). Finally, member checking was implemented as the findings were checked with the original participants to improve the trustworthiness of the findings (Creswell 2020).

3 RESULTS

3.1 Tables

Competencies identified through inductive and deductive coding are listed in Table 1.

Table 1. Competencies Identified by Early Career Women Empowering their Transition to Careers in Engineering

Leadership-enabling Competencies as Identified by Industry Leaders			
Communication	Professionalism	Self-awareness	Humility
Time management	Computer skills	Assertiveness	Teamwork/collaboration
Emergent Competencies from the Data			
Initiative	Continual learning	Confidence	Asking questions
Self-assurance	Setting boundaries	Prioritizing mental health/ wellbeing	Seeking mentorship/ guidance
Balance	Destressing skills	Resilience	Self-esteem

3.2 Themes Across Participant Narratives

Theme 1: Early career women value prioritizing mental health, boundary setting, and engaging in hobbies outside of work to maintain work-life balance and prevent burnout as they transition to engineering careers.

All participants described experiences of increasingly demanding workloads and a struggle to find work-life balance as they entered the engineering profession. Individuals highlighted the importance of prioritizing mental wellbeing especially when entering a career that is so mentally challenging. One participant advised,

Yes, you're here to work. You also have a life outside of work. Your mental health comes first. In engineering, you're constantly using your brain. It can be mentally *exhausting*. So prioritizing mental health would be one of the biggest things that I do to avoid burnout. (Victoria)

In addition to prioritizing mental health, some participants recommended adjusting personal schedules and engaging in de-stressing activities and enjoyable hobbies to counteract the stressful nature of engineering and project-based work. One participant shared,

Honestly, leaving school and starting work full time has been challenging [...] When I first started [work], it was really hard having that work-life balance because I would come to work and then be tired after and just go home and not do anything. So it's finding time just to take for yourself and do stuff for yourself, like waking up earlier to work out and then going home and cooking a meal and… just work-life balance is the hardest part. (Sam)

Sam emphasized that carving out even small portions of the day to commit to self-care had been impactful in helping her create a better work-life balance.

Another challenge that arose across all participant narratives was the pressure they felt as underrepresented engineers (i.e., women or Black women) to work harder to prove themselves and their abilities. This often resulted in taking on too many tasks and working hours and an internal fear of speaking up to ask for support or assistance. This resulted in increased stress and even feelings of burnout early in their career. One participant shared that setting boundaries and asking for help when needed was something she believed would help her succeed in the field.

I need to set more boundaries. My supervisor will ask me to do something, and I will do it. But I tend to be like 'No worries, I could do it right now.' And not like take a step back and be like *Can I?, Do I need anything else before I start doing it?, Do I need to tell them anything?* [...] I'm still trying to figure out how to get into the groove of working which is still very fresh. (Sandy)

Sandy reflected that she often immediately agrees to complete tasks right away to please her supervisor. However, she recognized it might be helpful to pause and evaluate the nature of the tasks and decide if there is any support or resources she might need.

Theme 2: Early career women recognize the significance of self-assurance, confidence, assertiveness, resilience, and seeking guidance or support for successfully navigating the transition into the engineering workforce.

In addition to battling external pressures associated with demanding workloads and high stress cultures in engineering workplaces, the early career women in this study were grappling with internal thoughts and pressures to prove themselves and their worth in the engineering workplace. One participant shared that having self-assurance and challenging these negative thoughts were useful skills in overcoming some of these internal challenges. She shared,

Just reminding myself I'm doing a good job. Honestly, I don't need to make up problems that don't exist. Like no one has said to me, ‘Hey, can you do this faster?’ ‘You're not learning fast enough.’ And I think internally I just need to remind myself that if a problem does arise, it will be brought up. My team is very communicative. I don't need to make it up in my head that I'm not doing a good enough job if they’re not telling me that. (Sandy)

Sandy emphasized that there were problems and challenges occurring in her head that were not being communicated to her directly by her team. She emphasized the importance of reminding herself of her skills, abilities, and past successes. Another participant emphasized the importance of gaining confidence in her engineering abilities and competence through work experiences. She shared,

Going into my first internship, I felt like a little baby[…] I didn't know anything about having a real job. The main theme of everywhere I've worked and my growth throughout my career thus far is just *gaining confidence*. And I have had some good mentors who have pushed me along my way and helped me realize that I have a voice that my education can apply to what they're doing, and that I can be independent and not have to worry about completely messing everything up. Little by little, *just gaining that confidence and that knowledge that I am capable and worthy of the spaces that I'm in*. (Brittany)

Brittany shared that she felt inexperienced and shy coming into her first engineering internship and work experiences. However, over time she identified solid mentors who helped support and empower her in these settings. This mentorship and maturity in her career resulted in her gaining confidence around her capabilities, worth, and belonging in engineering settings. Brittany further emphasized the importance of identifying role models and developing relationships with them to build confidence.

There's one girl. She was just very outspoken. Just very confident, not afraid to voice her opinion. And I think people really respected her for that. And I thought she was cool. So I've actually kept a relationship with her. (Brittany)

Brittany emphasized that identifying role models and mentors that shared a similiar identity was essential when entering an engineering career as an underrepresented engineer.

In a corporate [engineering] office settings just having those mentors and people that you can go to and voice concerns without fear of judgment, someone unbiased, is really important. And then just seeing examples of other women and people who look like you doing higher level work and not just… sitting on the sidelines […] just having that mindset of being open to everyone being friendly. And just being willing to work with people. (Brittany)

Across all participant narratives, establishing strong personal relationships and activating social capital by reaching out and asking for help when needed was critical to the success of these women in engineering spaces. Sam shared, “They toss you into the deep end, but that's the best way to learn. You ask a lot of questions and get exposed to a lot. That way you progress”. Another participant, China, emphasized the importance of resilience and asking for help. Even after negative interactions with her coworkers and feelings of exclusion, China expressed resilience and dedication to building relationships and seeking guidance. She shared,

You have to be willing to try again and not be so close minded as far as making relationships on the team. I even asked the guy that I don't like a question and he actually helped me. I had to push myself to do it because honestly, I didn't want to ask him, but I'm growing and I'm maturing and, I asked him and he helped me [...] I think just doing my part to develop stronger relationships, it's going good. I know it's going to take time with some people versus others, but I feel like it's going good direction. (China)

China emphasized the importance of strengthening team relationships and asking for help and support when needed. Kelsey reflected that to be successful as a new engineer requires overcoming fear of failure, trying new things, taking risks, getting comfortable with discomfort, and learning from mistakes. She shared,

One thing that a lot of students have is a “fear of failure.” I feel like women especially are scared to be wrong, so they are scared to try. This can really hold you back, so it’s important for new engineers to be willing to make mistakes as long as they are trying new things otherwise you won’t grow at all. You have to be willing to make yourself uncomfortable and put yourself in new/unfamiliar situations. (Kelsey)

4 SUMMARY

4.1 Discussion

This study highlights potential antecedents of positive outcomes for women in the engineering workforce, emphasizing the importance of work-life balance, self-confidence, assertiveness, resilience, developing strong relationships, and seeking guidance. These insights are crucial for empowering women during their transition into the engineering workforce. It also aligns with prior research highlighting the significance of relational factors, such as collaboration and feedback, for women's early career success (Marinelli et al. 2022). This study adds to the literature on the importance of relational empowerment (i.e., interactions that promote or prohibit autonomy in engineering work) and promoting student agency to practice and develop skills in the workplace (Lutz et al. 2019). Relational empowerment can be improved by granting early career individuals more control over decisions, tasks, and assignments (Lutz et al. 2019).

Additionally, the study reveals the internal challenges faced by early career women, including self-doubt, imposter syndrome, and pressure to excel. These challenges disproportionately impact underrepresented groups, notably Black women, who often experience heightened self-doubt and external pressures (Ross 2016; Smith et al. 2019). To sustain their engineering careers, these women found skills such as boundary setting, prioritizing stress-relieving activities, and seeking mentorship as useful in transitioning to engineering careers. These strategies helped participants navigate the invisible labor challenges associated with their underrepresentation and enhance career sustainability.

Recommendations for industry leaders and educators include providing positive reinforcement, mentorship opportunities, and support during the transition into the workforce. Engineering educators, faculty advisors, and mentors should provide opportunities for students to hear from and interact with women in engineering who have successfully navigated the transition from school to the engineering workforce and who are willing to share skills or advice they wish they had before they entered engineering careers. These encounters can contribute to fostering positive outcomes for early career women and emphasize the importance of social capital (i.e., access or availability of social networks that result in outcomes such as resources, jobs, information, support, or guidance (Lin 1999)) as students transition to the engineering workplace. Despite being based in the US, these findings are relevant globally, as studies in Europe also reveal similar challenges and disparities faced by women in engineering (Powell et al. 2012; Cannaerts et al. 2023).

In summary, this study underscores the internal and external challenges faced by early career women in engineering, offers skills and strategies for overcoming these challenges, and calls for comprehensive support systems to promote their success and inclusivity in the engineering workforce.

4.2 Limitations and Future directions for research

This research examined the lived experiences and reflections of a small sample population. Although the data's generalizability to all populations is limited, the findings may be transferable to those with similar identities working in similar fields. Future research should explore how, as part of their educational experience, women might develop competencies needed for a successful transition to the workforce. Further research could explore these transitions in different engineering disciplines and cultures.

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REFERENCES

Bae, Hwangbo, Madeline Polmear, and Denise R. Simmons. 2022. “Bridging the Gap between Industry Expectations and Academic Preparation: Civil Engineering Students’ Employability.” *Journal of Civil Engineering Education* 148 (3): 04022003. https://doi.org/10.1061/(ASCE)EI.2643-9115.0000062.

Beddoes, Kacey. 2019. “First Year Practicing Civil Engineers’ Challenges.” In *AAEE*, 7.

Beddoes, Kacey. 2022. “Gender as Structure in the Organisational Socialisation of Newcomer Civil Engineers.” *European Journal of Engineering Education* 47 (1): 102–16. https://doi.org/10.1080/03043797.2021.1915251.

Braun, Virginia, and Victoria Clarke. 2006. “Using Thematic Analysis in Psychology.” *Qualitative Research in Psychology* 3 (2): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Buse, Kathleen, Diana Bilimoria, and Sheri Perelli. 2013. “Why They Stay: Women Persisting in US Engineering Careers.” *Career Development International* 18 (2): 139–54. https://doi.org/10.1108/CDI-11-2012-0108.

Cannaerts, Mieke, Sofie Craps, Veerle Draulans, and Greet Langie. 2023. “A Look Inside The Engineering Students’ Backpack: Differences In Engineering Capital According To Gender Or Migration Background.” https://doi.org/10.21427/MZBQ-S627.

Chance, Shannon, Inez Direito, and J. Mitchell. 2020. “Understandings of "Global Responsibility’ Expressed By Civil Engineers Working in London.” https://doi.org/10.21427/46QH-GG22.

Chew, Yin Teng Elaine, Erhan Atay, and Serkan Bayraktaroglu. 2020. “Female Engineers’ Happiness and Productivity in Organizations with Paternalistic Culture.” *Journal of Construction Engineering and Management* 146 (6): 05020005. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001834.

Creswell, John. 2020. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. https://www.google.com/books/edition/Qualitative_Inquiry_and_Research_Design/Ykruxor10cYC?hl=en&gbpv=1&dq=john+W.+Creswell.+%E2%80%9CQualitative+Inquiry+and+Research+Design:+Choosing+Among+Five+Approaches.&printsec=frontcover.

Enshassi, A., S. Ihsen, and K. Al Hallaq. 2008. “The Perception of Women Engineers in the Construction Industry in Palestine.” *European Journal of Engineering Education* 33 (1): 13–20. https://doi.org/10.1080/03043790701745944.

Francis, Valerie, and Elisabeth Michielsens. 2021. “Exclusion and Inclusion in the Australian AEC Industry and Its Significance for Women and Their Organizations.” *Journal of Management in Engineering* 37 (5): 04021051. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000929.

Harper, Shaun R. 2010. “An Anti-Deficit Achievement Framework for Research on Students of Color in STEM.” *New Directions for Institutional Research* 2010 (148): 63–74. https://doi.org/10.1002/ir.362.

“International Women in Engineering Day 2022.” 2022. United Nations. June 23, 2022. https://www.un.org/technologybank/news/international-women-engineering-day-2022-malambo-and-tebello%E2%80%99s-stories-studying-industrial#.

Jensen, Karin J., and Kelly J. Cross. 2021. “Engineering Stress Culture: Relationships among Mental Health, Engineering Identity, and Sense of Inclusion.” *Journal of Engineering Education* 110 (2): 371–92. https://doi.org/10.1002/jee.20391.

Lin, Nan. 1999. *Building a Network Theory of Social Capital’*.

Loosemore, Martin, and Tom Waters. 2004. “Gender Differences in Occupational Stress Among Professionals in the Construction Industry.” *Journal of Management in Engineering* 20 (3): 126–32. https://doi.org/10.1061/(ASCE)0742-597X(2004)20:3(126).

Lutz, Benjamin David, Nathan E. Canney, and Samantha Ruth Brunhaver. 2019. “‘I Wish I Could Do More’: A Qualitative Meta-Analysis of Early Career Engineers’ Perceptions of Agency in Their Workplaces.” In .

https://peer.asee.org/i-wish-i-could-do-more-a-qualitative-meta-analysis-of-early-career-engineers-perceptions-of-agency-in-their-workplaces.

Marinelli, Melissa Jane, Linley Lord, and Sally Male. 2022. “Early Career Patterns, Experiences, and Influences: Reflections from Women Engineers in Senior Roles.” In *Towards a New Future in Engineering Education, New Scenarios That European Alliances of Tech Universities Open Up*, 510–19. Universitat Politècnica de Catalunya. https://doi.org/10.5821/conference-9788412322262.1361.

“National Science Board: Vision 2030.” 2020. NSF.

Powell, Abigail, Barbara Bagilhole, and Andrew Dainty. 2009. “How Women Engineers Do and Undo Gender: Consequences for Gender Equality.” *Gender, Work & Organization* 16 (4): 411–28. https://doi.org/10.1111/j.1468-0432.2008.00406.x.

Powell, Abigail, Andrew Dainty, and Barbara Bagilhole. 2012. “Gender Stereotypes among Women Engineering and Technology Students in the UK: Lessons from Career Choice Narratives.” *European Journal of Engineering Education* 37 (6): 541–56. https://doi.org/10.1080/03043797.2012.724052.

Ross, Monique S. 2016. “A Unicorn’s Tale: Examining the Experiences of Black Women in Engineering Industry.”

Ross, Monique S., James L. Huff, and Allison Godwin. 2021. “Resilient Engineering Identity Development Critical to Prolonged Engagement of Black Women in Engineering.” *Journal of Engineering Education* 110 (1): 92–113. https://doi.org/10.1002/jee.20374.

Saldaña, Johnny. 2013. *The Coding Manual for Qualitative Researchers*. 2nd ed. Los Angeles: SAGE.

Simmons, Denise R., Cassandra McCall, and Nicholas A. Clegorne. 2020. “Leadership Competencies for Construction Professionals as Identified by Construction Industry Executives.” *Journal of Construction Engineering and Management* 146 (9): 04020109. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001903.

Smit, Renee. 2023. “First-Generation Engineering Students’ Identity Development: Early Forays Into The Workplace.” *SEFI*.

Smith, Alexis, Marla Baskerville, Jamie Ladge, and Pamela Carlton. 2019. “Making the Invisible Visible: Paradoxical Effects of Intersectional Invisibility on the Career Experiences of Executive Black Women in the Workplace.” *Academy of Management Journal* 62 (June). https://doi.org/10.5465/amj.2017.1513.

A COMPARATIVE SCIENTOMETRIC ANALYSIS OF DIVERSITY, EQUITY, AND INCLUSION (DEI) PUBLICATIONS IN EUROPEAN JOURNAL OF ENGINEERING EDUCATION AND JOURNAL OF ENGINEERING EDUCATION

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ABSTRACT

It remains the case that the engineering profession fails to reflect the diversity of people impacted by its work, and issues of diversity, equity and inclusion (DEI) continue to be a key area of interest within engineering education research (EER). In this work we aim to understand the focus of DEI within engineering education: we applied a scientometric content analysis to EJEE and JEE articles published in 2023. Three authors independently screened each publication (using the title and abstract) for inclusion in the subsequent analysis and synthesis stage. The abstract of each paper was then evaluated to determine the primary DEI issue(s) covered. Findings indicate that DEI is currently a major focus for US scholars with 42% of the 71

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publications in JEE addressing DEI in some form. Articles studying underrepresented racial groups (43% of DEI articles identified) made up the largest part of these publications while 23% considered gender related under-representation. In the case of EJEE there were fewer DEI related papers overall in 2023: 15% of the 86 publications addressed DEI in some form. Of these publications 77% referred to gender related under-representation, which suggests that this area of DEI is currently the most studied by EJEE-published researchers

1 INTRODUCTION

Issues of diversity, equity and inclusion (DEI) have long been discussed within engineering education and practice, with the rationale for work in the area including a variety of arguments based on social justice to economics. Terms such as inclusion, diversity, equity, and equality, while commonly used within engineering education, tend to be used interchangeably and their meaning both evolves over time, and varies significantly across context and institution. Such changes and variation have implications for the areas in which efforts towards DEI, are focused, as well as our ability to learn from good practice and monitor progress. One way in which to gauge the areas of DEI that are of current interest is by understanding the common issues researched. This work therefore describes an analysis of papers published within the Journal of Engineering Education (JEE) and the European Journal of Engineering Education (EJEE) in 2023, to determine the DEI issues studied.

Scientometric methods have been used to understand the engineering education research (EER) publication landscape previously. For example, when mapping global trends in engineering education research, Jesiek et al. (2011) analysed the categories of research published in a range of journals and conferences between 2005 and 2008 and found that Diversity, classified as including Gender, Masculinity, Minority, Race, Underrepresentation and Women, appeared as 13th in a ranking of the most studied areas (the first three places in their ranking were occupied by Learning, Assessment and Educational Technology respectively).Previous EER in this area includes a content analysis of gender-related research published in JEE over a fourteen year period (1998-2012) whereby scientometric and other classification categories were developed and applied (Pawley, Schimpf, & Nelson, 2016). Articles primarily focused on quantitative studies of undergraduate students in university settings and applied a variety of theories. More recently, in their bibliometric review of papers published within JEE over a 53 period (1969-2021), encompassing 1251 articles, Qiu and Natarajarathinam (2022) identified diversity and inclusion as a major theme that was covered in 106 papers. Topics were found to include gender, student characteristics affecting enrollment and retention, value system and personal identity, and race and ethnicity, among others.

More recently, in a ‘Statement on Diversity and Inclusiveness’, the American Society for Engineering Education (ASEE) claims that “diversity and inclusiveness is essential to… innovations that drive the development of creative solutions in addressing the world’s challenges”. Similarly, in the ASEE & SEFI (French: Société Européenne pour la Formation des Ingénieurs, English: European Society for Engineering Education) Joint Statement on Diversity, Equity, and Inclusion (2020), the organisations claim that “engineers have not consistently made informed judgements that consider equitably the far-reaching societal impacts of engineering solutions" and that "history has shown that new technologies benefiting one part of society sometimes have less fortunate impacts on other segments" saying that "these unintended consequences partially result from an engineering profession with a limited diversity of lived experiences" (p.1). In a Position Paper on Diversity, Equality and Inclusiveness in Engineering Education (SEFI, 2018), SEFI states that "recognizing and supporting diverse individuals is more than a moral or ethical obligation. It is also the logical choice to improve the practice of engineering and its impact on society".

Despite such efforts, the lack of diversity within engineering continues to exist, with our ability to monitor changes in demographics being impacted by our changing and varying understanding of diverse characteristics. Such differences in semantics have been highlighted in the work of Pineda and Mishra (2023) who made use of computer-assisted content analysis to explore the extent to which the term 'diversity' appears to be global and universal within 2378 publications. Their findings reveal that diversity discourses are dominant within the USA and Canada, UK and Ireland and Europe, but not Asia, Africa, the Middle East and Latin America. They found academic literature on diversity to have emerged in the mid-1970s in both the USA and Canada, primarily in relation to race and gender, this extending to other English-speaking countries by the mid-2000s, with inclusion, gender, ethnicity and cultural diversity being referenced. Within Europe, diversity appeared later in the decade, often framed as inclusion and gender. They concluded that the interpretation was influenced by the local socio-political settings and that the semantics of diversity had not become global or universal.They subsequently proposed the use of new methods that allow and support the ability to view different regions simultaneously.

Given these differences in interpretation, it is encouraging that ASEE & SEFI call for a commitment to "deepen and broaden our understanding of inequities, so that we are prepared to take action to transform our institutions, universities, and the whole of the engineering community" (p. 2) within their Joint Statement on Diversity, Equity, and Inclusion (2020). The organisations claim that "steady gains have been made" in terms of "decreasing imbalance for white women" but acknowledge that progress is needed with respect to "all segments of our society, including minoritized races, immigrant populations, disabled persons, and economically marginalized groups". claim that it is "our engineering duty that no one is disadvantaged or receives less favourable treatment because of age, disability, neurodiversity, gender, gender identity and expression, sexual orientation, race, ethnicity, religion or belief, socio-economic status, national status, pregnancy and maternity, marriage and civil partnership, or any other minority status" (p. 3)

In keeping with such commitments, it is interesting to note that (what was) the SEFI *Gender and Diversity* Special Interest Group (SIG), changed their name to *Diversity, Equity and Inclusion* saying that they "embrace a broad understanding of diversity, equity and inclusion and work to better represent all SEFI members and the wider engineering education community. It is our experience that definitions of diversity, equity and inclusion vary considerably between different contexts and institutions, and that many initiatives have been primarily concerned with widening the participation of women in engineering".

As pointed out by Meija and Martin (2023) the fact that researchers use the same terms, whilst defining them and measuring them in different ways, makes it difficult to discuss DEI work meaningfully. Considerations for these broad understandings are of significance in terms of our ability to learn from best practice and make use of research findings within our own context, but also in supporting our ability to monitor progress and inform strategy and policy in the area. It is subsequently of interest to investigate and compare the focus of DEI research within engineering education. Consistent with this aim, here we present initial findings of a study involving the analysis of EJEE and JEE articles published in 2023 in terms of the primary DEI issue(s) covered.

This study aims to determine the current DEI issues under focus in two leading journals in the EER field. It poses the research question:

- what are the DEI topics addressed in the European Journal of Engineering Education and the Journal of Engineering Education in 2023?

2 METHODOLOGY

Adopting a scientometric content analysis approach (Hassan & Mathiassen, 2009), a list of all publications (including articles, editorials and erratum) in EJEE and JEE during 2023 were downloaded from the Scopus web interface. There were 86 EJEE publications and 71 JEE publications in 2023. We limit this work to the main EER journals, namely JEE, and EJEE which, as Jesiek et al. (2011) observe, have committed to publishing and disseminating high quality EER work, are highly cited journals. They are published by the American and European Societies for Engineering Education respectively, both of whom collaborated on the ASEE & SEFI Joint Statement on Diversity, Equity, and Inclusion (2020). We therefore chose JEE as a representative of US and EJEE of European EER journals. Furthermore, both journals specifically refer to EER in their scope.

Publications were vetted for inclusion in two main stages.The purpose of the first stage was to restrict the list to only those that discussed at least one DEI issue (Direito et al., 2021). The second stage focused on classifying the included papers into specific DEI categories that would subsequently be used for statistical analysis.

First, three authors independently screened each publication (using the title and abstract) for inclusion in the subsequent analysis and synthesis stage. Publications were tagged by the author for inclusion included using a binary yes/no inclusion criteria; publications that explicitly referred to any DEI issue within the title and/or abstract were tagged as ‘yes’. Following this, the authors met to compare their evaluations and any disagreements were resolved during discussion in which a consensus as to whether each article was to be included or excluded, was reached. Following this, the authors then evaluated each abstract together to inductively determine the primary DEI issue(s) covered, and allocated publications to these categories.

Editorials were included as they were considered to reflect emerging and significant areas of interest within the context. They have, alongside review papers, been separated from research papers in terms of analysis (see Table 3, Table 4). Abstracts in which DEI was not mentioned as a primary aim or focus of the research, but in which elements of DEI were mentioned or reported in the findings were included on the basis that they demonstrated an understanding of the impact of diverse characteristics on research outcomes. However, results are again presented separately (Table 2 and Table 6). Papers focused on belonging were also included to reflect the (often lesser used) term DEIB (Diversity, Equity, Inclusion, and Belonging), which originated in organisations in the 1960s and which recognises sense of belonging as associated with inclusion. Finally, abstracts which referred to 'mental health' were included as they were considered to relate more directly to ableism and disability as opposed to those who broadly referenced wellbeing.

The full-text of each paper was not evaluated, as it was outside the intended scope of this paper. We thus acknowledge that our analysis may have excluded papers that discuss diverse characteristics, for example within the findings, without this being mentioned in the abstract. The findings reflect the focus of journal articles published within 2 journals during a year one period and the degree to which they reflect wider trends is thus limited. We also recognise that published work only reflects a small amount of DEI work conducted within engineering education, and the validity of our findings are thus limited by the extent to which trends in published articles reflect the situation more widely.

3 RESULTS

Papers were assigned an individual ID (e.g. EJEE-3, JEE-18) based on the row in the spreadsheet exported from Scopus. e.g. EJEE-15 refers to the publication on the fifteenth row of the exported spreadsheet. The results below are presented first showing the results from EJEE, then the results from JEE.

3.1 European Journal of Engineering Education

There were 86 EJEE publications in our sample from 2023. A total of 9.3% of the publications primarily focused on addressing at least one specific DEI issue, with 7.0% focusing on gender related issues, 1.2% focused on belonging or inclusion, and 1.2% focused on diversity of nationality (Table 1). There were also another 6.8% of the publications which did not primairly focus on DEI issues, but included metrics or information related to DEI in the results or findings (Table 2).

Table 1. EJEE Articles which primarily focused on a DEI issue(s)

DEI Issue	%	Publications
Gender	7.0%	EJEE-02 Rokooei (2023) EJEE-09 Vellamo (2023) EJEE-11 Maji, Mitra, and Asthana (2023) EJEE-23 Chan, Rottmann, Reeve, Moore, Maljkovic, and Radebe (2023) EJEE-28 Qadhi, Du, Chaaban, Al-Thani, and Floyd (2023) EJEE-52 Moloney and Ahern (2023)
Belonging/Inclusion	1.2%	EJEE-38 Holmegaard, Madsen, and Nielsen (2023)
Diversity of Nationality	1.2%	EJEE-30 Bergman, Negretti, and Apelgren (2023)

Table 2. EJEE Articles which primarily focused on other issues, but included DEI in the results or findings

DEI Issue	%	Publications
Gender	4.6%	EJEE-22 Lockhart, and Rambo-Hernandez (2023) EJEE-37 Apostolellis, Taggart, and Schwartz (2023) EJEE-55 Behera, Alves de Sousa, Oleksik, Dong, and Fritzen (2023) EJEE-64 Chédru and Delhoume (2023)
Access/ Participation	1.2%	EJEE-73 Wint (2023)

3.2 Journal of Engineering Education

There were 71 JEE publications in our sample from 2023. A total of 30 (42%) publications primarily focused on addressing at least one specific DEI issue (Tables 3, 4, 5), with marginalised racial groups (18.3% total - articles 14.1%, review 1,4%, editorial 1.4%) gender (7.0% total - articles 7.0%), belonging (4.2% total - articles 4.2%) and mental health (4.2% total - articles 2.8%, review 1.4%) being the largest categories. Smaller categories included diversity of nationality, disability, historical marginalised groups only having 1.2% each. There were also another 5.6% of the publications which did not primarily focus on DEI issues, but included metrics or information related to DEI in the results or findings (Table 6). Overall, 43% of the 30 articles identified, were dealing with under-represented racial groups while 23% gender-related under-representation.

Table 3. JEE Editorials which primarily focused on a DEI issue

DEI Issue	%	Publications
Marginalized Racial Groups	2.8%	JEE-08 Secules (2023) JEE-12 Paige, and Morton (2023)
Diversity of Nationality	1.4%	JEE-14 Xu, Wei, and Cao (2023)

Table 4. JEE Review Papers which primarily focused on a DEI issue

DEI Issue	%	Publications
Marginalized Racial Groups	1.4	JEE-39 Reeping, Lee, and London (2023)
DEI (generally)	1.4	JEE-53 Andrews, and Boklage (2023)
Mental Health	1.4	JEE-71 Asghar, Minichiello, and Ahmed (2023)

Table 5. JEE Articles which primarily focused on a DEI issue(s)

DEI Issue	%	Publications

Gender	7.0	JEE-21 Patrick, Andrews, Riegle-Crumb, Kendall, Bachman, and Subbian (2023) JEE-24 Davis, Nolen, Cheon, Moise, and Hamilton (2023) JEE-25 Garriott, Pinedo, Hunt, Navarro, Flores, Desjarlais, Diaz et al (2023) JEE-37 Halkiyo, and Hailu (2023) JEE-59 Chen, Usher, Roeder, Johnson, Kennedy, and Mamaril (2023)
Marginalized Racial Groups	14.1	JEE-21 Patrick, Andrews, Riegle-Crumb, Kendall, Bachman, and Subbian (2023) JEE-24 Davis, Nolen, Cheon, Moise, and Hamilton (2023) JEE-25 Garriott, Pinedo, Hunt, Navarro, Flores, Desjarlais, Diaz et al (2023) JEE-37 Halkiyo, and Hailu (2023) JEE-39 Reeping, Lee, and London (2023) JEE-47 Coley, and Thomas (2023) JEE-52 Henderson, Junqueira, Benjamin, Hines, Alarcón, Davis, and Cavazos (2023) JEE-61 Taylor Jr, Mastrogiovanni, Lakin, and Davis (2023) JEE-66 Fleming, Coloyan, Patrick, Grote, Denton, Knight, Lee, Borrego, and Murzi (2023) JEE-68 Fletcher, Jefferson, Boyd, Park, and Crumpton-Young (2023)
Belonging	4.2	JEE-21 Patrick, Andrews, Riegle-Crumb, Kendall, Bachman, and Subbian (2023) JEE-63 Buckley, Robinson, Tretter, Biesecker, Hammond, and Thompson (2023) JEE-68 Fletcher, Jefferson, Boyd, Park, and Crumpton-Young (2023)
Mental Health	2.8	JEE-23 Wright, Wilson, Hammer, Hargis, Miller, and Usher (2023) JEE-71 Asghar, Minichiello, and Ahmed (2023)
Disability	1.4	JEE-67 Cech (2023)
Historically Excluded/ Marginalised Groups	1.4	JEE-06 Lee, Hall, Josiam, and Pee (2023)
DEI (generally)	1.4	JEE-53 Andrews, and Boklage (2023)

Table 6. JEE Articles which primarily focused on other issues, but included DEI in the results or findings

DEI Issue	%	Publications
Gender	2.8	JEE-16 Rocker Yoel, and Dori (2023) JEE-31 Beagon, and Bowe (2023)
Marginalized Racial Groups	1.4	JEE-27 Misra, Kardam, VanAntwerp, and Wilson (2023)
Belonging	1.4	JEE-27 Misra, Kardam, VanAntwerp, and Wilson (2023)

4 DISCUSSION

Given that the researchers whose work is published in JEE are predominantly US-based (Williams, Wankat & Neto 2018), our findings suggest that DEI is currently a major focus for US scholars with 30 of the 71 (42%) publications addressing DEI in some form. Underrepresented racial groups (43% of DEI articles identified) made up the largest part of these publications while 23% considered gender related under-representation. Other DEI contexts appearing in JEE included belonging, disability, mental health and diversity of nationality.

In the case of EJEE there were fewer DEI related papers overall in 2023: 15% of the 86 publications addressed DEI in some form. Of these publications 77% referred to gender related under-representation, which suggests that this area of DEI is currently the most studied by EJEE-published researchers. While authors in EJEE predominantly are Europe-based, they also include researchers from the US and other international contexts (Williams, Wankat & Neto 2018). Other DEI contexts appearing in EJEE included diversity of nationality and belonging.

The methodology presented here can be readily adapted to analyse a larger sample of journal articles and the authors plan to do this in future work.

CONCLUSION

While DEI issues were 13th in the ranking of the most studied areas in EER in the period 2003-2008 (Jesiek et al., 2011), they have become a high-priority area in recent years with race and gender issues being the most addressed in JEE publications and gender the most in EJEE. These findings will be helpful to inform the work of groups like the SEFI Special Interest Groups on Diversity, Equity and Inclusion and on Ethics as well as the ASEE ASEE Commission on Diversity, Equity and Inclusion.

REFERENCES

Andrews, Madison E., and Audrey Boklage. "Supporting inclusivity in STEM makerspaces through critical theory: A systematic review." *Journal of Engineering Education* (2023). (early online access)

Apostolellis, Panagiotis, Jessica Taggart, and R. X. Schwartz. "Creating effective project-based courses: personal relevance and its relations to successful group work." *European Journal of Engineering Education* 48, no. 6 (2023): 1165-1185.

Asghar, Muhammad, Angela Minichiello, and Shaf Ahmed. "Mental health and wellbeing of undergraduate students in engineering: A systematic literature review." *Journal of Engineering Education* (2023).

Beagon, Una, and Brian Bowe. "Understanding professional skills in engineering education: A phenomenographic study of faculty conceptions." *Journal of Engineering Education* 112, no. 4 (2023): 1109-1144.

Behera, Amar Kumar, Ricardo Alves de Sousa, Valentin Oleksik, Jingyan Dong, and Daniel Fritzen. "Student perceptions of remote learning transitions in engineering disciplines during the COVID-19 pandemic: a cross-national study." *European Journal of Engineering Education* 48, no. 1 (2023): 110-142.

Bergman, Becky, Raffaella Negretti, and Britt-Marie Apelgren. "Individual experiences of intercultural group work in engineering education over time: beyond 'home'and 'international'labels." *European Journal of Engineering Education* 48, no. 1 (2023): 143-156.

Brown, H. Paige, and Terrell R. Morton. "Sick and tired of being sick and tired." *Journal of Engineering Education* 112, no. 1 (2023): 7-11.

Buckley, J. B., B. S. Robinson, T. R. Tretter, C. Biesecker, A. N. Hammond, and A. K. Thompson. "Belonging as a gateway for learning: First-year engineering students' characterizations of factors that promote and detract from sense of belonging in a pandemic." *Journal of Engineering Education* 112, no. 3 (2023): 816-839.

Cech, Erin A. "Engineering ableism: The exclusion and devaluation of engineering students and professionals with physical disabilities and chronic and mental illness." *Journal of engineering education* 112, no. 2 (2023): 462-487.

Chédru, Marie, and Catherine Delhoume. "How does studying abroad affect engineering students' intercultural competence: A longitudinal case study." European *Journal of Engineering Education* 48, no. 3 (2023): 375-390.

Chan, Andrea, Cindy Rottmann, Doug Reeve, Emily Moore, Milan Maljkovic, and Dimpho Radebe. "Making the path to engineering leadership more equitable: illuminating the (gendered) supports to leadership." *European Journal of Engineering Education* 48, no. 6 (2023): 1249-1268.

Chen, Xiao-Yin, Ellen L. Usher, Madelyn Roeder, Alecia R. Johnson, Marian S. Kennedy, and Natasha A. Mamaril. "Mastery, models, messengers, and mixed emotions: Examining the development of engineering self-efficacy by gender." *Journal of Engineering Education* 112, no. 1 (2023): 64-89.

Coley, Brooke, and Katreena Thomas. "“the lab isn't life”: Black engineering graduate students reprioritize values at the intersection of two pandemics." Journal of Engineering Education 112, no. 2 (2023): 542-564.

Davis, Susannah C., Susan Bobbitt Nolen, Naeun Cheon, Elba Moise, and Eric William Hamilton. "Engineering climate for marginalized groups: Connections to peer relations and engineering identity." Journal of Engineering Education 112, no. 2 (2023): 284-315.

Direito, Ines, Shannon Chance, Lisa Clemmensen, Sofie Craps, Sophia B. Economides, Sierra S. Isaac, Anne-Marie Jolly, Fiona R. Truscott, and Natalie Wint. "Diversity, Equity, and Inclusion in Engineering Education: an Exploration of European Higher Education Institutions' Strategic Frameworks, Resources, and Initiatives." In *SEFI 49th Annual Conference Proceedings 2021*, pp. 189-193. SEFI-European Society for Engineering Education; Brussels, 2021.

Fleming, Gabriella Coloyan, Anita D. Patrick, Dustin Grote, Maya Denton, David Knight, Walter Lee, Maura Borrego, and Homero Murzi. "The fallacy of “there are no candidates”: Institutional pathways of Black/African American and Hispanic/Latino doctorate earners." Journal of Engineering Education 112, no. 1 (2023): 170-194.

Fletcher, Trina L., Jay P. Jefferson, Brittany Boyd, Sung Eun Park, and Lesia Crumpton-Young. "Impact of COVID-19 on sense of belonging: Experiences of engineering students, faculty, and staff at Historically Black Colleges and Universities (HBCUs)." Journal of Engineering Education 112, no. 2 (2023): 488-520.

Garriott, Patton O., Ayli Carrero Pinedo, Heather K. Hunt, Rachel L. Navarro, Lisa Y. Flores, Cerynn D. Desjarlais, David Diaz et al. "How Latiné engineering students resist White male engineering culture: A multi-institution analysis of academic engagement." Journal of Engineering Education 112, no. 3 (2023): 695-718.

Halkiyo, Atota B., and Meseret F. Hailu. "Black women's placemaking in undergraduate engineering." Journal of Engineering Education 112, no. 4 (2023): 918-937.

Hassan, Nik, and Lars Mathiassen. "Combining Scientometric and Content Analysis Methods for Identifying Core Concepts and Action Principles of Information Systems Development."

Henderson, Jerrod A., Waldemiro Junqueira, Le Shorn S. Benjamin, Erik M. Hines, Jeannette D. Alarcón, Jared L. Davis, and Sebastian Cavazos. "Circle of success—An interpretative phenomenological analysis of how Black engineering students experience success." Journal of Engineering Education 112, no. 2 (2023): 403-417.

Holmegaard, Henriette Tolstrup, Lene Møller Madsen, and Katia Bill Nielsen. "‘You have to ask the right questions': a spatial analysis of the sense of belonging within higher education computer science." European Journal of Engineering Education 48, no. 6 (2023): 1037-1050.

Jesiek, B. K., Maura Borrego, Kacey Beddoes, Miguel Hurtado, and Preeti Rajendran. "Mapping global trends in engineering education research 2005-2008." The International journal of engineering education 27, no. 1 (2011): 77-90.

Lee, Walter C., Janice L. Hall, Malini Josiam, and Crystal M. Pee. "(Un) equal demands and opportunities: Conceptualizing student navigation in undergraduate engineering programs." Journal of Engineering Education 112, no. 4 (2023): 890-917.

Lockhart, Mary Elizabeth, and Karen Rambo-Hernandez. "Investigating engineering identity development and stability amongst first-year engineering students: a person-centred approach." European Journal of Engineering Education (2023): 1-23. (early online access)

Maji, Sucharita, Sharmili Mitra, and Manish Kumar Asthana. "'Treading the no woman's land': the gender-STEM dynamics in higher education in premier institutions of India." European Journal of Engineering Education 48, no. 3 (2023): 422-447.

Misra, Shruti, Neha Kardam, Jennifer VanAntwerp, and Denise Wilson. "How did the landscape of student belonging shift during COVID-19?." Journal of Engineering Education 112, no. 4 (2023): 861-889.

Moloney, Grace, and Aoife Ahern. "Exploring the positive factors supporting women's decisions to study undergraduate engineering." European Journal of Engineering Education 48, no. 6 (2023): 1335-1350.

Patrick, Anita, Madison Andrews, Catherine Riegle-Crumb, Meagan R. Kendall, John Bachman, and Vignesh Subbian. "Sense of belonging in engineering and identity centrality among undergraduate students at Hispanic-Serving Institutions." Journal of Engineering Education 112, no. 2 (2023): 316-336.

Pawley, A.L., Schimpf, C. and Nelson, L. (2016), Gender in Engineering Education Research: A Content Analysis of Research in *JEE*, 1998–2012. J. Eng. Educ., 105: 508-528.

Pineda, P., Mishra, S. The semantics of diversity in higher education: differences between the Global North and Global South. *High Educ* **85**, 865–886 (2023). https://doi.org/10.1007/s10734-022-00870-4

Qadhi, Saba, Xiangyun Du, Youmen Chaaban, Hessa Al-Thani, and Alan Floyd. "The role identities of women middle management academic leaders in STEM higher education." European Journal of Engineering Education (2023): 1-17. (early online access)

Qiu, S., & Natarajarathinam, M. (2023). Fifty-three years of the *Journal of Engineering Education*: A bibliometric overview. *Journal of Engineering Education*, 1–20. (early online access)

Reeping, David, Walter Lee, and Jeremi London. "Person-centered analyses in quantitative studies about broadening participation for Black engineering and computer science students." Journal of Engineering Education 112, no. 3 (2023): 769-795.

Rocker Yoel, Shahaf, and Yehudit Judy Dori. "Interpersonal skills and STEM career choice of three types of FIRST mentors." Journal of Engineering Education 112, no. 4 (2023): 987-1011.

Rokooei, Saeed. "Analysis of engineering and construction students' perceptions to explore gender disparity." European Journal of Engineering Education 48, no. 6 (2023): 1051-1067.

Secules, Stephen. "On the importance of (white) humility: Epistemological decentering as a positional orientation toward research." Journal of Engineering Education 112, no. 2 (2023): 258-261.

Taylor Jr, Leonard, Margaret Mastrogiovanni, Joni M. Lakin, and Virginia Davis. "Give and gain: Black engineering students as near-peer mentors." *Journal of Engineering Education* 112, no. 2 (2023): 365-381.

Vellamo, Tea. "Gendered identities in a university merger–female academics' identifications in technical fields." *European Journal of Engineering Education* 48, no. 2 (2023): 267-283.

Williams, Bill, Phillip C. Wankat, and Pedro Neto. "Not so global: a bibliometric look at engineering education research." *European Journal of Engineering Education* 43, no. 2 (2018): 190-200.

Wint, Natalie. "Why do students choose to study on engineering foundation year programmes within the UK?." *European Journal of Engineering Education* 48, no. 1 (2023): 157-179.

Wright, Courtney J., Sarah A. Wilson, Joseph H. Hammer, Lucy E. Hargis, Melanie E. Miller, and Ellen L. Usher. "Mental health in undergraduate engineering students: Identifying facilitators and barriers to seeking help." Journal of Engineering Education 112, no. 4 (2023): 963-986.

Xu, Xinrui, Siqing Wei, and Yi Cao. "Moving beyond the “international” label: A call for the inclusion of the (in) visible international engineering students." Journal of Engineering Education 112, no. 2 (2023): 253-257.

EJEE THIS CENTURY IN THE WORDS OF TWO EDITORS-IN-CHIEF

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ABSTRACT

This paper uses an oral history approach to present an account of the evolution of the European Journal of Engineering Education over the last 16 years. In the words of two Editors-in-Chief it traces the process whereby the journal has become a home for high quality research in engineering education both in Europe and globally. The journal has adapted to a notable increase in submissions by broadening its editorial staff and defining its aims and scope to attract research that combines scholarliness and usefulness. At the same time, EJEE has consciously worked at building a broad community of scholars through the SEFI conferences and its networks. In addition it has assumed a role in pro-actively guiding and sharing research by introducing a new special-issue process.

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1 INTRODUCTION

1.1 Engineering Education Research: historical context

While formal education in engineering began in France with the establishment of the École Polytechnique in 1794, publication of research into engineering education (EER) gathered impetus in the1980s (Wankat et al. 2014). Early this century its status as a field of inquiry was the subject of debate among engineering educators, particularly in the US (Froyd & Lohmann, 2014) and by 2006, researchers began calling for "rigorous research" in engineering education (Loui and Borrego 2019).

Today research in engineering education is supported through the same structures as research in older academic disciplines: university departments, doctoral programs, research centers, academic journals, specialized conferences, and groups within professional societies.

The EER field has been represented as comprising five categories (Loui and Borrego 2019):

Engineering epistemologies

Engineering learning mechanisms

Engineering learning systems

Engineering diversity and inclusiveness

Engineering assessment

These five categories define the overall organization of the Cambridge Handbook of

Engineering Education Research (Johri & Olds, 2014), which provides a comprehensive overview of the field.

In addition to these five categories the importance of a meta research approach to study the historical evolution of the field and curate data and artefacts is being increasingly recognised (Froyd & Lohmann, 2014), Loui and Borrego 2019).

A recent example of this historical approach can be found in the Journal of Engineering Education (JEE) where interview data were presented from three recent editors in chief of that journal: Jack Lohmann, Michael Loui

Lisa Benson (Williams et al. 2023). Under Jack Lohmann, there was a shift in the journal's mission to a research journal aimed at highlighting rigorous engineering education scholarship. During Michael Loui's editorship, there was a significant increase in the number of qualitative and mixed-method studies appearing in the journal. Lisa Benson's tenure as editor-in-chief was a period when the journal made a commitment to supporting more inclusive practices in the engineering education community and to a more international and diverse editorial board.

1.2 SEFI: historical context

SEFI was founded in 1973 and in 1976 it decided to publish a quarterly journal, European Journal of Engineering Education, devoted to the presentation and discussion of important developments in higher engineering education, focusing on the European scene, but open to contributions from everywhere in the world.

The editorial board (Editorial Board, 1975) positioned the journal to include:

(1) scholarly articles and documented analytical reports,

(2) descriptions of institutions and of systems in member countries,

(3) editorials and letters to the editor to engender discussion,

(4) in-depth reviews of books, and

(5) news and features on SEFI.

Thus, SEFI apparently did not originally intend for EJEE to become the major research journal into which it has matured. By the beginning of this century, under the leadership of Jean Michel, EJEE had changed and the journal had the look and feel of an international research Journal (Côme et al., 2013). There were significantly fewer reports about engineering education at a specific institution or in a specific country – and an analysis in 2013 showed that by that year all the articles being published in EJEE could be classified as research (Wankat, Williams and Neto, 2014).

Given that SEFI recently celebrated its 50th anniversary and that in 2026 EJEE also will, we believed it would be instructive to capture the perspectives of the two editors -in-chief at the helm of the journal this century.

2 METHODOLOGY

Adopting an oral history methodology (Lambert and Frisch 2013) we interviewed Erik de Graaff (2008 to 2017) and Kristina Edström (2018 to the present). This approach is frequently applied in historical research (Janesick, 2020) although as yet it is not common in EER.

The procedure followed was in line with the Principles and Best Practices of the Oral History Association (2018). The interviews lasted between 40 and 60 minutes. They were conducted online, recorded and transcribed. The transcriptions were then sent to the interviewees who could refine their statements.

3 INTERVIEW DATA

Erik de Graaff (2008 to 2017)

“Somehow it appealed to me to have this position as journal editor. I thought I could improve the editorial process - when you're young and energetic, you have a lot of fantasies, how you can change things. And the biggest challenge was simply how to run the journal. Because it had been run in quite a traditional way where the EiC relied mainly on his personal network with much of the editorial process being done manually by the editor himself and so all dependent very much on knowing not only the system, but also all the people involved.

It really took quite some time before I had it sorted out in a way that we could communicate with the authors via email and run everything regularly. So actually, we had a problem in the first year to get six issues out and ended up missing one issue. That was a source of frustration later as it is likely to have delayed the process of our receiving a Web of Science Impact Factor.

After two years, we had everything running, having transferred to an electronic system with the help of the publisher Taylor and Francis. And with that system, I actually was able to manage the whole journal on my own with the help of a team of associate editors I brought on board. So that was that was the main challenge of getting started in the role of EiC.

And we had a different policy to that of the ASEE publication the Journal of Engineering Education (JEE). Jack Lohmann, the JEE EiC at that time had a policy of emphasising rigorous research whereas for EJEE our focus was on research that was relevant for engineering education practice. And I believe that spirit still prevails at EJEE today - I know that my successor is committed in that same way.

The electronic system we introduced allows you as an editor, to have access to everything from wherever you were on the world, every hour. And you could very easily communicate with all the reviewers, you could select them and have the preferences of people saved along with their knowledge and skills. So it was much less dependent on the personal network on your own individual knowledge. Of course, it always helps that you know people , and you know someone to be very, very strict, and another to be more lenient as that is not recorded. So you have to build that personal knowledge base. But it is more layer on top of a system that that works, independent of the people who operate it.

By 2017 when I was coming to the end of my term there were more and more papers coming to the European Journal and it had become hard for me to manage on my own. I had indicated that I would finish my term in 2018 and in the year before, we started the search for a new editor in chief. My aim was to hand it over in such a way that that there was a smooth transition. I have collaborated with my successor, Kristina Edström who could call on me if there were any questions or any things I could do. She still inherited a backlog of over a year by that time. And she took off differently, organising it much more as a team effort then as an individual effort. And that was the necessary kind of change that I could not have made. It was necessary, because the journal had grown so much and it was essential to organise the tasks in components that could be delegated to other people. And she started doing that right from the beginning.

I think that during the 10 year period that I was in charge, the scientific standard became more important - there was a growth of development and quality. Now, that is very difficult to measure that but if I look to the older issues, the ones before 2007, there were many articles presenting small scale classroom initiatives and this is no longer the case. The other changes I note are the transition to the online platform and the enormous growth in submissions from all over the world.”

Kristina Edström (2018 to present)

“When the call went out for a new Editor-in-Chief for EJEE, it was time for the journal to take a new step. Some colleagues had experienced delays when publishing in EJEE, which was particularly difficult for PhD students. The engineering education field had developed to a state where people were having careers. It was then imperative to have a well-functioning journal that could enable *and drive* the development of the field. Journals have the important function to help define the field and uphold quality standards, by selecting and highlighting work according to their aims and scope and their quality criteria. Without journals, you don't have a field.

At that time, seniors like Anette Kolmos, Erik de Graaff and Jonte Bernhard had been actively supporting my development for years. Now I thought it was my turn to support the new generation, and the journal would be a great platform for that. I understood that I would publish much less myself, because the editorship takes so much time and mental energy. In a way, being an editor is a dirty job, but someone has to do it. But I was over 50, had a permanent position and support from my university, so I could take one for the team here. I also saw it as an inherently stimulating task and was excited about actively shaping and furthering the field.

Beginning my editorship, the number one challenge was to build editorial capacity. Submissions had increased so much that handling them was a major effort, and there was a substantial backlog. I recruited two heroic deputy editors, Jonte Bernhard and Maartje van den Bogaard. Together we got the machinery up and running, reaching a healthy steady state during our first year. Affectionately, we called this period of hard work our “spring cleaning”. Perhaps a better metaphor would be “pulling off the bandaid”, because it meant that we raised the quality threshold immediately and significantly, with tough implications for many authors.

During our first months we also formulated the new aims and scope for the journal (Edström, Bernhard & van den Bogaard, 2018). The fundamental quality criteria state that the work should *combine scholarliness and usefulness*. In other words, the ambition was to raise the academic quality, while still emphasizing that the work had to be relevant and useful for engineering education. This positioning of the journal did not come out of the blue. The usefulness criterion meant staying firm on the course held by Erik de Graaff. My thinking on these matters had been developing since 2012, in relation to the CDIO initiative and my own motivation as a researcher (Edström, 2020). We see now that these criteria have been stable since we formulated them. They resonate with people and define a legitimate aim for the journal, and by extension for engineering education research.

During the years there were questions about EJEE not having a journal impact factor, but that was never a big worry for me. I always felt secure that we would eventually get it – as indeed we have. Especially since the matter was not in our control, my focus was only on developing the quality of the journal. It is the quality that drives the impact, whether it is formally listed as a journal impact factor or not. If the official impact factor had come in 2018 it would only have been 0,8 – but when we did get it in 2023, it was 2.3.

Looking back, I am particularly pleased to see the vibrant community that we have cultivated around the journal. When the journal was in steady state, we started recruiting. By now we have about a dozen associate editors, and another heroic deputy editor, Shannon Chance. It's such a pleasure to work with this brilliant editorial team. The fine relationship with SEFI is another strength of the journal. SEFI has supported its journal in thick and thin, and it would not be the same to publish a journal without a mother organization. The journal team is now a big group of people who are active in the SEFI conferences. We are all approachable and transparent about the journal, we give workshops for authors and for reviewers, and we participate in the SEFI doctoral symposium. One particular aspect of that is to encourage the PhD students to become reviewers. It is a relevant learning experience for them, as it helps them understand the peer review process. We think of it as inviting them to be members of the field.

Reviewers are a very special part of the journal community; there cannot be a journal without reviewers. We are so grateful for the amazing support they provide, and they do it anonymously, behind the scene. My worst frustration is also related to this: I am puzzled when people who publish in the journal still decline to review the work of others. My kindest interpretation is that they may not understand how a research field works. Reviewing is an integral part of being a scholar and people who want the advantages without contributing will undermine the system.

Another exciting development is that we have used special issues proactively. Rather than accepting incoming proposals and using them a means to unburden the Editor-in-Chief, I see them as a way to call for important work and to support the development of people and networks. We start by identifying a timely topic and shaping a guest editor team around it. Ideally, we combine younger scholars with key seniors, connecting different international groups. We require the team to contact potential reviewers upfront, already when the call-for-papers is being drafted. Finding reviewers must be done at some point anyway, and this way it alerts and involves key scholars within that topic. This approach has produced strong special issues that capture the state-of-the-art. It also strengthens the community around the journal, and some guest editors have stayed on as associate editors after their special issue is published. I've really enjoyed making this shift – recognizing that it is one way that the journal can take initiative and make good things happen.

Strengthening the community in all these various ways is a seamless and long-term activity. This is also the community in which it will be easy to find our successors as we turn over the editorial team."

4 Discussion

In this brief account of the evolution of EJEE over the last 16 years we have seen that the journal has become a home for high quality research in engineering education both in Europe and globally (De Graaff 2013, 2014, 2017). It has adapted to a notable increase in submissions by broadening its editorial staff and defining its aims and scope to attract research that combines scholarliness and usefulness (Edström, Bernhard & van den Bogaard, 2018; Edström 2020). At the same time, the journal has consciously worked at building a broad community of scholars through the SEFI conferences and its networks. In addition it has assumed a role in pro-actively guiding and sharing research by introducing a new special-issue process.

Overall while the EJEE evolutionary process described in these interviews has much in common with that of JEE this century as was referred to in the Introduction (Williams et al. 2023), the two journals differ somewhat in their aims and scope in that while EJEE aims to publish research that combines scholarliness and usefulness, JEE sees its main role as cultivating, disseminating, and archiving scholarly research.

5 Conclusion

As the European Journal of Engineering Education approaches its 50th anniversary, the journal will no doubt continue to evolve in tandem with the community it serves and we present this history in the hope that the Editor-in-Chiefs' observations set out here will contribute to the 50th anniversary reflections and will serve as a reference for future editors and readers of the journal.

REFERENCES

Come, F., X. Fouger, K. Hawwash, and W. Van Petegem. "*SEfi@ 40. Driving engineering education to meet future challenges.*" SEFI, Brussels (2013).

Editorial Board. 1975. "Letter from the Editorial Board." *European Journal of Engineering Education* 1 (1): 10–11. doi: 10.1080/03043797508903389

De Graaff, Erik (2013) "The European Journal of Engineering Education" in *SEfi@ 40, Driving Engineering Education to Meet Future Challenges*, 71-74, *SEFI*, Brussels

De Graaff, Erik (2014). "Research versus educational practice: positioning the European Journal of Engineering Education". *European Journal of Engineering Education*, 39(1), 1-6. https://doi.org/10.1080/03043797.2014.882146

De Graaff, Erik (2017). "Ten years in engineering education research: looking back ahead". *European Journal of Engineering Education*, 42(6), 587-590.: https://doi.org/10.1080/03043797.2017.1408942

Edström, Kristina. "The role of CDIO in engineering education research: Combining usefulness and scholarliness." European Journal of Engineering Education 45, no. 1 (2020): 113-127.

Edström, Kristina, Jonte Bernhard, and Maartje van den Bogaard. "Updating the aims and scope." European Journal of Engineering Education 43, no. 5 (2018): 651-651.https://doi.org/10.1080/03043797.2016.1202905

Janesick, Valerie J. "Oral history interviewing with purpose and critical awareness." (2020).

Johri, Aditya, and Barbara M. Olds, eds. *Cambridge handbook of engineering education research*. Cambridge University Press, 2014.

Lambert, Douglas, and Michael Frisch. "Digital curation through information cartography: A commentary on oral history in the digital age from a content management point of view." The Oral History Review 40, no. 1 (2013): 135-153.

Loui, Michael C., and Maura Borrego. "11 Engineering Education Research." The Cambridge handbook of computing education research (2019): 292.

Malmi, Lauri, Tom Adawi, Ronald Curmi, Erik De Graaff, Gavin Duffy, Christian Kautz, Päivi Kinnunen, and Bill Williams. "How authors did it–a methodological analysis of recent engineering education research papers in the European Journal of Engineering Education." European Journal of Engineering Education 43, no. 2 (2018): 171-189.https://doi.org/10.1080/03043797.2016.1202905

Oral History Association "OHA Principles and Best Practices", https://oralhistory.org/principles-and-best-practices-revised-2018/

Wankat, Phillip C., Bill Williams, and Pedro Neto. "Engineering education research in European Journal of Engineering Education and Journal of Engineering Education:

citation and reference discipline analysis." European Journal of Engineering Education 39, no. 1 (2014): 7-17. https://doi.org/10.1080/03043797.2013.867316

Williams, Bill, Alexander Vincent Struck Jannini, Joyce B. Main, and David Knight. "JEE in the 21st century: A brief history of the journal and retrospective of three past editors." *Journal of Engineering Education* 112, no. 4 (2023): 848-851.

Motivation and Hindering Factors in Engineering Education – Perspectives of Engineering Educators at European Universities

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***Keywords**: Motivation, Barriers, Engineering Faculty, Educational Change, European Universities*

ABSTRACT

Research highlights the influence of faculty on educational change in engineering education, emphasizing the need for interdisciplinary research and strategies aligned with individual perspectives. This study investigates the role of motivational and hindering factors among faculty engaged in engineering education across different

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European universities as part of the ENHANCE alliance. For this purpose, a survey was developed and distributed to faculty engaged in engineering education from the ENHANCE universities. Statistical analysis of 391 responses reveals intrinsic motivation as the most relevant factor for engaging in engineering education, with varying perceptions of extrinsic motivation and hindering factors among universities. Further analysis indicates financial constraints, bureaucratic challenges, and political influences as common barriers, with differences attributed to national policies and institutional contexts. The results underline the relevance of considering local and national contexts in addressing motivational factors and barriers to quality engineering education. Further research is needed to explore correlations with political frameworks and individual beliefs, aligning with strategies for educational change in engineering education.

1 INTRODUCTION

In the rapidly evolving landscape of engineering, engineering education stands as a cornerstone in preparing the next generation of engineers. Central to this endeavor are motivated and pedagogically skilled faculty members, shaping not only the technical skills of their students but also their professional identity and ethical outlook. A wide range of research reports on motivating and challenging factors of people engaged in engineering education, referring to several drivers and barriers to pursue educational change or to adopt effective teaching practices (e.g., Cutler and Coso Strong 2023; Finelli et al. 2014; Graham 2012; Henderson et al. 2011; Matusovich et al. 2014; Shadle et al. 2017). At the same time, Cutler and Coso Strong (2023) highlight an often-overlooked influence of engineering faculty on engineering education, as “Faculty can be the enactors of educational change practices” (p. 302). Faculty members, as teachers and supervisors, influence students’ ways to learn as well as their development of the engineering profession and belonging (Finelli et al. 2014). Moreover, engineering faculty has not only an influence on their classroom activities, but also on their participation in projects on educational change, curriculum design and the support and supervision of students (Cutler and Coso Strong 2023). Thus, pedagogical beliefs, positions, perspectives and institutional context may vary in terms of how faculty members as people influence students’ educational experiences (Cutler and Coso Strong 2023; Matusovich et al. 2014).

Graham (2012) identified common features in successful educational change in engineering education, such as leadership and faculty engagement or educational design and implementation. To initiate successful curriculum change requires especially a common goal between faculty and senior management (Graham 2012). In their literature review on change in undergraduate STEM practices, Henderson et al. (2011) highlight often discipline-siloed research on educational change (i.e., STEM education-, faculty development- and higher education-focused researchers) and call for more interdisciplinary research. In their review, they derived four categories of change strategies that include disseminating curriculum and pedagogy, developing reflective teachers, enacting policy and developing shared visions. The authors found that effective strategies for change are aligned with individual beliefs, long-term interventions, the understanding that universities are complex systems and the design of strategies that fit to these systems (Henderson et al. 2011).

However, research has shown that there are several barriers for engineering faculty members to educational change, where especially time constraints are cited frequently (Finelli et al. 2014; Henderson et al. 2011; Shadle et al. 2017). Other reported barriers are, for example, instructional challenges, such as large class sizes, loss of autonomy, resistance to change, funding opportunities, lack of support or lack of recognition (Henderson et al. 2011; Shadle et al. 2017). In contrast, factors such as encouraging collaboration and shared objectives, alignment with existing resources, flexibility, an actual improvement of students' outcomes or a faculty desire for students' success are reported as motivating and driving aspects (Finelli et al. 2014; Shadle et al. 2017).

In the context of the extensive and collaborative "Teaching Cultures Survey" (Graham 2020, 2022), the culture and state of the art of teaching in higher education worldwide is captured, where participating universities commit themselves to improve the state of the art of their teaching and education. The results of the previous two surveys show that most respondents perceived university teaching as widely undervalued and even career-limiting, where only a quarter of participants perceived spending time on teaching positively impacts their career advancement (Graham 2020). Moreover, participants did not perceive university teaching as being a priority area in their institutions. At the same time, most participants want university teaching to have a greater priority, where especially university leaders seem to be committed to change.

The context of this study is a joint research project on engineering education between Chalmers University of Technology, the Norwegian University of Science and Technology (NTNU) and RWTH Aachen University as part of the ENHANCE alliance. ENHANCE is an alliance of ten European technical universities, aimed at fostering collaborations between the universities at different academic levels (ENHANCE no date). The aim of this joint project was to explore teaching and learning experiences, attitudes and motivational aspects of people involved in engineering education from different countries and thus, different national and political frameworks. For this purpose, a survey was developed aimed at people from the ENHANCE universities involved in engineering education, i.e., teaching and educating engineering students. In this paper, we first focus on the analysis of motivational and challenging factors, i.e., this study refers to and uses only part of the data collected in order to expand and build on it in a next step. The focus of this paper is on the following research question: *What role do different motivating and hindering factors play in faculty engagement in engineering education across different universities?*

In doing so, we build on the existing literature on motivational and hindering aspects and focus on local differences between universities in different European countries, with each different national and policy frameworks, that have jointly committed to improving teaching in higher education as part of the ENHANCE Alliance.

2 METHODOLOGY

2.1 Survey Design and Data Collection

The survey was designed partly based on motivation and hindering factors mentioned in the literature (see section 1), and partly with the addition of our own factors. In total, the survey contains 19 items on motivating factors and 15 on hindering factors. Participants were asked to indicate to what extent they perceive the above aspects as motivating or hindering factors for engaging in engineering education. Further, the participants could add other aspects and there was also a section for free comments. The answers on the items based on a five-point Likert scale, ranging between strongly disagree and strongly agree.

Moreover, we asked for demographic information, such as employment status and duration and the academic discipline. All statistical analyses were performed using the statistical software R.

A pre-test, which was performed with test subjects to improve the questionnaire, verified the quality of the survey design. As described above, the survey was aimed at people who are engaged in engineering education at the ten member universities of the ENHANCE alliance. The invitation email to participate in the survey was sent to the university representatives for further distribution to people engaged in engineering education. The survey was available at SoSci Survey (https://www.soscisurvey.de/) between July and November 2023.

In total 489 persons, who stated that they are currently engaged in engineering education, from five ENHANCE member universities, namely Chalmers University of Technology (Sweden), Gdańsk University of Technology (Poland), Politecnico di Milano (Italy), RWTH Aachen University (Germany) and Warsaw University of Technology (Poland) participated in the survey. An analysis of the demographic data shows that 81 percent of respondents state that they are a professor (full, associate, and assistant professors). Due to the low proportion of other employment statuses, e.g., postdocs 2.2 percent or PhD students 4.7 percent, we only use the data sets of professors, which are 391, for the further analyses in this study in order to ensure comparability.

2.2 Data Analysis

In this study, we analyze which motivating and hindering factors are perceived by participants in engineering education and what differences exist between the universities surveyed. Before making any comparisons, we performed an explorative factor analysis. The analysis resulted in a model with two factors each for the motivating and hindering factors. Table 1 shows the assignment of the items to the respective factor. The factors *extrinsic motivation* and *extrinsic hindering* each comprise eight items with high factorial reliability (Cronbach's alpha = .89). The *intrinsic motivation* factor contains eleven items with equally high factorial reliability (Cronbach's alpha = .83) and the *intrinsic hindering* factor contains eight items with acceptable factorial reliability (Cronbach's alpha = .78). The item *lack of time* is not assigned to one of these factors and is therefore considered as a separate hindering factor, as it is also an established hindrance to the quality of teaching (e.g., Finelli et al. 2014; Henderson et al. 2011).

Table 1. Factor structure, associated items and internal consistency of the factors

Dimension	Factor	Item	Cronbach´s Alpha
Motivation	***Extrinsic***	Recognition from my colleagues Recognition from my line manager	.89

		Recognition from my department/faculty Recognition from my university senior management Recognition from my research community Funding opportunities The university supports an educational change	
	Intrinsic	Combining teaching and research Freedom to determine what and how to teach Motivation of the students The pleasure I get from teaching Responsibility for students´ skills development The desire to positively impact students´ skills development The desire to positively impact students´ future engineering career To apply best practice examples in my own teaching To educate students with newest teaching methods/approaches To bring actual research to the students To motivate and inspire students for the subjects of research To exchange with younger generation	.83
Hindering	***Extrinsic***	Lack of recognition from my colleagues Lack of recognition from my line manager Lack of recognition from my department/faculty Lack of recognition from my university senior management Lack of recognition from my research community Lack of funding opportunities Lack of climate for an educational change	.89
	Intrinsic	Difficulties in combining teaching and research Freedom to determine what and how to teach Lack of students´ motivation Lack of personal motivation Potential failure in teaching students Lack of confidence in my teaching skills Lack of practice examples from teaching to apply myself	.78
	Lack of time	Lack of time	-

We performed descriptive statistics for each factor and group (university). As Shapiro-Wilk tests showed that no normal distribution can be assumed for all factors except the factor *intrinsic hindering* ($p < .05$), the requirements for a parametric procedure were not satisfied. For the comparison between the universities non-parametric Kruskal-Wallis tests were therefore performed, followed by post-hoc paired Wilcoxon tests if the Kruskal-Wallis test proved to be significant. A significance level of $p < .05$ was used for all tests. All statistical analyses were performed using the statistical software R.

3 Results

Overall, the descriptive analysis shows that the intrinsic motivational factor is considered as most relevant for the participants (see Table 2).

Table 2. Means, standard derivations and Kruskal-Wallis test for the motivation and hindering factors

Factor	University	n	Mean	SD	p-Value
Extrinsic Motivation	Chalmers University of Technology	11	2.65	1.07	<.001
	Gdańsk University of Technology	152	3.06	.82	
	Politecnico di Milano	110	2.66	.78	
	RWTH Aachen University	50	2.34	.71	
	Warsaw University of Technology	66	3.21	.69	
Intrinsic Motivation	Chalmers University of Technology	11	4.05	.49	.766
	Gdańsk University of Technology	152	3.98	.50	
	Politecnico di Milano	110	4.01	.46	
	RWTH Aachen University	50	4.02	.44	
	Warsaw University of Technology	66	4.04	.47	
Extrinsic Hindering	Chalmers University of Technology	11	2.93	.97	<.001
	Gdańsk University of Technology	152	3.20	.72	
	Politecnico di Milano	110	2.65	.87	
	RWTH Aachen University	49	2.35	.89	
	Warsaw University of Technology	65	2.99	.82	
Intrinsic Hindering	Chalmers University of Technology	11	2.71	.77	<.001
	Gdańsk University of Technology	152	3.03	.65	
	Politecnico di Milano	110	2.74	.75	
	RWTH Aachen University	49	2.19	.47	
	Warsaw University of Technology	65	3.03	.73	
Lack of time	Chalmers University of Technology	11	3.45	1.21	.017
	Gdańsk University of Technology	149	3.95	.94	
	Politecnico di Milano	110	3.52	1.11	
	RWTH Aachen of Technology	49	3.67	1.11	
	Warsaw University of Technology	61	3.89	1.02	

For the intrinsic motivational factor across different universities, we observe mean values ranging from 3.98 and 4.05. Moreover, the Kruskal-Wallis test reveals no significant differences in *intrinsic motivation* levels among the universities ($p = .766$), indicating a rather uniform distribution of perceptions. In contrast, the analysis of *extrinsic motivation* yields more varied results that are generally lower compared to intrinsic motivation. Specifically, respondents from Warsaw University of Technology report a mean value of 3.21, with Gdańsk University of Technology slightly lower at 3.06. Considerably lower mean values are shown by participants from RWTH Aachen University ($m = 2.34$), Chalmers University of Technology ($m = 2.65$), and Politecnico di Milano ($m = 2.66$). The Kruskal-Wallis test confirms that the disparity among universities in terms of extrinsic motivation is statistically significant ($p < .001$). The subsequent post-hoc paired Wilcoxon tests reveal significant differences in extrinsic motivation between most pairs with varying effect sizes r. The effect is large for RWTH and Warsaw ($r = .55$), moderate for RWTH and Gdańsk ($r = .38$) as well as for Milano and Warsaw ($r = .38$), and small for Gdańsk and Milano ($r = .26$) as well as RWTH and Milano ($r = .19$). The effect sizes for all other pairs were not statistically significant. Notably for Chalmers, we mainly attribute this result to the comparatively low number of respondents limiting our ability to draw robust conclusions for this university.

Our analysis of hindering factors suggests a more homogeneous pattern across the universities. The mean values for the *intrinsic hindering factor* range from 2.19 to 3.03, with RWTH reporting the lowest, and both Gdańsk and Warsaw presenting the highest values. *Extrinsic hindrances* show a similar range of mean values between 2.35 and 3.20. Again, RWTH records the lowest mean value ($m = 2.35$), while Gdańsk has the highest ($m = 3.20$), followed closely by Warsaw ($m = 2.99$). The Kruskal-Wallis test indicates significant differences between universities in both intrinsic and extrinsic hindering factors ($p < .001$). Further analysis utilizing paired Wilcoxon tests shows moderate effect sizes in the differences of extrinsic hindering factors between RWTH and Gdańsk ($r = .41$) and Warsaw ($r = .36$) and between Milano and Gdańsk ($r = .32$). For intrinsic hindering factors, only RWTH and Milano show a significant moderate effect ($r = .35$). Moreover, no significant differences between the universities are found. As discussed in chapter 2.2, the item *lack of time* was evaluated as separate hindrance, as it does not fit into the two-factor model established through explorative factor analysis and Cronbach's Alpha. As single-item factor – widely recognized in literature as a critical barrier to quality teaching – lack of time shows mean values ranging from 3.45 to 3.95 across the universities. Although the Kruskal-Wallis test indicates significant differences ($p = .017$) between the universities, the post-hoc paired Wilcoxon tests only reveals a small, significant effect for Milano and Gdańsk ($r = .20$) and none of the other pairs. Notably, the standard deviations for this factor were relatively high across all universities (between .94 and 1.21), underscoring the variability in perceptions of time as a barrier to education.

4 DISCUSSION AND IMPLICATIONS

The results suggest that intrinsic motivation is considered the most relevant factor across all universities, indicating that regardless of the university, participants general value intrinsic factors similarly. In contrast, extrinsic motivation is deemed less relevant with varying mean values and significant differences across universities. Moreover, the results of the statistical analysis showed some significant differences between the universities. However, as these only provide limited information about the reasons for these differences, we also looked at the free comment fields in the survey with regard to extrinsic motivation and hindering factors. Both institutional and structural influencing factors were identified here.

Social responsibility of people involved in engineering education was added as a further motivating aspect, such as the "ability to shape the future of our society" and "making a positive social impact in the world". Moreover, the main recurring motivational barriers mentioned here among all universities were financial constraints in the context of low salaries, limited funding or a lack of financial incentives in general, bureaucratic challenges and a lack of support, a lack of recognition for teaching, and political influence in terms of negatively impacting political frameworks on teaching and research. However, these similarities with regard to motivational barriers vary when comparing different universities which can primarily be attributed to different political framework conditions.

The quantitative results have shown, for example, that the two Polish universities of Gdańsk and Warsaw often differ significantly from the results of the others. This can presumably be attributed to the Polish education system. Free comments in the survey, such as "*You did not ask if teaching in a given system is even considered important. Well, in Poland it is not*." and "*Any political force is actually not interested in improving the general level of society education*" also point to this aspect. Moreover, an emphasis on teaching load and university policies seem to differ between the universities, where, for example, no participant from Chalmers mentioned any barrier in terms of teaching load, participants from Warsaw frequently criticize the large number of teaching hours mandated by law.

Overall, the results not only confirm existing research in terms of motivating and hindering factors of engineering educators (e.g., Graham 2020; Henderson et al. 2011; Shadle et al. 2017), but also highlight the relevance of considering national and even local differences in higher education systems and their policies (see also Finelli et al. 2014; Henderson et al. 2011). Since the political framework conditions of the respective countries as well as university policies seem to have a decisive influence on the motivation of teachers in the field of engineering education, a further in-depth analysis is expedient here and the next step in our research. Considering that all the universities studied are part of the European Higher Education Area, the respective political implementation seems to pose challenges in individual countries. As our results are based on a survey, limitations must be taken into account accordingly. The data represent the self-perception of teachers, which may be biased. Confirmation bias cannot be ruled out here either. In addition, we have only considered the answers of the professors for reasons of comparability. In a further analysis, the perspectives of other people working in teaching, such as PhD students and research associates, could be included, especially as there are country-specific differences in teaching commitments, particularly for PhDs. Moreover, we acknowledge the small sample size for Chalmers, which restricts the generalizability of findings. Additionally, high standard deviations indicate variability within responses, particularly for extrinsic motivational factors. Further research will be necessary to analyze not only correlations and comparisons between the political framework conditions, but also teachers' attitudes and individual beliefs towards teaching in general as well as their knowledge and use of different teaching and learning methods, as these aspects are aligned with promising change strategies in engineering education (Henderson et al. 2011). A comparison of the country-specific structural and political conditions of engineering education in Europe could provide explanations for the identified differences in extrinsic motivating and hindering factors.

In summary, this study highlights the importance of intrinsic motivation across different universities and identifies significant differences in extrinsic motivation and hindering factors. These findings underline both to take a closer look and the need for local and national context-related approaches and political frameworks to address motivational factors and barriers to quality teaching in engineering education. Moreover, the results stress the need for establishing and strengthening alliances like ENHANCE to be able to create a common framework for European education and research by also being aware of different local and national contexts that may influence teacher's motivation in engineering education.

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REFERENCES

Cutler, S., and A. Coso Strong. 2023. "The Overlooked Impact of Faculty on Engineering Education." In *International Handbook of Engineering Education Research*, edited by A. Johri, 286-311. New York, NY: Routledge.

ENHANCE. no date. "About ENHANCE." Accessed 04 02, 2024. https://enhanceuniversity.eu/about/.

Finelli, C.J., S.R. Daly, and K.M. Richardson. 2014. "Bridging the Research-to-Practice Gap: Designing an Institutional Change Plan Using Local Evidence." *Journal of Engineering Education* 103 (2): 331-361. https://doi.org/10.1002/jee.20042.

Graham, R. 2012. *Achieving Excellence in Engineering Education: The Ingredients of Successful Change*. London, UK: The Royal Academy of Engineering.

Graham, R. 2020. *Teaching Cultures Survey. 2019 Findings*.

Graham, R. 2022. *Teaching Cultures Survey. 2022 Findings*.

Henderson, C., A. Beach, and N. Finkelstein. 2011. "Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature." *Journal of Research in Science Teaching* 48 (8): 952-984. https://doi.org/10.1002/tea.20439.

Matusovich, H.M., M.C. Paretti, L.D. McNair, and C. Hixson. 2014. "Faculty Motivation: A Gateway to Transforming Engineering Education." *Journal of Engineering Education* 103 (2): 302-330. https://doi.org/10.1002/jee.20044.

Shadle, S.E., A. Marker, and B. Earl. 2017. "Faculty drivers and barriers: laying the groundwork for undergraduate STEM education reform in academic departments." *International Journal of STEM Education* 4 (1). https://doi.org/10.1186/s40594-017-0062-7.

(RE)DEFINING ENGINEERS' RESILIENCE: AN EXPLORATORY STUDY INTO HOW ENGINEERING STUDENTS UNDERSTAND RESILIENCE (RESEARCH)

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Keywords: *Resilience, student development, thematic analysis, professional skills*

ABSTRACT

In recent years 'resilience' has increasingly been framed as contributing towards success within higher education (HE), particularly within engineering degrees which prepare students for a profession and thus place emphasis on graduate attributes. Engineering degrees are commonly associated with heavy workloads, high rates of attrition and, increasingly, with growing concerns about student mental health. This raises questions regarding the degree to which a focus on resilience can help students manage the pressures associated with their study, whilst also preparing them for the rate of technological advancement and societal change they will experience as graduates. There is currently a lack of research which focuses on how students perceive this apparent need for them to demonstrate and develop resilience. In this work we thus take a qualitative approach to understanding how engineering students conceptualise resilience. In so doing, we make use of data

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collected from semi-structured interviews with twenty-three engineering students at one UK-based university. Interview transcripts were analyzed using reflexive thematic analysis (RTA). Students described resilience and their resilient responses. Workload, the freedom of university, and peers were seen as the biggest threats to resilience, with teamwork being the most frequently cited learning experience in which resilience was required and developed. Participants primarily focused on the need for a plan and goals to aid motivation. Findings may be used to inform future interventions.

1 INTRODUCTION

From a psychological perspective 'resilience' is defined as "the process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioural flexibility and adjustment to external and internal demands" (American Psychological Association, 2019).

In recent years, particularly since the COVID-19 pandemic (Brammer, 2020), there has been an emphasis placed on the benefits of resilience to student success within HE (Beltman, Mansfield, and Price 2011; Brewer et al. 2019; UCAS, 2018; UNITE, 2017). Much of the literature focuses on resilience as necessary for successful navigation of the workplace (Sant 2013), focusing specifically on 'graduate resilience' (Morgan, 2016; Hodges 2017), 'academic resilience' (Hunsu, Carnell, and Sochackam 2021; Martin and Marsh 2006), and 'career resilience' (London 1983).

This perceived need for students to be resilient seems particularly pertinent within engineering. Firstly, because of the reported heavy workload (Armstrong 1996; Brainard, Staffin-Metz, and Gillmore 1999; Godfrey and Parker 2010; Rosenblatt and Lindell 2021; Seymour and Hewitt 1997; Stevens et al. 2007; Stevens et al. 2008) and high rates of attrition (Hunsu, Carnell and Sochacka 2021). Secondly, engineering degrees traditionally prepare students for a profession and therefore place additional emphasis on employability and graduate attributes (Lucas, Claxton and Hanson; Targetjobs), particularly the 'career resilience' (ECITB 2020; NAE 2014; Nieusma and Johnson 1996) needed for technological advancement and change.

In a systematic literature review on how engineering education research (EER) addresses resilience, Winkens and Leicht-Scholten (2023) found the term linked to engineering students as a personal attribute with the reasons for resilience being: persistence in completing studies; adapting to changes to educational settings during COVID-19; learning from failures/errors; coping with stress, adversity and challenging situations; and resilience as a desired attribute, outcome or competence. Within EER more widely, Huerta et al. (2021) describes resilience as the "enhanced ability to manage or bounce back from stress" (p. 652). Hunsu, Carnell, and Sochacka (2021) introduce the more specific term of 'academic resilience' (Martin and Marsh 2006) as a theoretical framework to explore how students react to academic challenges. Elsewhere the term has been associated with 'coping with stress' (Ssegawa and Kasule ,2017), an 'internal thriving competency' (Gesun et al., 2021), self-regulation (Concannon et al. 2019*)* and self-efficacy (Anthony et al. 2016; Concannon et al. 2019*)*. Finally, the term has been used in relation to equity, diversity and inclusion, with studies focused on the resilience of underrepresented students (Khilji and Pumroy 2019; McGivney 2007; Ross, Huff, and Godwin 2021; *S*ervant-Miklos, Dewar and Bøgelund 2021; Samuelson and Litzlerb 2016).

Mapaling, Webb and du Plooy (2023) made use of data from semi-structured interviews to understand students' perceptions of their own resilience in the South African context. Participants alluded to personal resources, and social resources. Students also expressed tension between maintaining self-care and academic attainment, something associated with a lack of acknowledgement for the systematic, structural nature of issues they faced. In a different study (Mapaling, Webb and du Plooy, 2021) in the same context, students identified language and cultural barriers, as well as their educational background, as impacting their ability to adapt to university. In terms of facilitators of resilience, they identified support of lecturers and peers. Finally, in quantitative work into self-perceptions of resilience among 167 first-year engineering undergraduates, white males and females were found to have slightly higher levels of perceived resilience than underrepresented groups (Moreno-Hernandez and Mondisa, 2021).

However, concerns regarding this discourse within HE more widely (Russell-Watts & Stringer, 2018; Stevenson, 2016; Turner et al., 2017), highlight the use of deficit-based approaches which fail to recognize wider structural inequalities (Stevenson, 2016). Within EER, Pawley (2018) describes how the burden of developing resilience is placed on the individual. Such concerns are significant considering the increasing focus on the mental health of engineering students (e.g., Danowitz & Beddoes, 2018), with barriers to seeking mental health support including a stigma, and cultural norms that suggest "engineering students (should) be resilient through mental health challenges" (Jensen et al., 2023, p.13). Such tensions point to a need to further understand the perceptions of engineering students.

As pointed out by Mapaling, Webb and du Plooy (2023) in their work into academic resilience, "there is a lack of literature that engages engineering students to draw on their own perspectives and lived realities" (p. 178). In this work we address the gap in the literature by taking a qualitative approach to understanding how engineering students conceptualise resilience and how university supports its development.

2 METHODOLOGY

The study is situated within a qualitative research paradigm allowing and focusing on understanding the meaning participants drew from experiences over a variety of contexts. It adopts an interpretivist constructionist approach (Denzin and Lincoln 2003; Lincoln and Guba 2005; Smith 1992). In-depth semi-structured interviews were selected as the method for data collection as they provided the opportunity to explore subjective meanings, experiences, and specific details of each participant (Guba and Lincoln 1994). A semi-structured interview protocol was developed to ensure coverage of key research questions and dimensions of resilience identified in the literature, but also allowed the opportunity for the interviewer to guide the discussion in directions that had not previously been considered and/or that were interpreted as meaningful for the interviewee. Questions thus focused on participants' prior educational experience, their understanding of resilience, examples of times they had demonstrated or developed resilience, and their views regarding the need for resilience in education and the workplace.

Ethical approval was obtained. A call for participants was distributed via internal departmental mailing lists within a public research university located in Wales, UK. As of 2021/2022 the student population was approximately 22,000 students, 81 % of which were home students, and 15% of which studied engineering (HESA, 2022). Twenty-three individuals (see Table 1) provided informed consent to participate. Participants varied in terms of engineering discipline studied and year of study (foundation year, undergraduate/UG and postgraduate/MSc). 17 identified as male and six as female, nine being classed as 'home' students and 14 as international. Interviews took place online or in person according to the preference of the participant and lasted between 20 minutes and one hour. Interviews were recorded and transcribed by the first author and analyzed using reflexive thematic analysis (RTA) following the six-stage process proposed by Braun and Clarke (2006).

Table 1: Participant Characteristics

ID	Gender	Age	Nationality	Engineering Discipline	Year of Study
1	M	20	Zimbabwean	Civil	Year 1 UG
2	M	26	Indian	Nanotechnology	MSc
3	M	26	Indian	Power	MSc
4	M	21	British	Materials	Year 1 UG
5	M	39	Iranian	Civil	MSc
6	M	21	Polish	Chemical	Foundation Year
7	M	25	Indian	Mechanical	MSc
8	F	19	British	Electrical & Electronics	Foundation Year
9	F	22	Nigerian	Aerospace	MSc
10	F	20	British	Biomedical	Year 1 UG
11	M	33	Nigerian	Aerospace	MSc
12	M	24	Sri Lankan	Nanotechnology	MSc
13	M	20	British	Electrical and Electronics	Year 3 UG
14	M	25	Indian	Power	MSc
15	M	21	British	Aerospace	Year 2 UG
16	M	23	British	Mechanical	Year 2 UG
17	F	20	Italian	Aerospace	Year 2 UG
18	F	18	Nigerian	Electrical and Electronics	Year 1 UG
19	M	21	British	Mechanical	Year 2 UG
20	F	23	Kenyan	Civil	Year 2 UG
21	M	18	British	Aerospace	Year 1 UG
22	M	32	British	Power	MSc
23	M	23	Polish	Aerospace	Year 3 UG

A limitation is that participants were self-selected. The findings reflect perspectives of students in one university and transferability is limited.

3 RESULTS

Three themes were generated. This paper focuses on themes 1 and 2. Excepts are labelled (1) to (23) to allow readers to identify quotes from the same participant.

3.1 What exactly is a resilient response?

This theme focuses on differences in views and judgements pertaining to resilience and is split into two subthemes. The first (*A. To change or not to change?)* describes differences in how resilience was conceptualised. The second (*B. "it depends on the situation…different situations demand different things from us")* relates to varying ways participants react to situations that require resilience.

A *To change or not to change?*

For participants, resilience was necessary, firstly *"because failure will happen at some point"* (2), and secondly due to the rate of change. In the former case, students generally described resilience by making use of terms such as 'overcome', 'failure', 'setbacks', 'hardships' and 'challenges', and characteristics such as 'strength', 'courage', 'determination', 'perseverance', and 'capacity' were typically considered as prerequisites to a resilient response. One participant made use of engineering-based analogies, for example, by comparing resilience to *"Newton's third law…equal and opposite reactions"* (16), and describing *"pushing, pushing, kind of like Kaizen in the Toyota production system of this constantly iteratively improving"* (16). Resilience was considered particularly relevant within engineering which was *"harder than most degrees"* and *"challenging"* (20). Engineering industry was considered a *"cut-throat environment"* (16) whereby companies were *"highly selective"* (17) and in which resilience was necessary as it is *"not always going to be a good environment"* (1). This sense of hardship was considered to have increased in a world that is *"changing fast"* (22), and in which *"hard work yields less"* (17), with one participant saying that *"it's getting harder, there are more expectations to meet"* (20).

This notion clearly links with the second reason to demonstrate resilience, which was associated with change. Participants made use of terms such as 'flexibility', 'adaptability' and 'transferability', particularly when referring to transitions between education and the workplace. In the workplace, resilience was deemed as beneficial in terms of innovation, creativity, and the flexibility to transfer knowledge to unfamiliar problems. In relation to this, one perspective was that *"resilience would be what we actually learn in this class, and how useful these newly taught for use in the industry"* (5), with one student saying *"you're going to look up and say, okay. I've never seen this before. I don't have a reference to start from, but I'm going to look at it, and I want to find the solution. I'm going to find a way. I'm going to keep looking at it "(*1). In comparison, a different participant who had worked in India, explained that industry did not require resilience as *"you are not allowed to think outside the box…you need to go as per their regulations and rules"* whereby managers have *"power in their hands"* and in which you *"needed to be loyal to the organization"* (7).

However, there was some variation in views as to what resilience was. For example, on the contrary to those who spoke of flexibility and adaptability, one participant believed that resilient people were *"very steadfast in how they think about their own ideas... you could equate it to being a little bit stubborn in resisting change"* (15).

B "It depends on the situation…different situations demand different things from us"

Participants described different responses to failure, this being articulated clearly by one student who said that how they react *“depends on the situation because different situations demand different things”* (3). For many, their response involved stages, the first involving stress and emotion, with one student saying *“I also do allow myself to be down and to feel sad. …maybe, after a few days get back to my thing because I feel like life must go on”* (20) and another that they *“stress out a lot at the beginning. Then, after that I’d kind of calm down, and actually do something about it”* (10). This stage was typically followed by *“putting it into perspective”* (6) and a more philosophical approach, which was sometimes linked to religion and faith. For example, students told themselves *“there are more opportunities”* (5) and that it’s not *“the end of the world”* (6). This helped them look forward, with one saying that *“once something is done, it is done, and you're not getting back that time, so make sure you do that thing better the next time”* (2), and another that you have to *“accept the past is in the past. You can only change what happens in the future” (*15). For one participant, not moving on “*would somewhat cost in the future as well”* (9). This more philosophical approach was often related to having a growth mindset, for example *“the idea that instead of focusing on the fact that last time when I did a lot of work, it didn't go so well, like its instead trying to build on what I did” (*6). One participant described asking themselves *“are you happy with what you have done? If you die tomorrow, are you happy with where you are”* (12), using this as motivation.

A third, more strategic phase was then required, or what one student referred to as *“sober decisions…when I’m in a very clear mind and I know what I am doing”* (12) and involved making use of strategies, and techniques, for example determining *“what the steps are, and how to get it done”* (4) or making use of time management by *“chart(ing) it out on a priority basis”* (3). In some cases, participants described the stages involved, for example questioning *“what could you have done differently?”* (19) and another that they would *“try to understand what might have gone wrong….and if it makes sense to me, I would like really change the way that I do it, because I just it's all about learning from your mistakes”* (3). The need to analyse the situation was mentioned by several participants, one described the need *“to analyze it to the point where I cannot analyze it”* (8). The mix of approaches was perhaps articulated most clearly by one student who said that sometimes *“you just have to accept the situation… look at myself, try and improve myself the best way I can. Also look at the other lens of sometimes there’s nothing more you can do, you’ve done the best you can”* (1). To this end, there appeared to be some level of judgment required in terms of response, for example if *“It’s a lost cause I don't worry about it. But if there is something we could do about that's when I stress out.”* (10).

3.2 Facilitating factors and inhibiting influences

This theme focuses on factors impacting resilience levels and is split into two subthemes. The first (*C. The cohort effect*) focuses on the degree to which resilience depends on individuals compared to others around them and the second (*D. Failing to plan and planning to fail*), on the role of planning in enabling resilience.

C. The cohort effect

Many participants spoke of resilience as an individual characteristic. One student said it must *“come from like inside…an internal sort of mental mindset”* (16), another describing it as being *“able to internalize things”* (20). These views were linked to accountability and responsibility, with one participant saying *“I’m not treating this as* *someone else's mistake. I rather try to take it as my own"* (23), another believing that *"a lot of engineering students just don't really except that reality"* (16).

Despite this focus on the individual, peers were seen as influential, this being unsurprising considering the time spent together in university. One participant claimed that *"if this group of students has a negative outlook, that does not help an individual at all"* (12) and another that *"if I'm surrounded by people who are lazy, then I'll tend to be same"* (21). Another student said, *"say our peers are not succeeding, that would mean the resilience of the group is lower"* (23). A different participant added that it was problematic *"if you have people around you that just are in a perpetual self-doubt situation, and they come to you for confidence"* (16). On the contrary, *"if you're with a group of people that is very studious and resilient… I would be more likely to be like that"* (17). Likewise, one student stated that they *"try to find the people that are resilient and that just gives a boost of morale"* (18) and that if friends show *"show resilience, you kind of want to do the same"* (19).

It is perhaps unsurprising therefore, that teamwork was the main learning activity that was considered to require and help develop resilience. For example, one participant claimed that *"working in a team can help you better understand resilience and learn from the views around how to handle tough situations"* (3) and another that *"when you're in a group you've got the motivation of working with people around you"* (13). Another participant alluded to the accountability involved saying that they had to think *"about the group as a total…so I should deliver this"* (23).

D. Failing to plan and planning to fail:

Participants mentioned several factors influencing resilience including diet and physical health as well as past success. For some, external *"distractions"* were considered as *"test(ing) you a lot"* (1). These distractions were seen as particularly problematic for those new to university *"because now you can do whatever you want to… so like that's also kind of one that pushes my resilience because now I have to keep my morals"* (1). Many participants also mentioned a need to be resilient because of the distraction of social media.

Most of those interviewed spoke about their motivation or goals. For one participant, you were able to be resilient *"once you have goals, no matter what you go through. Sometimes you do slip…. but as long as you have goals"* (20). Perhaps unsurprisingly given the context, the majority of students spoke about career plans, with one speaking of having *"had all the career paths, everything set in plan …. And I didn't want to give up my dream of…I had that mental picture of me*" (2), this meaning that they were motivated to react in a resilient manner when encountering failure. However, sometimes having a clear plan was considered detrimental, with one participant saying that you could be more upset when encountering failure *"if you're a very, planning oriented person and don't like things to not go to plan"* (17). A different student added that *"planning is an important part, but to be too rigid in your planning can also, you know, impacts negatively. So, I'm happy to change the way, to analyze and plan and change the way that I do things"* (3).

For many, it was these goals, and the consequences of not meeting them, which enabled them to take *"a bit of pain for that pleasure later"* (19) with one participant saying that **"***having consequences as well helps build that resilience"* (1) and another explaining that sometimes *"the consequences can be quite big if something goes wrong"* (22). Another mentioned that they thought they were *"far more resilient since*

I've come to university because there is almost a lot more on the line" (21). However, one participant claimed that unfair consequences "kind of messes with your resilience" (1) explaining that *"there were multiple times I was punished for nothing, and that pushed me to be resilient"* and that *"sometimes I'd work hard in high school, and the reward wouldn't come. But then that would push me to work harder. And then, now that I'm here I sometimes don't work hard but then I get more reward than I deserve… I mean I did the wrong thing"* (1).

4 SUMMARY

The findings suggest the existence of inconsistencies in the way resilience is conceptualised, from being flexible and dealing with change, to being 'steadfast' and 'stubborn'. Participants all saw the benefits of being resilient, this often being discussed in relation to how fast the world was changing technologically, but also in terms of competitiveness. Students described dealing with failure in several ways: by letting themselves feel emotion, by taking perspective, and by planning for the future. How they reacted appeared to depend on several factors including the importance of the situation and how motivated they were. Peers were seen as one of the most influential factors impacting individual resilience, with teamwork being the primary learning experience in which students claimed to develop and demonstrate resilience. Together, the findings point to a need to support students in understanding the situations in which it is desirable to be resilient, as well as assessing the short- and long-term benefits and costs of resilience at an individual level, something which would require students to have an understanding of their own values and moral beliefs.

REFERENCES

Anthony, A. B., H. Greene, P. E. Post, A. Parkhurst & X. Zhan .2016. "Preparing university students to lead K-12 engineering outreach programmes: a design experiment." *European Journal of Engineering Education* 41, no. 6: 623-637. https://doi.org/10.1080/03043797.2015.1121467.

APA. (2018, 19th April). APA Dictionary of Psychology. Accessed 7th April 2024. https://www.apa.org/topics/resilience#:~:text=Resilience%20is%20the%20process%20and%20outcome%20of%20successfully,flexibility%20and%20adjustment%20to%20external%20and%20internal%20demands.

Armstrong, J. 1996. "Workload in engineering courses and how to reduce it." In *Proceedings of 8th Annual Conference of the Australasian Association for Engineering Education. Melbourne, Australia*.

Beltman, S., C. Mansfield, and A. Price. 2011. "Thriving not just surviving: A review of research on teacher resilience". Education Research Review 6, no.3: 185–207. https://doi.org/ 10.1016/j.edurev.2011.09.001.

Brainard, S., G., S. Staffin-Metz, and G, M. Gillmore. 1999. WEPAN pilot climate survey: Exploring the environment for undergraduate engineering students. Accessed 7th April 2024. www.wepan.org/climate.html

Brammer, M, S. 2020. “Student Resilience and COVID-19: A Review of the Literature”. *Associative J Health Sci*. 1, no. 3: 1-5. https://doi.org/ 10.31031/AJHS.2020.01.000511

Braun, V., and V. Clarke. 2006. “Using Thematic Analysis in Psychology.” *Qualitative Research in Psychology* 3, no. 2: 77–101. https://doi.org/ 10.1191/1478088706qp063oa.

Brewer, M. L., G. van Kessel, B. Sanderson, F. Naumann, M. Lane, A. Reubenson, and A. Carter. 2019. “Resilience in higher education students: a scoping review.” *Higher Education Research & Development* 38, no.6: 1105-1120. https://doi.org/10.1080/07294360.2019.1626810.

Concannon, J. P., S. B. Serota, M. R. Fitzpatrick, and P. L. Brown.2019. “How Interests, self-efficacy, and self-regulation impacted six undergraduate pre-engineering students’ persistence.” *European Journal of Engineering Education* 44, no.4:484-503. https://doi.org/10.1080/03043797.2017.1422695.

Danowitz, A., and K. Beddoes. 2018. “*Characterizing Mental Health and Wellness in Students Across Engineering Disciplines*”. Paper presented at 2018 CoNECD - The Collaborative Network for Engineering and Computing Diversity Conference, Crystal City, Virginia.

Denzin, N. K., and Y. S. Lincoln. 2003. “Introduction: The Discipline and Practice of Qualitative Research.” In *Strategies of Qualitative Inquiry*, edited by N. K. Denzin and Y. S. Lincoln, 1–45. Thousand Oaks, CA: Sage Publications.

Engineering Construction Industry Training Board. 2020. “Skills Transferability in the Engineering Construction Industry.” Accessed 7th April 2024. https://www.ecitb.org.uk/wp-content/uploads/2020/08/Skills-Transferability-Report-FA.pdf.

Gesun, J., R. Gammon-Pitman, E. J. Berger, A. Godwin, and J. Froiland. 2021. “Developing a consensus model of engineering thriving using a Delphi process.” *International Journal of Engineering Education* 37: 939–959.

Godfrey, E., and L. Parker. 2010. “Mapping the cultural landscape in engineering education.” *Journal of Engineering Education* 99, no.1: 5–22. https://doi.org/10.1002/j.2168-9830.2010.tb01038.x.

Guba, E. G., and Y. S. Lincoln. 1994. “Competing Paradigms in Qualitative Research.” In *Handbook of Qualitative Research*, edited by N. K. Denzin and Y. S. Lincoln, 105–117. Thousand Oaks, CA: Sage Publications.

Higher Education Student Data (HESA). 2022. Accessed 16th December 2023 https://www.hesa.ac.uk/data-and-analysis/students.

Hodges, J. 2017. “Building capabilities for change: the crucial role of resilience. Development and Learning in Organizations 31, no.1: 5-8. https://doi.org/10.1108/DLO-07-2016-0064.

Huerta, M. V., A. R. Carberry, T. Pipe, and A. F. McKenna. 2021 “Inner engineering: Evaluating the utility of mindfulness training to cultivate intrapersonal and interpersonal competencies among first-year engineering students.” *Journal of Engineering Education*, 110, no. 3: 636– 670. https://doi.org/ 10.1002/jee.20407.

Hunsu, N. J., P. H. Carnell, and N. W. Sochacka. 2021. “Resilience theory and research in engineering education: what good can it do?.” *European Journal of Engineering Education* 46, no.6: 1026-1042. https://doi.org/10.1080/03043797.2021.1975096

Jensen, K. J., J. F. Mirabelli, A.J. Kunze. 2023. “Undergraduate student perceptions of stress and mental health in engineering culture. *IJ STEM Ed* 10:30. https://doi.org/10.1186/s40594-023-00419-6

Khilji, S. E. and K. Harper Pumroy. 2019. “We are strong and we are resilient: Career experiences of women engineers.” *Gender, Work and Organization* 26: 1032– 1052. https://doi.org/10.1111/gwao.12322.

Lincoln, Y. S., and E. G. Guba. 2005. “Paradigmatic Controversies, Contradictions, and Emerging Confluences.” In *The Sage Handbook of Qualitative Research*, edited by N. K. Denzin and Y. S. Lincoln, 195–220. Thousand Oaks, CA: Sage Publications.

London, M. 1983. “Toward a Theory of Career Motivation.” *Academy of Management Review* 8, no. 4: 620-630.

Long, L.L., and J. A. Mejia, J.A. 2016. “Conversations about Diversity: Institutional Barriers for Underrepresented Engineering Students.” *Journal of Engineering Education,* 105: 211-218. https://doi.org/10.1002/jee.20114.

Lucas, B., G. Claxton, and J. Hanson. 2014. “*Thinking like an engineer: Implications for the education system*.” Royal Academy of Engineering. https://raeng.org.uk/media/brjjknt3/thinking-like-an-engineer-full-report.pdf.

Mapaling, C., P. Webb, and B. du Plooy. 2021. “Everyone plays a key role”: Students, lecturers and support staff in South Africa talk about the academic resilience of engineering students. ICERI 2021: 14th International Conference of Education, Research and Innovation, Seville (Spain), November 2021.

Mapaling, C., P. Webb, and B. du Plooy. 2023. “I would help the lecturer with marking”: Entrepreneurial Education Insights on Academic Resilience from the Perspectives of Engineering Students in South Africa. In: Transforming Entrepreneurship Education edited by J. Halberstadt, A. Alcorta de Bronstein, J. Greyling, and S. Bissett. Springer. https://doi.org/10.1007/978-3-031-11578-3_10

Martin, A. J., and H. W. Marsh. 2006. “Academic resilience and its psychological and educational correlates: A construct validity approach.” *Psychology in the Schools* 43, no.3: 267–281. https://doi.org/10.1002/pits.20149.

McGivney, V. .2007. “Understanding Persistence in Adult Learning.” Open Learning: *The Journal of Open, Distance and e-Learning* 19, 1: 33–46. https://doi.org/10.1080/0268051042000177836.

Morgan, S. 2016. “Graduate Resilience Project Report”. Accessed 7th April 2024.

https://www.hecsu.ac.uk/assets/assets/documents/University_of_lancaster_graduate_resili ence_report_2017.pdf .

National Academy of Engineering, 2004. *The engineer of 2020: Vision of engineering in the new century*. Washington, DC: National Academies Press.

Nieusma, D., and D. Johnson. 1996. “Engineering Education and Career Resilience: A Contradiction?.” Proceedings of IEEE Careers Conference - Winning in a Global Economy: Helping Engineers Develop Career Resilience: 66-70.

Pawley, A. L. 2019. “Learning from small numbers: Studying ruling relations that gender and race the structure of U.S. engineering education.” *Journal of Engineering Educ*ation 108:13– 31. https://doi.org/10.1002/jee.20247.

Rosenblatt, R., and R. Lindell. 2021. “Transitioning from faculty-centred to student-centred communication”. 2021 IEEE Frontiers in Education Conference (FIE), Lincoln, NE, October 13-16, 2021.

Ross M.S., J. L. Huff, A. Godwin. 2021.“Resilient engineering identity development critical to prolonged engagement of Black women in engineering.” *Journal of Engineering Education*. 110: 92–113. https://doi.org/10.1002/jee.20374.

Russell-Watts, L., & Stringer, H. (2018). Enhancing Students’ Career Resilience. AMOSSHE and The University of Edinburgh. Accessed 7th April 2024. https://www.rsb.org.uk/images/Resilience_research_briefing.pdf.

Samuelson, C. C., and E. Litzler. 2016. “Community cultural wealth: An assets-based approach to persistence of engineering students of color.” *Journal of Engineering Education* 105, no.1: 93– 117. https://doi.org/10.1002/jee.20110.

Sant, R. 2013. “Developing Graduate Resilience: Core to What We Do”, AGCAS Pheonix, 139, May, 4-6.

Servant-Miklos, V. F. C., E. F. A. Dewar, and P, Bøgelund. 2021. “‘I started this, and I will end this': a phenomenological investigation of blue collar men undertaking engineering education as mature students.” *European Journal of Engineering Education* 46, no.2:287-301. https://doi.org/10.1080/03043797.2020.1783209.

Seymour, E., and N. M. Hewitt. 1997. *Talking about leaving: Why undergraduates leave the sciences.* Boulder, CO: Westview Press.

Smith, J. K. 1992. “Interpretive Inquiry: A Practical and Moral Activity.” *Qualitative Issues in Educational Research* 21 (2): 100–106.

Ssegawa, J. K., and D. Kasule. 2017. “A self-assessment of the propensity to obtain future employment: a case of final-year engineering students at the University of Botswana.” *European Journal of Engineering Education* 42, no. 5: 513-532. https://doi.org/10.1080/03043797.2016.1193124.

Stevens, R., D., M. Amos, A. Jocuns, and L. Garrison. 2007. “Engineering as lifestyle and a meritocracy of difficulty: Two pervasive beliefs among engineering students and their possible effects.” In Proceedings of the 2007 American Society for Engineering Education Annual Conference and Exposition. Honolulu, HI.

Stevens, R., K. O’Connor, L. Garrison, A. Jocuns, and D. M. Amos. 2008. “Becoming an engineer: Toward a three dimensional view of engineering learning.” *Journal of Engineering Education* 97, no. 3: 355–68. https://doi.org/10.1002/j.2168-9830.2008.tb00984.x.

Targetjobs. “What Skills do engineering employers look for?” What skills do engineering employers look for? Accessed 7th April 2024. (targetjobs.co.uk).

Turner, M., C. M. Scott-Young, and S. Holdsworth. 2017. “Promoting Wellbeing at University: the Role of Resilience for Students of the Built Environment.” *Construction Management and Economics* 35, no. 11-12: 707-718. https://doi.org/10.1080/01446193.2017.1353698.

UCAS. 2018. “Preparing for Careers the Skills Employers are looking for”: Accessed 7th April 2024. https://www.ucas.com/file/130381/download?token=zX_vZu_9.

UNITE. 2017. “Student Resilience Exploring the positive case for resilience”. Accessed 7th April 2024. https://www.unitegroup.com/wp-content/uploads/2021/10/student-resilience.pdf.

Winkens A.-K., and C. Leicht-Scholten. 2023. “Does engineering education research address resilience and if so, how? – a systematic literature review.” *European Journal of Engineering Education* 48, no. 2: 221-239. https://doi.org/10.1080/03043797.2023.2171852.

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EXPLORING THE ROLE OF NATIONAL EDUCATION SYSTEM ON PATHWAYS INTO ENGINEERING: A COMPARITIVE STUDY (WORK IN PROGRESS)

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ABSTRACT

Reported shortages within the engineering workforce have resulted in significant efforts to promote engineering facilitating education pathways across Europe, particularly to those underrepresented within the sector. Such work has become significant in recent decades because of global demographic changes which are

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likely to have increasing impact upon higher education (HE) systems. Given contextual differences between countries, understanding opportunities and barriers to recruitment of students requires a comparative approach which considers differences in education systems and admissions processes. At this initial pilot phase of this exploratory study, we have focused on understanding national education systems and admissions practices in three European countries, namely Belgium (Flanders), Czechia, and the UK. The analysis of the data provided is guided by research questions focused on 1.) the main education paths into an engineering career and any remedial routes, 2.) the qualifications and prerequisites required to study engineering within HE, and 3.) details of any exposure students have to engineering, both within and outside the curriculum, prior to university. Findings from this work in progress study will be used to inform design of large-scale research project to identify practices across SEFI.

1 INTRODUCTION

Europe faces demographic issues associated with an ageing population and low birth rates which influence the population at working age, and thus economic growth (United Nations, 2022). At present, impact on higher education (HE) systems is limited. However, the (at least) 18-year gap between birth and university enrolment means this is likely to change. Universities may take several approaches to such situations, for example focus efforts on widening access and participation.

Such challenges are particularly pertinent within engineering, for which attraction and retention of students has long been an issue. The 2023 annual review of the ‘Employment and Social Developments in Europe’ report identified engineering as an occupation/sector expected to face shortages in labour (European Commission, 2023). Furthermore, the report describes the persistent labour shortages in sectors with low percentages of female[1] workers, directly attributing this to differences in study fields of qualifications (particularly at tertiary level) held by women and men (European Commission, 2023). In keeping with this, the European Strategy for Universities articulated a commitment to strengthening women’s and girls’ participation in STEM (European Commission, 2022).

At such times, the role of admission processes become significant. Orr et al. (2017), consider how admissions systems are understood in different social, cultural, political, and economic contexts (such as those found across Europe). Within this perspective, they describe three ways in which schools influence students’ access to HE: by assigning grades; by streaming by academic ability; and by providing careers information, and guidance. With respect to higher education institutes (HEIs), they highlight differences in autonomy over selection processes, and assessment of academic ability. Finally, they describe the complexity of student decision making.

1.1 Typology of Admissions Systems

Orr et al. (2017), defined a four-field matrix to produce a typology of admission systems based on a comparative study of 36 European countries. Within this, one

[1] Whilst the report cited primarily focuses on the gender employment gap, the authors acknowledge the underrepresentation of students with several characteristics within engineering, for example by disability, age, sexual orientation, ethnicity (e.g., see Mejia and Martin, 2023)

dimension represents the freedom of HEIs with respect to their ability to set their own criteria to select students. The other dimension focuses on the pathways to HE and streaming within the secondary system (i.e., whether all streams lead to HE).

- Type 1 (selection by schools) includes countries in which HEIs cannot select with additional criteria and where students are placed in various streams where at least one stream does not allow access into HE.
- Type 2 (selection by HEIs) is used for contexts in which all pathways allow access to HE and in which HEIs can typically select with additional criteria.
- Type 3 (least selection) is similar to Type 2, but HEIs have less autonomy to select additional criteria.
- Type 4 (double selection) is the same as Type 2, but at least one of these stream qualifications do not allow access into HE.

They used this typology to examine admission systems in terms of three dimensions: (1) equity dimension (who gets into HE), (2) efficiency dimension (how many complete studies), and (3) effectiveness dimension (final attainment and outcomes). Their analysis revealed differences in unemployment, job mismatches, participation rates, graduation/completion rates across the types of systems, some of which could be linked to selectivity. The research highlights both the relationship that education systems and admissions processes have with recruitment and retention of students, and the way in which systems vary between country. It may therefore be expected engineering students' demographics vary between countries characterised by different education typologies. Table 1 shows typology and student characteristics for the three countries considered in this study.

Table 1: Country typology and engineering student characteristics

Country/ Typology	CZ (Type 2; selection by HEIs)	Flanders, Belgium (Type 3; least selection)	UK (Type 4; Double selection)
Engineering student demographics	58% male, 42% female 85% Czech 15% non-Czech	74% male, 26% female 85% Belgian, 15% non-Belgian	80% male, 20% female 63% UK, 37% non-UK (HESA, 2023)

Understanding the opportunities and barriers with respect to attracting students to engineering within Europe thus requires a comparative approach which considers differences across contexts. As such, this work in progress study aims to improve our understanding of how education systems and HEI admissions practices vary across Europe. Such data will be used to identify trends and patterns across systems and the resultant admissions and retention figures in engineering.

2 METHODOLOGY

At this initial pilot phase, we have focused on three European countries in which the authors of the paper reside, namely Belgium (Flanders), Czechia, and the UK.

In mapping the education systems and admissions processes within Europe, we position ourselves as 'experts' in our own contexts. In the initial stages the authors shared context specific information pertaining to 1.) the primary and secondary education systems and educational pathways to becoming an engineer and 2.) the admissions processes of universities within their context. This process allowed for initial comparison and identification of relevant contextual factors previously omitted. It also provided an opportunity for authors to engage in critical reflection regarding perceptions, enhance understanding and interpretation, and examine the limits of reflexivity. The Flemish context was analysed by two authors independently and compared to decrease the impact of author's own perceptions. The limited disagreements were discussed and resolved.

Data was subsequently combined, with publicly available information allowing for triangulation and ensuring creation of a comprehensive picture. Data analysis was guided by the following research questions (RQs) and Orr et al.'s (2017) typology.

1.) What are the main educational pathways/'remedial routes' into engineering?
2.) What are the qualifications/prerequisites required to study engineering in HE?
3.) Do students have exposure to engineering during secondary education?

The complexity of school education systems, in terms of starting age, grouping of ages, organisation of the school year/week/day, geographical accessibility, admissions systems, funding models, governance and teacher profile, amongst other factors, has led to the development of a variety of different methodologies by which to compare them. For example, one may make use of philosophical, social, historical, quantitative/statistical, descriptive or scientific methods. In this work we focus on the pathways into engineering, with particular focus on routes to studying engineering in HE. In so doing, we make use of Orr et al.'s framework (2017) because of its focus on university admission processes. In doing this we acknowledge inherent limitations of our work which does not include consideration for aspects such as societal and cultural perceptions of HE, and the engineering profession, as well as other factors which impact transitions into engineering.

3 RESULTS

Belgium: Flanders:

In the Flemish system, a certificate of upper secondary education grants unrestricted access to HE (Eurydice, 2024). It can therefore be considered a Type 3 system.

As shown in Figure 1, at 12 years old, pupils start secondary education, the majority in the A stream (84.25%) (Onderwijs Vlaanderen, 2024), a general stream leading to different pathways at 14 years old. The secondary education system in Flanders used to be divided into general, technical, arts and vocational secondary education but, recently, the system was reformed offering three pathways. Tracks in the first pathway '*transfer*' lead to HE studies, tracks in the second '*vocational*' pathway lead to the labour market, tracks in the third pathway '*double'* can lead to both HE and labour market. Each pathway consists of different study domains (STEM, Arts and Creation, Language and Culture, Cross-domain, etc.) with more discipline specific study tracks. Students from the cross-domain and STEM domain tracks are attracted to, and best prepared for, engineering. The first important study domain and track choice is at 14 years old, with a more discipline specific track choice at age 16.

Depending on the chosen study track, the weekly hours of mathematics vary. Also, students' experience with engineering varies, ranging from limited or no experience with an integrated STEM subject in the cross-domain tracks, to whole subjects titled ‘engineering’ available in some of the STEM domain study tracks. Despite the availability of study tracks focussing - to a larger or smaller extend - on technology and engineering, the main recommendation for successful study completion in an academic engineering programme is a prior education with at least four, preferably six, weekly hours of mathematics (Pinxten et al., 2017). Despite open HE access and flexibility for late commitment to study engineering, students’ choice for study tracks and domains with few math hours (e.g., languages and arts) decreases the chance to continue in engineering.

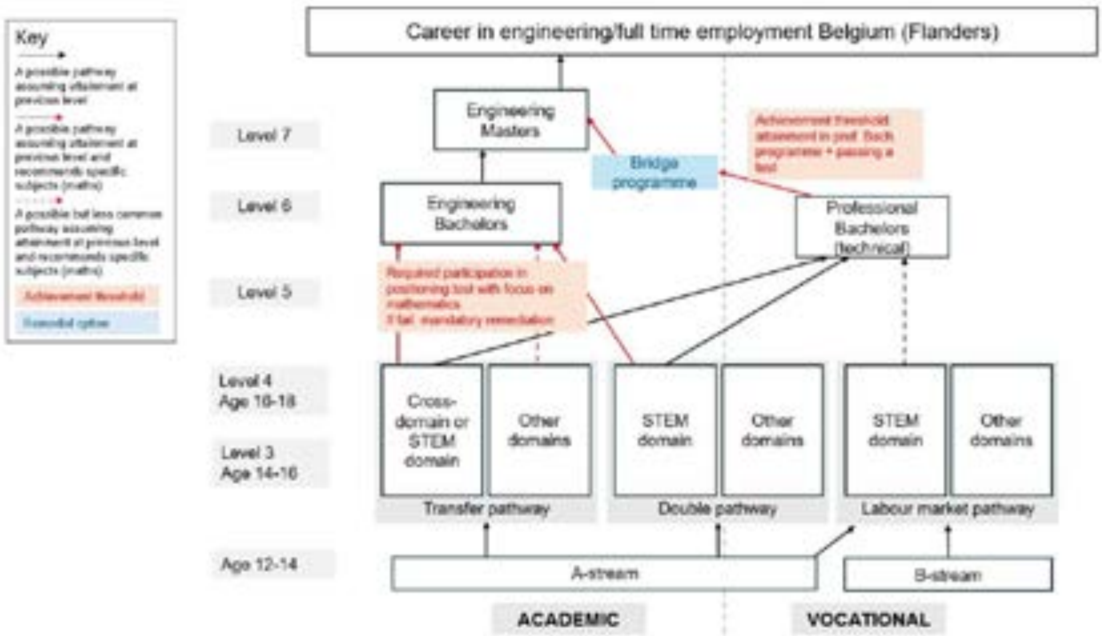

Figure 1: Schematic showing pathways to engineering in Belgium (Flanders)

To emphasize the importance of mathematical mastery, all engineering science and engineering technology HE programmes across Flanders initiated a positioning test in 2013 (Vanderoost, 2014; Hanssens, 2024). Although these tests are perceived as useful for students to assess their level of starting competencies, and for HEIs to identify students-at-risk, the test may also create unrealistic expectations of the engineering programme by creating feelings of high anxiety or overconfidence to start the programme (Hanssens et al., 2023). Students who fail follow a mandatory remedial programme in the first year of HE. The university foresees remedial routes for students obtaining vocational STEM undergraduate degrees in university colleges. After successful completion of bridge programmes, students who fulfil access requirements have permission to start an academic engineering programme. Although this route into engineering is often presented as attractive by university colleges, the bridge programmes have relatively high dropout rates. The different HEIs in Flanders reorganised these programmes recently and made access criteria stricter and programmes longer (60 to 90 credits). When choosing HE studies, students are often not aware of this.

The title “engineer” is not legally protected. A professional title is only granted to Master graduates of Flemish engineering HE programmes in Engineering Sciences (ir) or Bioscience Engineering (ir), and in (Bio)Engineering Technology (ing).

Czechia

The route to being granted the Ing. (engineer) title is not strictly defined but it mostly involves education in technical fields (with some historical exemptions e.g., economic fields) at master level. The Czech education system (Type 2) includes two main recognised pathways leading to engineering at a HEI (see Figure 2): academic and vocational (CNAIER, 2023). The first is by general secondary education (e.g., lyceum) which offer a more theoretical approach to scientifical and technical fields in comparison to full vocational secondary education programmes, which are more focused on practical aspects. Students need to make their choice at age 15. Students of both pathways have different background knowledge and skills entering HE and remedial courses are often offered as a part of bachelor programmes.

According to current statistics published by the Czech Ministry of Education (MSMT, 2024), the distribution of graduates of secondary education system in Czechia between these pathways has been fairly constant for the last decade as 43% of students graduated in full vocational secondary education programmes and only 25% at general education schools. The rest of secondary education students in Czechia graduated secondary education programmes with vocational education training certificates, with no direct possibility of continuation to tertiary education.

The official statistics pertaining to HEI *engineering* programmes applicants show that 57% come from full vocational secondary education programmes and 41% come from general secondary education (MSMT, 2024). These statistics are different in the Prague's metropolitan area where 60% of applicants come from general secondary education and only 40% come from full vocational secondary education.

This trend may result from 1.) differences in programme portfolio at technical universities that are more academically oriented and/or 2.) composition of secondary education in this region in favour of general secondary schools. The percentage of students admitted to, and graduating from, HE engineering programmes are similar for each pathway and there is not considered to be a significant difference in terms of graduate success rate from different secondary education paths.

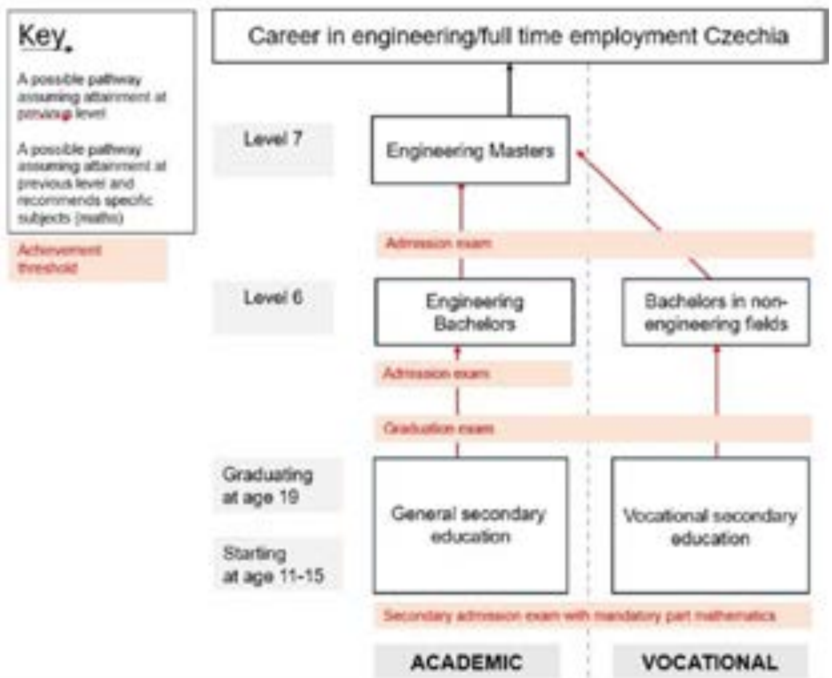

Figure 2: Schematic showing pathways to engineering in Czechia

United Kingdom (UK)

The UK is a Type 4 system, in which at least one stream of qualifications do not allow access to HE and in which HEIs typically select with additional criteria.

Professional titles of Engineering Technician (EngTech), Incorporated Engineer (IEng), and Chartered Engineer (CEng) can only be used by those to whom they are granted through registration with the Engineering Council. The CEng is open to anyone demonstrating the required competences, the application process being more straightforward for those with academic qualifications to masters level. In 2019, 23.4% of those working in engineering occupations studied engineering degrees with 33.9% having a degree or equivalent as their highest qualification and 39.4% having A-Levels or equivalent (ONS, 2019).

Defining the parameters of what constitutes an ‘engineering-facilitating educational pathway’ is difficult as shown in Figure 3. The options chosen at each point have long-term implications and potential to restrict future opportunities. This is considered particularly detrimental to engineering which does not feature in the national curriculum. Young people not aware of engineering are less likely to consider it as a career or understand the educational pathways required to pursue it (Engineering UK, 2020). Access to engineering is therefore seen as correlated with access to high-quality careers advice and guidance (teachers and peers). It is unusual for STEM teachers to have experience or expertise in engineering, and it is likely only to be mentioned by teachers with a specific personal interest.

Subjects and qualifications required to study engineering vary between HEI, with some (often those of lower status/ranking) accepting vocational qualifications. Non continuation data published by HESA (2022) shows the percentage of entrants to

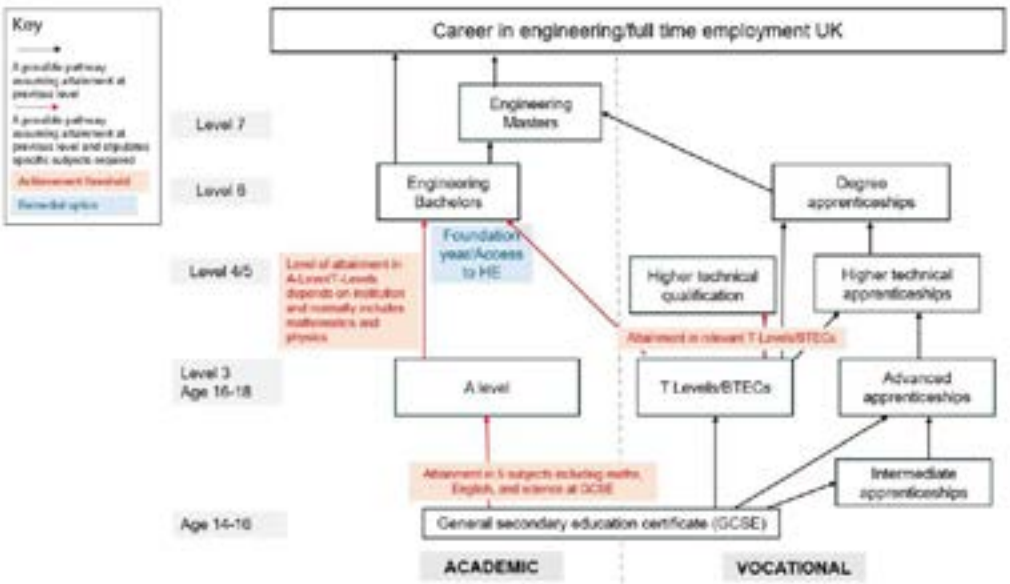

Figure 3: Schematic showing pathways to engineering in UK

engineering degree courses who are no longer in HE is relatively high for those entering with vocational BTECs, compared to A-Levels as well as compared to

those with BTECs entering other degree disciplines. Despite the variety of qualifications held by the engineering workforce, there is some consensus on the most relevant subjects recommended to keep options open. It is widely accepted that mathematics and physics are important at secondary level and are often prerequisite at A level to study engineering and technology degrees.

4 SUMMARY

The findings demonstrate that despite differences, all three education systems feature important crossroads in the trajectory into engineering at ages 14-16 and 18. These are important moments to raise awareness of the consequence of choices. Remedial routes are considered important (e.g., in Belgium, the route recently became more difficult), but are difficult to maintain in light of increasing student numbers and pressure for quality education, particularly in open admission systems. Exploration of pathways via apprenticeship, like in the UK, may be beneficial.

This paper presents findings from an initial pilot phase of an exploratory study focused on understanding national education systems and admissions practices in the three European countries in which the authors reside, namely Belgium (Flanders), Czechia, and the UK. In future it would be beneficial to extend analysis to include more countries. It would also be of interest to explore any relationships between education and admissions systems, and factors such as cohort diversity, retention, attainment, and employment opportunities, particularly pertaining to reasons different groups are lost at various crossroads. It is also of interest to further understand pathways to becoming a chartered engineer and levels of retention within the workplace having completed an engineering degree. Obtaining an understanding pertaining to countries within Europe would allow for identification of patterns which may be used to inform future practice in engineering attractiveness.

REFERENCES

CNAIER. 2023. Diagram of the education system of Czechia 2023/24. Accessed March 27, 2024. https://www.dzs.cz/sites/default/files/2023-11/CZ_schema_2023_24_2.pdf.

Engineering UK. 2020. Educational pathways into engineering. Accessed March 27, 2024. engineering-uk-report-2020.pdf (engineeringuk.com)

Eurydice. 2024. Belgium – Flemish community. Accessed March 27. 2024. https://eurydice.eacea.ec.europa.eu/national-education-systems/belgium-flemish-community/overview Accessed: 19/01/2024.

European Commission. 2022. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a European Strategy for Universities. Accessed March 27, 2024. https://education.ec.europa.eu/sites/default/files/2022-01/communication-european-strategy-for-universities.pdf.

European Commission (Directorate-General for Employment, Social Affairs and Inclusion). 2023. "Employment and social developments in Europe 2023". Accessed March 27, 2024. https://op.europa.eu/en/publication-detail/-/publication/680d6391-2142-11ee-94cb-01aa75ed71a1.

Hanssens, J., G. Langie, and C. Van Soom. "Students' perceptions of low stakes positioning tests at the start of higher STEM education: A mixed methods approach."

International Journal of Education in Mathematics, Science, and Technology (IJEMST), 11,5 (2023): 1094-1112. https://doi.org/10.46328/ijemst.2889.

Hanssens, J. (2024). *Validation of positioning tests for higher STEM education – an argument-based approach*.

HESA. 2022. Non Continuation : UK Performance Indicator. Accessed March 27, 2024. https://www.hesa.ac.uk/data-and-analysis/performance-indicators/non-continuation.

HESA. 2023. What do HE students study? Accessed March 27, 2024. https://www.hesa.ac.uk/data-and-analysis/students/what-study.

Institution of Mechanical Engineers. 2017. The Culture of Engineering in Schools. Accessed April 6, 2024. https://www.imeche.org/docs/default-source/1-oscar/reports-policy-statements-and-documents/culture-of-engineering-in-schools-imeche-final.pdf?sfvrsn=3df1da12_2.

Mejia, J. A., and J. P. Martin. “Critical Perspectives on Diversity, Equity, and Inclusion Research in Engineering Education”. In *International Handbook of Engineering Education Research*, edited by A. Johri, 218-239. New York, NY, USA: Routledge, 2023.

MSMT. 2024. Accessed March 27, 2024. https://statis.msmt.cz/statistikyvs/prohlizece.aspx

Onderwijs Vlaanderen. 2024. Dataloep: aan de slag met cijfers over onderwijs. Accessed June 8, 2024. https://onderwijs.vlaanderen.be/nl/onderwijsstatistieken/dataloep-aan-de-slag-met-cijfers-over-onderwijs

Orr, D., A. Usher, G. Atherton, H. Cezar, and I. Geanta. *Study on the impact of admission systems on higher education outcomes Volume I: Comparative report Vol. I.* Publications Office of the European Union, 2017.

Pinxten, M., C. Soom, C. Van, Peeters, T. De Laet, and G. Langie. “At-risk at the gate : prediction of study success of first-year science and engineering students in an open-admission university in Flanders — any incremental validity of study strategies.” *European Journal of Psychology of Education*, 34, 1 (2017): 45–66. https://doi.org/10.1007/s10212-017-0361-x.

United Nations. 2022"World Population Prospects 2022”. Accessed March 27, 2024.https://population.un.org/wpp/.

Vanderoost, J., R. Callens, J. Vandewalle, and T. De Laet. “Engineering positioning test in Flanders : a powerful predictor for study success?” In *Proceedings of the 42nd Annual SEFI Conference*, *Birmingham, 2014.*

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The Inclusion of Emotional Intelligence in Engineering Education: A Review

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Conference Key Areas: *Teaching the knowledge, skills, and attitudes of sustainable engineering, Educating the whole engineer: teaching through and for knowing, thinking, feeling, and doing.*
Keywords: *Emotional intelligence, EQ, EI, diversity, and inclusion.*

ABSTRACT

In recent years there has been an increase in research focused on the role that emotion plays within engineering practice. Of the related themes present within engineering education research (EER), emotional intelligence (EI) is reported as one of the most researched, its development being associated with multiple benefits. However, it is also claimed that emphasis on EI justifies an expectation for students to conform to norms, something which can result in inequality, and retention of power hierarchies. It can thus be argued that although the inclusion of emotion, and indeed EI, may, at first, appear advantageous in terms of diversity, it can act to sustain the status quo. This work is intended to examine the underlying assumptions associated with the inclusion of EI in engineering curricula. In so doing, a review of the literature is completed with the aims of understanding the way in which EI has been introduced within engineering education, as well as the reasoning behind its inclusion. 34 research articles were reviewed, with most motivated by the general benefits of EI in the context of the workplace. Whilst the majority of studies included use of EI measurement tools, the type varied significantly. Test results were typically used to identify domains of EI in which students scored least, this informing future course design, or student personal development plans. There was a lack of evidence to suggest that interventions included critical analysis of EI within a wider context, something which should be addressed in future work in the area.

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1 INTRODUCTION

1.1 Introduction to EI

In recent years there has been an increase in research which considers the role that emotion plays within engineering. Much of this work was included in a scoping review of emotion within engineering education (Lönngren et al., 2021) which identified four themes: academic emotions; emotions and ethics; emotional intelligence (EI) and other socio-emotional competencies; and mental health. Of these, EI was one of the most researched something which was proposed to be because the quantitative methods used to study EI appeal to engineering researchers (Lönngren et al., 2023).

EI is used to conceptualise the relationship between cognition and emotion and can be considered as an attempt to counter views of emotion as associated with lower intelligence, and as a possible source of bias (Solomon, 2008). This is of particular interest within engineering, a profession associated with rationality (Lönngren, Adawi, & Berge, 2021). It became influential through popular work such as that of Goleman (1995; 1998; 2013), with the EI model (Mayer, Salovey, and Caruso, 2000), defining EI as “the subset of social intelligence that involves the ability to monitor one’s own and others’ feelings and emotions, to discriminate among them and to use this information to guide one’s thinking and actions” (Salovey and Mayer, 1990, p. 189), and as involving the ability to: perceive and express emotions; understand emotions and emotional change processes; use emotions to facilitate particular types of cognition; and regulate emotions in oneself and others. Whilst this (ability) model considers EI as a group of cognitive abilities, other work frames it as a personality trait involving dispositions (Petrides, Frederickson, and Furnham, 2004).

EI is typically studied using quantitative instruments developed within psychology, with the two EI models introduced being differentiated with respect to the measurement method used to operationalize them (Petrides, 2011). Trait EI involves self-perception measured via self-report, whilst ability EI measures cognitive abilities related to emotion measured via maximum performance tests. The model used has significant implications for the development of EI within education, with the ability model focusing on possessing certain cognitive competencies, and trait EI focusing on consistent, cross-situational traits such as self-esteem and happiness, which form part of personality. Although the distinction between the types is well documented, in some cases the distinction is not acknowledged, this having implications for the ability to organize development and accumulation of knowledge in the field (Petrides, 2011). Examples of the commonly used measures are shown below.

Ability based measures:

- The Mayer Salovey Caruso Emotional Intelligence Test (Mayer & Caruso, 2002; Mayer, Salovey and Caruso, 2004).) considers EI as four abilities.

Trait based measures:

- Schutte Emotional Intelligence Scale (Schutte et al., 1998) a self-report tool which focuses on users’ perceptions of their abilities.
- Bar-On Emotional Quotient Inventory (Bar-on, 1997a; 1977b; Bar-On, Brown, Kirkcaldy, and Thomé’s (2000) EQ-i) which considers emotional-social intelligence as a mixture of skills, competencies and facilitators.

- Trait Emotional Intelligence Questionnaire/ TEIQue-SF (Petrides, Pita, and Kokkinaki., 2007) which considers EI as a subset of personality.

A significant amount of the work published in the area focuses on the gendered nature of results which have been shown to depend on the way in which the test is presented (Horgan & Smith, 2006; Ickes, Gesn, & Graham, 2000; Koenig & Eagly, 2005). In the case of self-report measures, the focus is on “abilities and the potential for performance” rather than performance itself (Bar-On., Brown, Kirkcaldy, & Thomé, 2000, p.1110) and results are often skewed by desire for positive self-presentation (Dawda & Hart, 2000; Mandell & Pherwani, 2003). Any gender differences tend to be associated with particular aspects of EI.

1.2 EI and participation and access in STEM

Findings pertaining to gender differences are particularly relevant within engineering. Several papers have focused on benefits of EI in terms of gender representation within STEM. For example, Tripon (2022) claims the ‘superior’ EI of girls could be key to motivating girls to study STEM. Besser et al. (2020) investigate how the inclusion of empathy needed for EI may act as a mechanism for cultural change and result in a critical mass of women in engineering. Van Oosten, Buse and Bilimoria (2017) describe a leadership course aimed at advancing and retaining women within STEM which featured “skill development in the areas of leadership and emotional intelligence” (p.3). Melbourne (2016) suggests that STEM educators trained in EI emphasize how emotion regulation skills can help someone succeed, something they say is essential for women and other underrepresented groups, saying that those not trained in EI may “internalize their failures” (p. 9). Similarly, Musa (2020) claims EI “can lead her to success in any engineering disciplines” (p. 3917).

1.3 Criticism of use of EI

There is a limited amount of literature within EER that highlights the need to be cautious with respect to EI. For example, in talking about experiential learning, McDermott, Göl, and Nafalski (2001) question “is it ethically defensible to seek to modify students’ intuitive or emotional behaviour?” (p. 74). Chan et al. (2020) draw upon the work of Blackmore (2011) to critique the way EI focuses on individualised competencies rather than context, as well as the power relations which define how expressions of emotion are controlled and understood. Lönngren et al. (2023) highlight the emphasis on individual self-improvement and expectations to conform to norms and encourage research to draw upon sociological perspectives. They highlight the work of Zembylas (2007) who compares EI to ‘emotional capital’, a concept based on the work of Bourdieu (e.g. Bourdieau, 1997).

More broadly with respect to equality, diversity, and inclusion (EDI), critical work in the area has highlighted the role of power and status in determining the components of EI considered of higher social value, and the way beliefs regarding ‘good’ and ‘bad’ emotion are tied to beliefs about characteristics such as social class and race (Shields, MacArthur, and McCormick, 2018). Shields and Warner (2007) argue that EI “favor(s) those who are in the position to recognize privileged knowledge and deploy it”, pointing out that “recognizing knowledge is distinct from the ability or privilege to use it. (p.172)”. They comment on the way types of EI that women are ‘supposedly’ not good at are framed to ignore structural issues, and how those emotions which are considered as ‘undesirable’ are often the ones experienced by those who undergo gender discrimination (Gibson, Schweitzer, Callister, & Gray, 2009; Vescio et al., 2005). Drawing upon expectation states theory (Ridgeway and Bourg, 2004), Shields and Warner (2007) describe political dimensions of emotions, claiming that judgments pertaining to how and when emotion should be felt and displayed serve interests of regulating organization and functioning of social groups.

In the context of education, Boler (1999) questions "how emotions are disciplined to maintain social control" (p. 22), this linked to the idea of 'feeling rules' which define who can feel which emotions, how they should feel them, and in which situations (Hochschild, 1979; 1983). In work examining emotional literacy programmes, Boler (1999) failed to observe instances in which emotions were analysed within the wider context and concluded that students were learning to perceive prescriptive rules regarding acceptable emotional behaviour. They raise several concerns around: imposing emotional rules that stem from embedded or arbitrary values; reinforcing the notion of victim blaming and advocating self-control; and contributing towards the maintenance of social hierarchies and capitalist interests.

It can therefore be argued that although the inclusion of EI, may, at first, appear advantageous in terms of diversity, it can act to sustain the status quo within engineering. This review is completed with the aims of understanding the way in which EI has been introduced within engineering education. It is not intended to act as a criticism and there is little doubt that the initiatives included provided a beneficial learning experience to students involved. Analysis is intended to examine underlying assumptions associated with inclusion of EI within engineering, and how educational practices are embedded within larger societal discourses.

2 METHODOLOGY

The research questions (RQs) focus on 1.) the ways in which the concept of EI is utilised within engineering programmes and 2.) the way in which the inclusion of EI within engineering programmes is justified. A systematic literature review (SLR) was chosen as an appropriate methodology to understand this emerging area and serve as a basis for future work. In general, an SLR involves: identifying scope and research questions; defining inclusion and exclusion criteria; appraising and synthesising studies; and reporting findings (Borrego, Foster, and Froyd, 2014).

The following inclusion criteria were used:

- Publications written in English, taking form of peer reviewed journal articles (excluding reviews), conference papers, books, or chapters.
- Work conducted in engineering programmes in higher education (HE).
- EI of engineering students is addressed (for examples as part of an intervention) or measured as part of the study.

Three of the databases recommended for SLRs in engineering education by Borrego, Foster, and Froyd (2014) were chosen, these being ERIC (ProQuest), Web of Science and SCOPUS. The search was completed in February 2024 and the keywords used were "engineering education" AND "emotional intelligence"'. The search resulted in 173 records. 28 duplicates were removed because they appeared in multiple databases, 9 could not be accessed, 3 had been redacted. One literature review and one workshop were excluded. The remaining records were partly screened by abstract and partly by full paper to examine whether they met inclusion criteria. Most records removed were done so for: describing workplace-based studies; focusing on use of technology to develop EI more widely; mentioning EI briefly as something required in engineering, along with other skills and competencies; focusing on skills surveys or employer needs; being theoretical or conceptual in nature; focusing on staff within engineering education. The remaining 34 papers were read and further analysed in a spreadsheet using the following categories: author, title, publication year, journal/conference name, reason for focusing on EI/purpose (RQ2), context, measurement tool used (if any) and justification of choice (RQ1), findings, teaching approaches (RQ1).

3 RESULTS

Of the 34 papers, 14 were journal articles and 20 conference proceedings. Table 1 shows the locations in which studies took place. Perhaps unsurprisingly, over a quarter of papers describe studies situated in the USA. Although the number of articles per year are relatively similar, there are some peaks, primarily more recently in 2023, but also in 2017.Although the number of articles considered limits the extent to which trends can be identified, the increase in recent years may be linked to increasing focus on professional skills and competencies such as cultural awareness, within accreditation criteria and engineering education more broadly.

Table 1. A summary of EI papers by year published and context of study

Location of study	Number of papers	Year of Publication	Number of Papers
Abu Dhabi	2	2001	1
Brazil	1	2007	1
Canada	2	2009	3
China	1	2010	2
Colombia	1	2012	2
Hungary	1	2013	1
India	1	2014	1
Malaysia	4	2015	1
Morocco	1	2016	2
Peru	2	2017	4
Portugal	3	2018	1
Saudi Arabia	1	2019	2
Spain	3	2020	3
Turkey	1	2021	3
Ukraine	1	2022	1
USA	9	2023	6

In answering RQ1, papers were broadly split into three categories: those describing just the use of measurement tools (21); those focused on EI based interventions (6); and those including both (7).

3.1 EI measurement tools

28 of the 34 papers described studies that employed the use of EI measurement tools, 7 of which being used in combination with teaching based interventions. A summary of the 21 papers that made use of tools alone is provided in Table 2.

In three cases the tools were not named. Two studies used both Trait Meta-Mood-Scale (TMMS-24) and the Emotional Quotient Inventory, presumably to provide coverage of both ability and trait-based EI models. The variation in the tools used is of significance when considering transferability of practice within the community, something which was highlighted in one paper (Sushchenko, Borova, and Petrenko, 2023) which suggested a need for instruments that can be used to understand EI associated with activities within the engineering profession. Very few papers discussed differences between ability and trait-based intelligence, this having implications for the development of knowledge (Petrides, 2011). Furthermore, few studies included justification for choice of tool (generally or in the context of EI model used), which impacts on the ability to design curricula or teaching practices based on findings of such work. One study (Kumar, 2019) made use of TEIQue-SF to measure students EI levels claiming it "has been successfully applied in the educational context" and that "traits EI is also able to suggest the right academic or vocational line in the higher education setting" (p. 210). Koontz (2017) made used of the EQI, claiming that the "assessment gives educators a way to measure student's emotional development and offer specific personal-development recommendations" (p. 9268). Lye et al. (2023) said that the TEIQue-Short Form was selected because it measures 'trait' EI, which has a better predictive value compared to the 'ability' EI, in anticipating actual behaviours or outcomes in a range of situations" (p. 481). Although Belanger et al. (2007) do not provide reasons for using Schutte's scale, they do discuss the implications of doing so with respect to findings that suggested no correlation between EI and academic performance, saying that Schutte's scale is trait rather than ability based, meaning that it measures personality traits as opposed to cognitive ability which would be expected to have stronger correlation with academic performance.

6 papers made use variations of tools. One group of authors made use of the EQI adapted for Malaysian traditional culture where individuals may be more prone to appreciate and respect elder people and practice spiritual aspects (Saibani et al., 2012; 2013). Chen, He, and Yang (2020) made use of the Wong and Law Emotional Scale (WLEIS) which was based on 418 undergraduates in Hong Kong. Khefacha, and Sellei (2023) used the Hungarian version of the EQ-I but do not allude differences. Magano et al. (2021) and Nogueira, Castro, and Magano (2023) made use of an EI scale validated by Rego and Fernandes for the Portuguese population. Sushchenko, Borova and Petrenko (2023) used a Ukrainian variant of the Hall EI test which they claimed was short and more accessible for the context. In light of such discussions, it is interesting that some authors discussed potential impacts of socio-cultural factors on test results. For example, Kumar (2019) described a negative perception of emotions which should be avoided to show professionalism in Malaysia. Similarly, when exploring EI in the context of teamwork, Deveci (2015) suggested that higher satisfaction with teamwork, despite low EI, may occur as a

result of the collectivist nature of Arab culture, and discouragement of expressing negative emotions explicitly.

Finally, in some papers there was a noticeable use of deficit-based language when justifying use of EI tools (RQ2). For example, Saibani et al., (2013) claimed that a "test is able to determine the EQ level …which is also beneficial towards consolidating any domain that is deemed flawed" (p.78). Likewise, the same authors (Saibani et al., 2012) justified use of an EI tool "as an effort to examine what domain is lacking amongst the students and what can be done to elevate the low domains." (p. 525).

3.2 EI measurement tools and interventions

Seven papers described the use of EI tools alongside a teaching intervention. One (Casado, Fernández, and Lapuerta, 2016) made use of a pre-post tests to evaluate EI training effectiveness. Deveci and Nunn (2016) used a tool with seminar discussions within a project-based module, claiming results could be used to inform content.

Other studies in this category made use of tools to help guide personal development activities. Stewart, Chisholm, and Harris (2010) used the College Achievement Inventory-Revised (CARI-R) because the "self-report assessment measures

Table 2. A summary of EI papers making use of EI measurement tools

Topic of interest	Tool(s)	Categories of Analysis	Reference
Coping strategies and EI as contributors to -major grade point average (GPA)	Schutte's EIS	GPA, discipline	Belanger et al. (2007)
EI as a moderator of design capability and computational thinking Relationship between EI and innovation	Wong and Law EIS (WLEIS)		Chen, He, and Yang (2020)
Relationship between teamwork satisfaction and EI	Schutte's EIS	Gender and nationality	Deveci (2015)
Levels of EI according to achievement	WLEIS	Gender, year/level of study, discipline	Encinas and Chauca (2020)
Strengths and weaknesses of students' EI to identify areas for development using neurolinguistics programming	EQI (Hungarian version)		Khefacha and Sellei (2023)
Impact of liberal arts on EI as an indicator for general success	Not provided	Gender, discipline, year/level of study	Kissani and Boudihaj (2019)
Relationship between academic performance and EI	Schutte's EIS	Gender	Koppad et al. (2023)
Gender differences in EI/EDI	TEQIue-SF	Gender	Kumar (2019)
EI as an indicator of how much time spent in each of the design activities	EQI-2.0	Year/level of study, gender, major	Koontz et al. (2017)
Determine differences in EI of high academic performance (HAP) students	TMMS-24 and EQi-S	HAP vs non HAP	Pertegal-Felices et al. (2017)

Relationship between team project marks and EI	EQI		Leicht et al. (2009)
Effects of EI and demographic characteristics on Psychological Capital	TEIQue-SF	Gender	Lye et al. (2023)
Impact of EI on students' motivation to learn more about sustainability and whether it plays a role in moderating the relationships between those variables	Rego and Fernandes	Gender, year/level of study, nationality	Nogueira, Castro, and Magano (2023).
Employability/performance in the workplace	EQI-S	Comparison with teaching students and survey results about competencies related to EI needed in workplace	Pertegal-Felices, Castejón-Costa, and Jimeno-Morenilla (2014).
Connection between achievement and EI in women, inclusivity, and diversity	Not provided	Gender, year/level of study, discipline, academic performance	Rizwan et al. (2019)
Cultural differences in EI	Malaysian EQI	major races in Malaysia	Saibani et al. (2012)
Employability/competitive advantage	Malaysian EQI	Year group/level of study	Saibani et al. (2013)
Relationship between EI and personality traits and resilience (needed for project management including teamwork and communication) of GenZ students.	Rego and Fernandes	Gender	Silva et al.(2020) Magano et al. (2021)
Development of (engineering specific) self-evaluation tools, represented by qualimetric instruments to evaluate EI	Hall (Ukrainian version)	Year/level of study	Sushchenko, Borova and Petrenko (2023)
General benefits/employability	Schutte's EIS	Age, gender, hobbies, engineer in family, professional pessimism	Tekerek and Tekerek (2017)

behavioural tendencies and self-perceived abilities" which is suitable when "the intent of EI assessment of students is to provide the student with an awareness of their behavioural tendencies and how to improve their self-perceived abilities." Price, and Cordova-Wentling (2009) claim that EI tests allow for self-assessment and feedback necessary for improvement, and asked students to use their results as the basis of a personal development plan for the semester. Degen et al. (2022) describe teaching students on a programme for first generation students about the EQ-i 2.0 instrument, saying that they made use of their results to produce SMART goals for personal development. In their work into leadership development, Didiano, Simpson, and Reeve (2021) combined the use of a tool with one-on-one debriefs with the instructor which they said allowed students to clearly understand their strengths and areas for growth, this forming the basis of a personal development plan. Crowley et al. (2010) also described the use of EI tools to inform students' development plans.

3.3 EI measurement based interventions

Six papers described EI based teaching interventions. These typically involved an introduction to the concept and discussion. Such content was introduced in leadership (Bayless, Mitchell, and Robe, 2009; Bayless and. Robe, 2010) and management (Burgos-Vera et al., 2021) courses and as a core element of an Innovation, Leadership, and Engineering Entrepreneurship BS Degree Program (Newell, and Varshney, 2017). Catalano, Abdalla, and Delicato (2012) describe introducing EI to help students to differentiate themselves in the labour market. Rojas-Martínez et al. (2021) describes utilising a problem-based learning approach to introduce content addressing three axes within EI: motivation, tolerance, and resilience. The learning outcomes include identifying factors that affect emotional well-being, motivations, identifying situations of stress, setting goals and actions, healthy relationships, support groups, social and academic connections and activities which activate resilience.

4 SUMMARY

The main limitation of this work is the focus on only three databases and the exclusion of non-English publications or non-academic articles or reports. There are also limitations associated with the search terms used. Nevertheless, the findings show that, in the context of EER, EI based studies primarily make use of EI measurement tools. Results were typically analysed by characteristics such as gender, race, year of study and discipline and used to identify constructs of EI which are underdeveloped, to inform course design, or to help inform student personal development plans. In some cases, pre-post EI tests were used to assess the effectiveness of an intervention. In a few cases authors did not report the tool used and there was little consistency in tool used across range of papers. It would be beneficial for researchers to justify reasons for use of tools in the context of trait based or ability-based EI models and research aims. A more consistent approach would help facilitate faster development of knowledge within the field. In some cases, papers took a deficit approach to EI and there was little evidence to suggest that courses included critique of the emphasis on individual self-improvement and the expectation to conform to norms, or analysis of emotions within a wider context. Future interventions within engineering should focus on highlighting such issues. For example, Boler (1999) suggests several ways in which EI can be made explicit, suggesting reflective, collaborative, critical analysis of gendered and cultural differences in emotions and the role emotions play in maintaining power structures, topics which may be considered particularly relevant within engineering, which suffers from a lack of diversity.

REFERENCES

Bar-On, R. (1997). Bar-on emotional quotient inventory (EQ-i) A test of emotional intelligence. Multi-Health Systems.

Bar-On, R. (1997a). The Emotional Quotient Inventory (EQ-i): A test of emotional intelligence. Toronto, Canada: Multi-Health Systems, Inc.Bar-On, R. (1997b). The Emotional Quotient Inventory (EQ-i): Technical manual. Toronto, Canada: Multi-Health Systems, Inc.

Bar-On, R. 2004. "The Bar-On Emotional Quotient Inventory (EQ-i): Rationale, description and summary of psychometric properties." In *Measuring emotional* *intelligence: Common ground and controversies,* edited by G. Geher, 115–145. Nova Science Publishers.

Bar-On, R., Brown, J. M., Kirkcaldy, B. D., & Thomé, E. P. (2000). Emotional expression and implications for occupational stress: An application of the Emotional Quotient Inventory (EQ-i). Personality and Individual Differences, 28, 1107–1118. http://dx.doi.org/ 10.1016/S0191-8869(99)00160-9.

Bayless, D. J., J. Mitchell, and T. R. Robe. 2009. "Engineering leadership studies and the Robe Leadership Institute model in the Russ College of Engineering and Technology at Ohio University." 2009 39th IEEE Frontiers in Education Conference, San Antonio, TX, USA, 2009, 1-6.https://doi.org/10.1109/FIE.2009.5350619.

Bayless, D., and T. R. Robe. 2010. "Leadership education for engineering students." Proceedings – 40th Frontiers in Education Conference, Washington DC, USA, October 27-30, 2010. https://doi.org/10.1109/FIE.2010.5673554.

Belanger, F., T. Lewis, G. M. Kasper, W. J. Smith, and K. V. Harrington. 2007. "Are Computing Students Different? An Analysis of Coping Strategies and Emotional Intelligence," in *IEEE Transactions on Education* 50, no. 3:188-196. https://doi.org/ 10.1109/TE.2007.900029.

Besser, D., K. Brown, A. Haugh, T. Brass, R. Leininger, and A. Thomas. 2020. "Empathy, Engineering, and Girls". Presented at 2020 ASEE Virtual Annual Conference. https://doi.org/10.18260/1-2--34525.

Blackmore, J. 2011. "Lost in translation? Emotional intelligence, affective economies, leadership and organizational change," *Journal of Educational Administration and. His*torty 43, no. 3: 207–225. https://doi.org/ 10.1080/00220620.2011.586455.

Boler, M. 1999. "Feeling power: Emotions and education." Routledge.

Borrego, M., M. J. Foster, and J. E Froyd. 2014. "Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields." Journal of Engineering Education 103: 45-76. https://doi.org/10.1002/jee.20038.

Bourdieu P. 1997. "The forms of capital." In *Education: Culture, Economy, Society*, edited by A. H. Halsey, H. Lauder and P. Brown, 46–58. Oxford: Oxford University Press.

Burgos-Vera, O., C. Sotomayor-Beltran, D. Llulluy-Nuñez, and H. R. del Carmen. "Teaching management skills to first year engineering students." 2021 IEEE World Conference on Engineering Education (EDUNINE), Guatemala City, Guatemala, 2021, 1-4. http://doi.org/doi: 10.1109/EDUNINE51952.2021.9429141.

Casado, M., D. Fernández, and V. Lapuerta. 2016. "Socio-emotional competencies in engineering education." *International Journal of Engineering Education* 32: 1660-1678.

Catalano, F., A. Abdalla, and F. Delicato. 2012. "What is Missing for Traditional Design-Centric Engineering Education to Better Prepare Newly Graduated Engineers for the Global Era?*". *International Journal of Engineering Education*. 28, no.4:852–858.

Chan, A., C. Rottmann, D. Reeve, E. Moore, M. Maljkovic, and E. Macdonald-Roach. 2020, June. *Wisdom through Adversity: Situated Leadership Learning of Engineering*

Leaders .Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual On line . https://doi.org/10.18260/1-2—35583.

Chen, G. Y. He, and T. Yang. 2020. "An ISMP Approach for Promoting Design Innovation Capability and Its Interaction With Personal Characters," in *IEEE Access*, vol. 8, 161304-161316. http://doi.org/10.1109/ACCESS.2020.3019290.

Crowley, L., R. Price, J. Dolle, and B. Litchfield. 2001. “Engineering Emotional Intelligence: Course Development and Implementation.” Proceedings of 2001 ASEE Annual Conference and Exposition, Albuquerque, NM, United States, 24-27 June 2001, 4285-4309. https://doi.org/10.18260/1-2--9193.

Dawda, D., and S. D. Hart. 2000. “Assessing emotional intelligence: Reliability and validity of the Bar-On Emotional Quotient Inventory (EQ-i) in university students.” *Personality and Individual Differences* 28:797–812. http://dx.doi.org/10.1016/S0191-8869(99)00139-7.

Degen C.M., A. Jensen; J. J. Kellar, M. West, L. Carlson, J. Herrera, M. E. Moore. 2022. “First-generation student success and the SD-FIRST program”. ASEE Annual Conference and Exposition, Conference Proceedings.

Deveci, T. 2015. “Freshman Students' Emotional Intelligence and Team-Work Satisfaction Levels. A Comparative Study: Gender and Nationality.” *Yuksekogretim Dergisi*. 5, no.1: 35-43. https://doi.org/10.2399/yod.15.007.

Deveci, T., and R. Nunn. 2016. “Development in freshman engineering students' emotional intelligence in project-based courses.” *The Asian ESP Journal* 12: 54-92.

Didiano, T., A. Simpson, and D. Reeve. 2021. A Leadership-Development Ecosystem for Engineering Graduate Students. 2021 ASEE Virtual Annual Conference. https://doi.org//10.18260/1-2--36589.

Encinas, J. J., and M. Chauca. 2020. “Emotional intelligence can make a difference in Engineering Students under the Competency-based Education Model.” *Procedia Computer Science* 172:960-964. https://doi.org/10.1016/j.procs.2020.05.139.

Gibson, D. E., M. E. Schweitzer, R. R. Callister, and B. Gray. 2009. “The influence of anger expressions on outcomes in organizations.” *Negotiation and Conflict Management Research*, 2: 236–262. http://dx.doi.org/ 10.1111/j.1750-4716.2009.00039.x.

Goleman, D. 1995. *Emotional intelligence*. Bantam Books.

Goleman, D. 1998. *Working with emotional intelligence*. Bantam Books.

Goleman, D. 2013. *Focus: The hidden driver of excellence*. Harper.

Hochschild, A. 1979. “Emotion work, feeling rules, and social structure”. *American Journal of Sociology* 85: 551–575.

Hochschild, A. 1983. *The managed heart: Commercialization of human feeling*. University of California Press.

Horgan, T. G., and J. L. Smith. 2006. “Interpersonal reasons for interpersonal perceptions: Gender incongruent purpose goals and nonverbal judgment accuracy”. *Journal of Nonverbal Behavior* 30: 127–140. http://dx.doi.org/10.1007/s10919-006-0012-4.

Ickes, W., P. R. Gesn, and T. Graham. 2000. “Gender differences in empathic accuracy: Differential ability or differential motivation?” *Personal Relationships* 7: 95–109. http://dx.doi.org/10.1111/ j.1475-6811.2000.tb00006.x.

Khefacha, A., and B. Sellei. 2023. “Engineering Students Emotional Intelligence And Neuro-Linguistics Programming (NLP) As Developmental Tool.” 51st Annual Conference of European Society for Engineering Education (SEFI), Dublin, Ireland, 11-14 September, 2023. https://doi.org/10.21427/W0X3-B872.

Kissani, I., and A. Boudihaj. 2019. "Emotional Intelligence a Success Indicator for Implementing Liberal Arts Education in Morocco," *2019 IEEE Global Engineering Education Conference (EDUCON)*, Dubai, United Arab Emirates, 2019, 738-743. https://doi.org/10.1109/EDUCON.2019.8725054.

Koenig A. M. and A. H. Eagly. 2005. “Stereotype threat in men on a test of social sensitivity.” *Sex Roles* 52: 489–496. https://doi.org/10.1007/s11199-005-3714-x.

Koontz, R., D. Dolan, K. Osberg, and J. Gibson. 2017. “Emotional intelligence and its connection to engineering design cognitive processes”. Proceedings of Conference: International Technology, Education and Development Conference, 6th-8th March 2017, Valencia, Spain, 9267-9275. https://doi.org/10.21125/inted.2017.2192.

Koppad, S., J. Gadad, P. Patil and V. M. 2023 "Understanding the Influence of Student’s Emotions in Academic Success," *2023 2nd Edition of IEEE Delhi Section Flagship Conference (DELCON)*, Rajpura, India, 2023, 1-6. https://doi.org/10.1109/DELCON57910.2023.10127402.

Kumar, J. A.. 2019. “Exploring Engineering Undergraduates’ Emotional Intelligence: A Gender Comparison Study In Malaysia”. Proceedings of ICEEPSY 2018: Education and Educational Psychology, 198-210. https://doi.org/10.15405/epsbs.2019.01.20.

Law, K. S., C. S. Wong, and Song. 2004. “The Construct and Criterion Validity of Emotional Intelligence and Its Potential Utility for Management Studies.” *Journal of Applied Psychology,* 89, no. 3: 483–496. https://doi.org/10.1037/0021-9010.89.3.483.

Leicht, R., A. Lewis, D. Riley, J. Messner, and B. Darnell. 2009. “Assessing Traits for Success in Individual and Team Performance in an Engineering Course.” Building a Sustainable Future - Proceedings of the 2009 Construction Research Congress. https://doi.org/10.1061/41020(339)138.

Lye, A. J., P. Y. Liew, H. M. Fadzil, and C. C. Foong. 2023.

“Effect of Emotional Intelligence and Demographic Characteristics on Psychological Capital among Chemical Engineering Students.” *Journal of Chemical Education* 100, no. 2: 479-488. https://doi.org/10.1021/acs.jchemed.2c00105.

Lönngren, J., T. Adawi, and M. Berge. 2021. “Using positioning theory to study the role of emotions in engineering problem solving: Methodological issues and recommendations for future research.” *Studies in Engineering Education* 2, no.1: 53–79. https://doi.org/10.21061/see.50.

Lönngren, J., A. Bellocchi, P. Bøgelund, I. Direito, J. Huff, K. Mohd-Yusof, H. Murzi, and R. Tormey. 2021. “Emotions in engineering education: Preliminary results from a scoping review." Proceedings of 9th Research in Engineering Education Symposium, Perth (online), December 5–8, 2021, 641-650. https://doi.org/10.52202/066488-0071

Lönngren, J., I. Direito, R. Tormey, and J. Huff. 2023. "Chapter 8: Emotions in Engineering Education." In *International Handbook of Engineering Education Research,* edited by A. Johri, 156-182. New York: Routledge.

Magano, J., C. S. Silva, C. Figueiredo, A. Vitória and T. Nogueira. 2021. "Project Management in Engineering Education: Providing Generation Z With Transferable Skills," in *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, 16, no. 1, 45-57, Feb. 2021. http://doi.org/10.1109/RITA.2021.3052496

Mandell, B., and S. Pherwani. 2003. "Relationship between emotional intelligence and transformational leadership style: A gender comparison." *Journal of Business and Psychology* 17: 387–404. http:// dx.doi.org/10.1023/A:1022816409059.

Mayer, J. D., and D. R. Caruso. 2002. Mayer-Salovey-Caruso emotional intelligence test (MSCEIT) user's manual. Multi-Health Systems.

Mayer, J. D., P. Salovey, and D. Caruso. 2000. "Models of emotional intelligence". In *Handbook of intelligence*, edited by R. J. Sternberg, 396–420. Cambridge University Press.

Mayer, J. D., P. Salovey, and D. R. Caruso. 2004. "Emotional intelligence: Theory, findings, and implications." *Psychological Inquiry* 15*,* no. 3: 197–215. https://doi.org/10.1207/s15327965pli1503_02.

McDermott, K., Ö. Göl, and A. Nafalski. 2002. "Considerations on Experience-based Learning."" *Global Journal of Engineering Education* 6, no.1:71–78.

Melbourne, K. 2016. "Keeping Women in Science: How Emotional Intelligence Training Supports Healthy Classroom Environments" Available from http://katiemelbourne.me/STEM_Education_and_EI.pdf.

Musa, T. (2020, August). "Sudanese Women in Extractive Industries: Engineering Education Point of View." In *5th North American International Conference on Industrial Engineering and Operations Management*. https://doi.org/10.46254/NA05.20200778.

Newell, B. S., and L. R. Varshney. 2017. "The first cohort in a new innovation, leadership, and engineering entrepreneurship B. S. degree program," 2017 IEEE Frontiers in Education Conference (FIE), Indianapolis, IN, USA, 2017, 1-6. https://doi.org/10.1109/FIE.2017.8190631.

Nogueira, T.; R. Castro, and J. Magano. 2023. "Engineering Students Education in Sustainability: The Moderating Role of Emotional Intelligence." *Sustainability,* 15: 5389. https://doi.org/10.3390/ su15065389.

Pertegal-Felices, M. L., J. L. Castejón-Costa, and A. Jimeno-Morenilla. 2014. "Differences between the personal, social and emotional profiles of teaching and computer engineering professionals and students." *Studies in Higher Education* 39, no.7: 1185-1201. https://doi.org/10.1080/03075079.2013.777410

Pertegal-Felices, M. L., J. L. Castejón-Costa, R. Gilar-Corbí, R., and H. Mora-Mora. 2017. "Emotional Intelligence Profile of High Academic Performance Students in

Computer Engineering." *Journal of Education*, 197, no. 3: 25-33. https://doi.org/10.1177/0022057418782343.

Petrides, K. V. 2011. "Ability and trait emotional intelligence." In *The Wiley-Blackwell handbook of individual differences*, edited by T. Chamorro-Premuzic, S. von Stumm, and A. Furnham, 656–678. Wiley Blackwell.

Petrides, K.V., N. Frederickson, and A. Furnham. 2004. "The role of trait emotional intelligence in academic performance and deviant behavior at school." *Personality and Individual Differences* 36*,* no. 2: 277–293. https://doi.org/10.1016/S0191-8869(03)00084-9

Petrides, K. V., R. Pita, and F. Kokkinaki. 2007. "The location of trait emotional intelligence in personality factor space". *British Journal of Psychology* 98, no. 2: 273–289. https://doi.org/10.1348/000712606x120618.

Price, R., and R. M. Cordova-Wentling. 2009. "Human behavior skills and emotional intelligence in engineering." 2009 ASEE Annual Conference and Exposition, Conference Proceedings.

Rego, A. and C. Fernandes "2005. Inteligência emocional: Contributos adicionais para a validação de um instrumento de medida." *Psicologia* 19: 139–167.

Ridgeway, C. L. and C. Bourg. 2004. "Gender as status: An expectation states theory approach." In *The Psychology of Gender*, edited by A. H. Eagly, A. E. Beall, and R. J. Sternberg, 217-241. New York: Guildford.

Rizwan, A., H. Alsulami, N. Elnahas, M. Bashir, F. Bawareth, R. Kamrani, and R. Noorelahi. 2019. "Impact of emotional intelligence on the academic performance and employability of female engineering students in Saudi Arabia." *International Journal of Engineering Education* 35, no.1:119-125.

Rojas-Martínez, S. L., C. A. Castelblanco-Torres, L. Y. Parra-Rodríguez, A. P. Acosta, and G. Muñoz-Puerta. 2023. "Strengthening of Love and Meaning of Life in Engineering Students supported by Problem-Based Learning." Proceedings of the PAEE/ALE'2023, International Conference on Active Learning in Engineering Education 15th International Symposium on Project Approaches in Engineering Education (PAEE) 20th Active Learning in Engineering Education Workshop (ALE) São Paulo - Brazil, 28-30 June 2023, 120-129.

Saibani, N. & B. Deros, N. Muhamad, D. Abd Wahab, and J. Sahari. 2012. "The Influence of Type of Race among Engineering Students towards the Level of Emotional Intelligence (EQ) Scores." *Procedia - Social and Behavioral Sciences* 56: 523–529. http://doi.org/10.1016/j.sbspro.2012.09.684.

Saibani, N., M. Sabtu, N. Muhamad, D. Abd Wahab, and J. Sahari. 2013. "The Score Difference of Emotional Intelligence among Engineering Students at Different Levels of Academic Year". *International Education Studies* 6, no. 6: 72-79. https://doi.org/10.5539/ies.v6n6p72.

Salovey, P., and J. D. Mayer. 1990. "Emotional Intelligence." *Imagination, Cognition and Personality*, 9, no. 3: 185-211. https://doi.org/10.2190/DUGG-P24E-52WK-6CDG

Schutte, N. S., J. M. Malouff, L. E. Hall, D. J. Haggerty, J. T. Cooper, C. J. Golden, and L. Dornheim. 1998. "Development and validation of a measure of emotional intelligence.” *Personality and Individual Differences* 25, no. 2: 167–177. https://doi.org/10.1016/S0191-8869(98)00001-4.

Shields, S. A., H. J. MacArthur, and K. T. McCormick. 2018. “The gendering of emotion and the psychology of women”. In *APA handbook of the psychology of women: History, theory, and battlegrounds,* edited by C. B. Travis, J. W. White, A. Rutherford, W. S. Williams, S. L. Cook, & K. F. Wyche, 189–206). American Psychological Association. https://doi.org/10.1037/0000059-010.

Shields S. A. and L.R. Warner. 2007. “Gender and the emotion politics of emotional intelligence”. In *The emotional organisation: Passions and powers*, edited by S. Fineman, 167-183. London, UK: Blackwell.

Silva, C. J. Magano, C. Figueiredo, A. Vitória and T. Nogueira. 2020. "A multi generational approach to project management: implications for engineering education in a smart world," *2020 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, 2020, 1139-1148. https://doi.org/10.1109/EDUCON45650.2020.9125144.

Stewart, M. F., C. Chisholm, and M. Harris. (2010) "Engineering Student Learning and Emotional Competencies," *2010 IEEE Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments*, Dublin, Ireland, 2010. 1-17. http://doi.org/10.1109/TEE.2010.5508871.

Solomon, R. C. 2008. “The philosophy of emotion”. In *Handbook of emotions (3rd ed.,* edited by M. Lewis, J. M. Haviland-Jones, and L. Feldman Barrett, 3–16. The Guilford Press.

Sushchenko, T. Borova and V. Petrenko. 2023. "Measuring Engineering Students' Emotional Competence With Qualimetric Instruments," *2023 IEEE 5th International Conference on Modern Electrical and Energy System (MEES)*, Kremenchuk, Ukraine, 2023, 1-5. http://doi.org/10.1109/MEES61502.2023.10402509.

Tekerek, M., and B. Tekerek. 2017. “Emotional intelligence in engineering education.” *Turkish Journal of Education* 6, no. 2 88-95. https://doi.org/10.19128/turje.306499.

Tripon, C. 2022. “Fostering women to choose stem career by using emotional intelligence as key element.” *Journal of Educational Sciences* 45, no. 1: 51-68. https:// doi.org/10.35923/JES.2022.1.04.

Van Oosten, E. B., K. Buse, and D. Bilimoria. 2017. “The Leadership Lab for Women: Advancing and retaining women in STEM through professional development.” *Frontiers in Psychology* 8*.* https://doi.org/10.3389/fpsyg.2017.02138.

Vescio, T. K., S. J. Gervais, M. Snyder, and A. Hoover. 2005. “Power and the creation of patronizing environments: The stereotype-based behaviors of the powerful and their effects on female performance in masculine domains.” *Journal of Personality and Social Psychology* 88: 658–72.

Wong, C.-S., and K. S. Law. 2002. *Wong and Law Emotional Intelligence Scale (WLEIS)*. APA PsycTests.

Zembylas, M. 2007. “Emotional capital and education: Theoretical insights from Bourdieu.” *British Journal of Educational Studies* 55, no.4: 443–463. http://dx.doi.org/10.1111/j.1467-8527.2007.00390.x.

DOES ARTS TRULY PROMOTE SCIENCE? AN INVESTIGATION INTO THE IMPACT OF ARTS EDUCATION ON THE RESEARCH PERFORMANCE OF SCIENCE AND ENGINEERING GRADUATE STUDENTS IN TOP CHINESE UNIVERSITIES

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ABSTRACT

The positive impact of art on science is often mentioned in academic circles, yet there is scarce empirical research and a lack of universal consensus based on evidence. Against the backdrop of numerous new opportunities in arts education, the relationship between the two requires further clarification. Therefore, this study focuses on science and engineering graduate students from top Chinese universities, exploring the potential impact of arts education on graduate research performance and its underlying mechanisms.Therefore, this paper focuses on

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science and engineering graduate students from top Chinese universities, and employs methods such as correlation analysis, independent samples t-test, regression analysis, and structural equation modeling to exploring the relationship between arts education and research performance. The research finds that science and engineering graduate students in top Chinese universities who have received systematic arts education often exhibit more pronounced creative personalities, and such creative personalities can positively influence research performance. Therefore, this paper proposes integrating artistic elements into research guidance and incorporating research elements into arts education, aiming to enhance their creative personalities and thereby improve research capabilities and performance.

1 INTRODUCTION

Due to the influence of the Enlightenment movement in France, science and art have long been perceived as two separate and independent domains by the public. Furthermore, the rapid development of modern technology has fostered an education system that prioritizes tools and scientific rationality, which is not conducive to the comprehensive development of students. This phenomenon is particularly evident among science and engineering graduate students engaged in research. More critically, the absolute centrality of scientific and technological knowledge in science and engineering education has resulted in a neglect of cultivating students' social responsibility awareness. However, throughout history, many great scientists have had strong connections with the arts. Albert Einstein, for example, had a passion for playing the violin alongside his scientific research, Santiago Ramón y Cajal attributed much of his research success to his pursuit of the arts, and Academician Qian Xuesen had repeatedly advocated for researchers and science and engineering students to study literature and art. Currently, both domestically and internationally, the education sector is gradually beginning to integrate arts education into the curriculum, replacing STEM education with STEAM education [1]. Sustainable development, equity, and social justice are at the core of STEAM [2].

This leads us to ponder: as arts education is poised for vibrant growth, can empirical evidence and mechanisms be found to establish the correlation between art and science? Furthermore, can the existing forms of arts education in China enhance the research performance of science and engineering graduate students in top Chinese universities, such as Tsinghua University, Peking University, and Zhejiang University? Unfortunately, to date, although many scholars have focused on the topic of art and science, their efforts have often been limited to speculative or experiential descriptions[3].Even though there are a few relevant empirical studies, they mostly focus on students in the K-12 education stage[4,5], making it difficult to identify and confirm the relationship between the two. By exploring the aforementioned unresolved questions, this study aims to provide new theoretical guidance for the comprehensive development of science and engineering research graduate students.

2 RESEARCH HYPOTHESES

The process of artistic creation shares similarities with the process of scientific discovery, as both require the synthesis of intuition and holistic cognition [6]. Researchers in academia integrate non-vocational experiences and abilities gained from arts education with professional skills and knowledge into interdisciplinary research. This combined approach of learning and practice enables them to perceive problems at the intersection of disciplines, transfer ideas and techniques from one field to another, and even integrate interdisciplinary knowledge [7].

Through a review of related studies, it is found that creative personality is significantly associated with both art education and academic research performance. On the one hand, some scholars argue that the level of artistic literacy among technology talents directly impacts their thinking patterns and creativity [8]. Art education not only advances the brain's visual cognitive system but also promotes the balanced development of cognitive, perceptual, and memory functions. These positive impacts enhance visual-spatial abilities, analytical skills, and mathematical abilities, ultimately fostering changes and shaping creative personality [9–11].

On the other hand, previous studies have shown that innovative personality has an inherent stability and plays a certain predictive role in individual innovative performance [12,13]. When individuals possess higher creative personality traits, they generate more diverse ideas and attempt to transform their ideas into concrete and feasible innovative behaviors, resulting in more innovative performance and creative achievements [14,15].The essence of scientific research in science and engineering disciplines involves creative activities, which are the "rediscovery" and "reproduction" of knowledge, characterized by high accumulation and innovation. Graduate students with creative personalities often possess solid professional foundations, stronger research interests, and more active thinking.

In keeping with this line of reasoning, we propose the following:

Hypothesis 1: Students who have received arts education are more likely to achieve higher research performance compared to those who have not.

Hypothesis 2: Students who have received arts education exhibit more pronounced creative personalities compared to those who have not.

Hypothesis 3: The creative personality of students positively influences research performance.

Hypothesis 4: Arts education play a moderating role in the relationship between creative personality and research performance.

3 RESEARCH DESIGN

3.1 Study Subjects

“Double First-Class” Universities being a group of top Chinese universities and their disciplines that are expected to enter the world's top tier. Most of China's postgraduate education is concentrated in these institutions. Thus, this study selects graduate students from "Double First-Class" universities in science and engineering disciplines as survey subjects to investigate their arts education, creative personalities, research performance levels, and their interrelationships. This study adopts random sampling for the survey. Over a period of four months, a total of 302 questionnaires were distributed through online and offline methods, and 251 questionnaires were collected, resulting in a response rate of 83.1%. Before distributing the questionnaire, participants were informed that completion signifies consent and authorization for data use in research. Subsequently, rigorous screening was conducted on the collected questionnaires, and those with incomplete responses, those with all answers filled as the same option, and those not meeting the requirements were excluded. Finally, 219 valid questionnaires were obtained, with an effective questionnaire recovery rate of 87.3%. The distribution characteristics of the sample are detailed in Table 1.

Table 1 Sample Characteristics (N=219)

Variable	Option	Frequency	Variable	Option	Frequency
Gender	Male	156	Residence	Township	25
	Female	63		Rural	68
Age	≤20 years	2	Discipline	Science	51
	21-23 years	76		Engineering	168
	24-26 years	112	Education Degree	Master	152
	27-29 years	24		Doctoral	67
	≥30 years	5	Arts Education	None	154
	Urban	126		Some	65

3.2 Research Instruments

The variables in this study were established through a rigorous and scientific process. Most of the scales used were adapted from mature scales both domestically and internationally. Additionally, experts in education management were invited to modify items in the initial questionnaire that were conceptually ambiguous, semantically biased, or unclear. Before formally distributing the survey questionnaire, a small-scale and small-sample pre-survey was conducted to delete items with inadequate reliability and validity.

(1) Arts Education: The art categories of discussed in this paper mainly include music (vocal and instrumental), painting, calligraphy, dance, and drama performance. In this study, art education is considered a binary variable with two options: "yes" and "no". Those who select "yes" indicate that they have received systematic art learning and training for at least 1 year (with no interruption of more than half a year). It does not include those who have occasionally received arts education or only received general art literacy education and aesthetic education in school.

(2) Creative Personality: The International widely-used "Williams Creativity Assessment Packet" was employed to measure creative personality. It mainly consists of four dimensions: adventurousness, curiosity, imagination, and challenge[16]. Taking into consideration the characteristics of college students and the context of the art and science fields, 16 items with high reliability and validity were selected. Each dimension consists of 4 self-assessment items, with each item having three options: "fully agree", "partially agree", and "disagree".

(3) Research Performance: In assessing research performance, mainly references were drawn from the research performance scale constructed by Van Scotter and Motowidlo (1996). The research performance of this study includes task performance and relationship performance. Task performance mainly refers to the performance of graduate students in completing research work, while relationship performance mainly refers to graduate students' interpersonal relationship management and their contribution to research work. The scale is rated on a Likert five-point scale, with a total of 10 positively-worded items. Options range from "strongly agree" to "strongly disagree," with scores of 5 to 1, respectively.

(4) Control Variables: Considering the potential influence of individual characteristics on personal research performance, control variables were extracted from individual characteristics. These mainly include gender, age, education level, and discipline.

3.3 Control and Test for Common Method Bias

The questionnaire data were derived from self-reported cross-sectional surveys, which may lead to common method bias. Therefore, two methods, namely pre-procedural control and post-statistical identification, were employed to control and test for the influence of common method bias. Pre-procedural controls included anonymous measurements and random mixing of measurement items corresponding to different variables. Post-statistical identification included using Harman's single-factor test to test for common method bias in the collected data. The results of unrotated exploratory factor analysis extracted 11 factors with characteristic roots greater than 1, and the maximum factor variance explanation rate was 19.834%. Therefore, there is no serious common method bias in the data collected for this paper.

3.4 Reliability and Validity Analysis

This study primarily employs Cronbach's Alpha coefficient to assess the reliability of the scales for creative personality, research performance, and artistic ability. Additionally, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity, based on orthogonal varimax rotation and principal component analysis, are used to assess the validity of the variables. Table 2 shows that the Cronbach's Alpha coefficients for each variable are generally above 0.8, indicating good reliability for the scales of creative personality and research performance. Thus, the data results are stable and reliable, validating the research hypotheses. Moreover, the KMO values for each variable are generally above 0.7, and Bartlett's test of sphericity yields significant values below 0.01. The cumulative explained variance values are all above 50%, indicating good structural validity for each scale. Therefore, the measurement results to some extent reflect the true levels of creative personality, research performance, and artistic ability among graduate students from top Chinese universities in science and engineering disciplines.

Table 2. Results of Reliability and Validity Analysis for Each Variable

Variable	Cronbach's Alpha	KMO Value	Bartlett's Test of Sphericity	Cumulative Explained Variance (%)
Creative Personality	0.834	0.848	931.357 (P < 0.001)	0.616

Research Performance	0.908	0.911	994.306 (P < 0.001)	0.615

4 Empirical Analysis

4.1 Descriptive Statistics and Correlation Analysis

Table 3 presents the mean, standard deviation, and correlation matrix of each research variable. It can be observed that the mean values of the four dimensions of creative personality among surveyed graduate students from top Chinese universities in science and engineering disciplines are ranked in the following order: curiosity (2.454), challenge (2.448), imagination (2.188), and adventure (2.151). These values are at a moderately lower level (based on a five-point scale, with 3 as the median) indicating that the creative personality level of top Chinese university graduate students in science and engineering disciplines is generally moderate. However, the research performance (3.288) is at a moderately higher level.

In terms of correlation analysis, creative personality (r=0.292, P<0.01) and its dimensions are significantly correlated with research performance. The correlation coefficients are ranked in the following order: curiosity (r=0.335, P<0.01), challenge (r=0.300, P<0.01), adventure (r=0.194, P<0.01), and imagination (r=0.135, P<0.05). Therefore, the creative personality and its dimensions of top Chinese university graduate students in science and engineering disciplines are positively correlated with research performance.

Table 3. Descriptive Statistics and Correlation Analysis Results

	Creative Personality	Challenge	Curiosity	Imagination	Adventurousness	Research Performance
Creative Personality	1.000					
Challenge	0.796**	1.000				
Curiosity	0.842**	0.663**	1.000			
Imagination	0.781**	0.453**	0.487**	1.000		
Adventurousness	0.825**	0.510**	0.614**	0.539**	1.000	
Research Performance	0.292**	0.300**	0.335**	0.135*	0.194**	1.000
M	2.310	2.448	2.454	2.188	2.151	3.288
SD	0.356	0.409	0.417	0.480	0.453	0.721

4.2 Hypothesis Testing

The independent samples t-test was initially employed to examine the differences in arts education across various variables. As shown in Table 4, there was no significant difference in research performance related to experience in arts education

(P > 0.05), thus rejecting Hypothesis 1. Additionally, artistic experience exhibited significant differences in creative personality and its sub-dimensions, including curiosity, imagination and adventurousness (P< 0.05). It was observed that research students from top Chinese universities who have received systematic arts education generally had higher levels of creative personality and its sub-dimensions compared to those who have not. Therefore, Hypothesis 2 was supported.

Table 4. Differential Analysis

Variable	None (N=154)	Some (N=65)	T	P
Creative Personality	2.261±0.359	2.421±0.326	-3.081	0.002
Challenge	2.413±0.400	2.527±0.422	-1.883	0.061
Curiosity	2.413±0.437	2.546±0.353	-2.166	0.031
Imagination	2.125±0.485	2.331±0.438	-2.928	0.004
Adventurousness	2.093±0.454	2.281±0.425	-2.836	0.005
Research Performance	3.326±0.723	3.202±0.715	1.157	0.249

Next, multiple linear regression analysis was conducted using SPSS 26.0 software to examine the influence of creative personality and its dimensions on research performance, with gender, age, and education of top Chinese university graduate students majoring in science and engineering as control variables. The results are presented in Table 5. Creative personality (β=0.268, P<0.001) significantly positively influenced research performance, and its sub-dimensions of challenge (β=0.182, P<0.05) and curiosity (β=0.215, P<0.05) also significantly positively affected research performance. This suggests that as the creative personality of science and engineering graduate students from top Chinese universities, especially in terms of challenge and curiosity, strengthens, their research performance will significantly improve, thus supporting hypothesis 3.

Table 5. Direct Effects Analysis

Predictor Variable	Research Performance			Research Performance			Research Performance		
	β	T	P	β	T	P	β	T	P
Gender	-0.016	-0.234	0.815	-0.024	-0.357	0.721	-0.014	-0.214	0.831
Age	0.022	0.313	0.755	0.019	0.276	0.783	0.011	0.159	0.874
Education	0.147	2.112	0.036	0.145	2.163	0.032	0.149	2.235	0.026
Creative Personality				0.268	4.125	0.000			
Challenge							0.182	2.062	0.040

Curiosity							0.215	2.283	0.023
Imagination							-0.088	-1.119	0.264
Adventurousness							0.015	0.168	0.867
R^2	0.024			0.096			0.135		
F	1.782			5.690^{***}			4.703^{***}		

Furthermore, employing AMOS 24.0 software, a multi-group analysis was conducted, categorizing top Chinese university engineering and science graduate students into groups with "artistic experience" and "no artistic experience" to examine the moderating effect of arts education on the relationship between creative personality and research performance. From Table 6, it can be seen that the comparative analysis of the fit indices for six models, including the unrestricted model and the measurement-weighted model, shows that all models exhibit good fit.

Table 6. Fit Indices for Multi-Group Analysis Models

Model	CMIN/DF	P	CFI	TLI	IFI	RMSEA	AIC	ECVI
Unrestricted	1.674	0.017	0.98	0.965	0.979	0.050	103.513	0.389
Measurement Weighted	1.703	0.009	0.973	0.964	0.974	0.051	102.791	0.386
Structural Weighted	1.725	0.007	0.972	0.963	0.972	0.052	103.197	0.388
Structural Covariance	1.706	0.007	0.971	0.964	0.972	0.052	102.296	0.385
Structural Error	1.667	0.009	0.972	0.966	0.972	0.050	100.671	0.378
Measurement Error	1.655	0.005	0.967	0.966	0.967	0.050	97.838	0.368

However, as shown in Table 7, compared to the unrestricted model, the changes in significance (P) values for all models were greater than 0.05, while changes in CFI, TLI, and IFI were less than 0.05. This indicates structural stability in the models, suggesting no significant differences in multi-group analysis. Consequently, it is evident that the influence of creative personality on research performance among top Chinese university engineering and science graduate students does not significantly differ based on whether they have received systematic arts education. Experience in arts education does not moderate the relationship between creative personality and research performance, thereby rejecting hypothesis 4. For ease of reference, a comprehensive table summarizing the findings is included at the end of this section (Table 8).

Table 7. Test of Differences

Model	ΔCMIN	ΔDF	P	ΔCFI	ΔTLI	ΔIFI
Measurement Weighted	9.278	5	0.098	-0.005	-0.001	-0.005
Structural Weighted	11.684	6	0.069	-0.006	-0.002	-0.007
Structural Covariance	12.783	7	0.078	-0.007	-0.001	-0.007
Structural Error	13.158	8	0.107	-0.006	0.001	-0.007
Measurement Error	24.325	15	0.06	-0.011	0.001	-0.012

Table 8. Hypothesis Testing Results

No	Hypothesis	Status
1	Students who have received arts education are more likely to achieve higher research performance compared to those who have not.	rejected
2	Students who have received arts education exhibit more pronounced creative personalities compared to those who have not.	supported
3	The creative personality of students positively influences research performance.	supported
4	Arts education play a moderating role in the relationship between creative personality and research performance.	rejected

5. Conclusion and Discussion

Although numerous studies have focused on the relationship between art and science, many remain at the level of speculative or anecdotal descriptions, lacking sufficient empirical research and a general consensus based on empirical findings. Through empirical research, this study did not directly prove the enhancement of research performance by art education. However, it found significant differences in creative personality between students who received art education and those who did not, and demonstrated a significant positive impact of creative personality on research performance. These findings indirectly support the potential influence of art on scientific endeavors. The specific discussion is divided into the following two aspects:

Firstly, this study concluded that the creative personality, along with its sub-dimensions of challenge, curiosity, and imagination, are generally higher among science and engineering graduate students from top Chinese universities who have received systematic and continuous art education compared to their peers who have not.These findings align with and provide empirical evidence to support previous research from a neuroscience perspective, which suggests that learning art can promote the development of creative personality[9–11].

Secondly, This study also found that the creative personality and its sub-dimensions of challenge and curiosity significantly positively influence scientific research performance among graduate students in top Chinese universities majoring in science and engineering. Previous research has confirmed that creative personality affects the research output of universities faculty[18], and this study further demonstrates its positive impact on science and engineering graduate students in universities.

Therefore, this paper proposes implementing various measures to encourage and promote arts education aimed at enhancing transferable skills such as creativity among science and engineering graduate students in universities. According to the theory of transfer of learning, the greater the overlap and similarity between the conditions of arts education and scientific research contexts, the better the transfer effects of creativity across different domains. This can be achieved by integrating artistic elements into research guidance and incorporating research elements into arts education, thereby promoting their research capabilities and performance.

This study still has some limitations.

In the future, it is necessary to further explore the substantive factors in arts education that effectively influence science, and to delve into other potential mediators and moderators. Future research could also consider empirical or experimental studies analyzing the relationship between art and science in STEAM education contexts or in scenarios assisted by artificial intelligence.

REFERENCES

Mejias, S., N. Thompson, R.M. Sedas, M. Rosin, E. Soep, K. Peppler, J. Roche, J. Wong, M. Hurley, and P. Bell. "The Trouble with STEAM and Why We Use It Anyway." Science Education 105, no. 2 (2021): 209–231. https://doi.org/10.1002/sce.21605.

De La Garza, A. "Internationalizing the Curriculum for STEAM (STEM + Arts and Humanities): From Intercultural Competence to Cultural Humility." Journal of Studies in International Education 25, no. 1 (2021): 123–135. https://doi.org/10.1177/1028315319888468.

Braund, M., and M.J. Reiss. "The ‘Great Divide’: How the Arts Contribute to Science and Science Education." Can. J. Sci. Math. Techn. Educ. 19, no. 2 (2019): 219–236. https://doi.org/10.1007/s42330-019-00057-7.

Hardiman, M.M., R.M. JohnBull, D.T. Carran, and A. Shelton. "The Effects of Arts-Integrated Instruction on Memory for Science Content." Trends in Neuroscience and Education 14 (2019): 25–32. https://doi.org/10.1016/j.tine.2019.02.002.

Todhunter-Reid, A. "In-School Arts Education and Academic Achievement: A Child Fixed Effects Approach." Arts Education Policy Review 120, no. 2 (2019): 112–119. https://doi.org/10.1080/10632913.2018.1423595.

Weisberg, R.W. Creativity: Understanding Innovation in Problem Solving, Science, Invention, and the Arts. John Wiley & Sons, 2006.

Root-Bernstein, M., and R. Root-Bernstein. "Polymathy Among Nobel Laureates as a Creative Strategy—The Qualitative and Phenomenological Evidence." Creativity Research Journal 35, no. 1 (2023): 116–142. https://doi.org/10.1080/10400419.2022.2051294.

Lukaka, D. "Art Education and Its Impact on Creativity and Critical Thinking Skills: A Review Literature." IJAH 1, no. 1 (2023): 31–39. https://doi.org/10.61424/ijah.v1i1.15.

Cullen, S.A. "Research on The Effects of Art Education on Childhood Cognitive Development: A Literature Review Thesis Surveying Brain Architecture and Neural Activity." The Ohio State University, 2022. https://etd.ohiolink.edu/acprod/odb_etd/etd/r/1501/10?clear=10&p10_accession_num=osu1656503816014569 (accessed April 7, 2024).

Green, B. "Revisiting the Conceptual Domain: Educational Knowledge and the Visual Arts." International Journal of Art & Design Education 40, no. 3 (2021): 436–448. https://doi.org/10.1111/jade.12355.

Jensen, E. Arts with the Brain in Mind. ASCD, 2001.

Sternberg, R.J., and T.I. Lubart. "The Concept of Creativity: Prospects and Paradigms." Handbook of Creativity 1 (1999): 3–15.

Tang, C. "The Effects of Creative Personality on Scientist Creativity." Thinking Skills and Creativity (2024).

McCrae, R.R., C.E. Löckenhoff, and P.T. Costa Jr. "A Step Toward DSM-V: Cataloguing Personality-Related Problems in Living." European Journal of Personality: Published for the European Association of Personality Psychology 19, no. 4 (2005): 269–286.

McCrae, R.R., and O.P. John. "An Introduction to the Five-Factor Model and Its Applications." Journal of Personality 60, no. 2 (1992): 175–215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x.

Williams, F.E. Creativity Assessment Packet. Aurora, NY: DOK Publishers, 1980.

Van Scotter, J.R., and S.J. Motowidlo. "Interpersonal Facilitation and Job Dedication as Separate Facets of Contextual Performance." Journal of Applied Psychology 81, no. 5 (1996): 525–531. https://doi.org/10.1037/0021-9010.81.5.525.

Kim, K., and S.B. Choi. "Influences of Creative Personality and Working Environment on the Research Productivity of Business School Faculty." Creativity Research Journal 29, no. 1 (2017): 10–20. https://doi.org/10.1080/10400419.2016.1239900.

Leveraging Large Language Models for Actionable Course Evaluation Student Feedback to Lecturers

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ABSTRACT

End of semester student evaluations of teaching are the dominant mechanism for providing feedback to academics on their teaching practice. For large classes, however, the volume of feedback makes these tools impractical for this purpose.

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This paper explores the use of open-source generative AI to synthesise factual, actionable and appropriate summaries of student feedback from these survey responses. In our setup, we have 742 student responses ranging over 75 courses in a Computer Science department. For each course, we synthesise a summary of the course evaluations and actionable items for the instructor. Our results reveal a promising avenue for enhancing teaching practices in the classroom setting. Our contribution lies in demonstrating the feasibility of using generative AI to produce insightful feedback for teachers, thus providing a cost-effective means to support educators' development. Overall, our work highlights the possibility of using generative AI to produce factual, actionable, and appropriate feedback for teachers in the classroom setting.

1. INTRODUCTION

Feedback is a powerful means of supporting learning (Hattie 2008) to inform the learner about their actual state of performance (Narciss 2008). Academics spend significant energy providing students with quality feedback on their work; but the pathways in which academics themselves receive feedback on their teaching are less supported. There are a range of approaches, such as structured university pedagogy programs and peer reviews from colleagues, but the dominant form of feedback to academics is the end of semester student evaluation.

Student teaching evaluations usually comprise a series of quantitative Likert-scale items as well as open-ended survey questions. The intention is that every student has the opportunity to contribute meaningful feedback about their learning experience, but as class sizes grow larger this feedback becomes less and less workable. For large classes the volume of open-ended feedback becomes unworkable, leading to a reliance upon the averages of the quantitative questions. These in turn become useful only if their values are very high (for the purpose of recognising teaching excellence) or very low (for the purpose of identifying needed interventions).

Recent breakthroughs in natural language processing (NLP), and in particular large language models (LLMs) have shown to have influenced a wide variety of research fields (Wahle et al. 2023), including education (Kasneci et al. 2023). These models show a remarkable ability to synthesise large quantities of text, taking as input long text sequences and generate text depending on the likelihood of the next token in the sequence. One can also tune these models to be able to take instructions and generate text based on these instructions.

There is a wide array of previous work on automated feedback, in the context of student learning, peer-to-peer learning, or peer reviewing. To elaborate, they are focused on comprehensive overviews of peer-to-peer feedback (Bauer et al. 2023), using sentence similarity methodologies for aligning answers to open responses in mathematical questions (Botelho et al. 2023), using language models to assist students improve their critical thinking skills by argumentation (Guerraoui et al. 2023), benchmarking whether GPT-style models (Brown et al. 2020; Achiam et al. 2023) align with feedback on research papers (Liang et al., 2023) and using LLMs in-the-loop during student programming assignments (Pankiewicz and Baker 2023).

In the context of automated feedback tools for teachers, previous studies have extensively explored automated feedback tools, which provide insights into student engagement and progress monitoring (Schwarz et al., 2018; Aslan et al., 2019; Alrajhi et al., 2021). These tools empower educators by offering analytics for intervention when necessary. Recent advancements in NLP enable feedback on educators' classroom discourse, promoting self-reflection and instructional enhancement in real time (Samei et al., 2014; Kelly et al., 2018; Jensen et al., 2020; Suresh et al. 2021; Demszky and Liu, 2023; Demszky et al. 2023). Wang and Demszky (2023) investigate whether ChatGPT can be used for generating feedback that is useful for teacher development. However, to the best of our knowledge, previous work has not looked at using course evaluations as a feedback source. Another line of work is the usage of LLMs for coding student evaluations (Katz et al. 2024), the difference between this and our work is that we use the student evaluations directly as a source of critical information to give feedback on for the instructor of a course.

In this work, we explore whether such models can be used to synthesise meaningful feedback summaries from open-ended student evaluation responses. Therefore our key research question is:

RQ: How can LLMs be applied to automatically synthesise student feedback in a manner that is factual, actionable, appropriate, and generates value for individual lecturers?

In doing so, we must ensure that the output of our models demonstrates three key features, inspired by previous work (Wang and Demszky 2023; Wang et al. 2023; Guo et al. 2023; Chang et al. 2023):

1. **Factuality** – whether the model accurately generates feedback according to the input text, i.e., course evaluation, and does not hallucinate irrelevant information.
2. **Actionability** – that it is feedback that could be actioned by the lecturer, instead of giving a summarisation of the course evaluations.
3. **Appropriateness** – if the feedback that addresses teaching rather than being personal in nature. For example, if a student writes down an unwanted comment, this would not be echoed by the model.

This work was conducted at the Computer Science department of Aalborg University. Our dataset comprises student evaluations of 75 courses ranging across the five different year levels of the degree programs within the Department. Response rates varied from a single response in a course up to a maximum of 44 responses per course, with a total of 742 responses in the dataset. The dataset was drawn from a Covid-19-era teaching semester.

2. OUR MODEL

In this work, we used Llama2 (7B; Touvron et al. 2023) as the core LLM to synthesise the student feedback. Llama2 is an open-source 7-billion-parameter language model based on the Transformer architecture (Vaswani et al. 2017) and it generates text autoregressively.

We used a *zero-shot inference* (direct *prompting*) approach, relying on the ability of the model to make predictions or perform tasks in the absence of explicit training data pertaining to those specific tasks (Romera-Paredes and Torr 2015; Xian et al. 2017) and not showing any examples.

The decision not to fine-tune the model allows for a simpler and faster implementation process. It also allows for a transferable implementation, because it does not rely upon an extensive (and expensive) training or alignment process in order to achieve its results. In doing so, however, we forego the improved performance that tailoring the model to our context would provide.

We adopted a two-stage approach to synthesising the student feedback into an actionable summary. In the first stage we concatenated all of the student feedback for a particular course, and prompted the model to summarise that feedback:

Prompt_1: "Summarise, to a maximum of {X} tokens this text that is based on course evaluations: {INPUT}"

Where "X" number of tokens is determined by a heuristic so that the total input text length does not exceed the working capacity of the model. Having made a summary, we then prompted the model to provide actionable feedback for the lecturer:

Prompt_2: "You are now an actionable feedback bot. Give actionable feedback, based upon these summarised course evaluations, to the instructor of the course. Leave out names that could identify entities. Make sure that the feedback is factual, actionable, and appropriate to the instructor: {SUMMARISATION}"

This process resulted in 75 feedback summaries, one per unique course in our dataset.

3. RESULTS

In this section, we show several excerpts of the output of the LLM and consolidate emergent formatting standards of the LLM. The input of the LLM is a mixture of Danish and English course evaluations. We get the output of the LLM in free text format. We notice there were some issues with the translations between Danish and English, most likely due to our Llama2-based model, being an English-based model.

We observe that there are three key formats the model generates output given our input, without intentionally prompting for these formats. Overall, the majority of the emergent formats blended feedback with comments and listed the feedback points one by one (first format). A second format generated a direct response to the instructor, by listing the strengths, areas for improvement, positive feedback, and recommendations making it more verbose than the first format. In the third format, the model first presents a summary of the key aspects of the feedback (both positive and negative points) and gives the recommended actions in the second paragraph.

Decoupling the issues from the suggestions allows a holistic view of the class to emerge, and ensures that the focus of the feedback is on being actionable, rather than focussing on suggesting actions to the academic. This has similarities to the Chain of Thought reasoning abilities of LLMs (Wei et al. 2022; Zhang et al. 2022), where a series of intermediate reasoning steps improves the LLM on complex reasoning.

In Table 1, we show illustrative examples of the output of the model, specifically of the first and third format.

Table 1. Illustrative Excerpts. We show examples of the generated output of the LLM. To save space, note that these outputs are excerpts of the full output of the LLM.

Generated Output of the Model
(1) Based on the course evaluations, here are actionable feedback points to improve the "flipped classroom" model: 1. Workload Management: Students found the workload excessive, suggesting a reduction in assignments or more breaks. 2. Adjusting Difficulty Levels: Some assignments were too challenging, suggesting a review and adjustment for consistency. 3. Providing Additional Resources: Students suggested additional resources like past assignment reviews and solutions for better understanding. 4. Peer Learning: Encourage interaction through group work or peer-to-peer activities. 5. Exam Structure: Consider revising exams to align better with student needs, possibly integrating a separate programming course. 6. Code Review: Incorporate more code review activities to demonstrate real-world implementation. Overall, while the flipped classroom model was beneficial, addressing these points can enhance the course experience.
(3) Dear Instructor, Here's a concise summary of the key feedback points derived from the course evaluations: 1. Course Materials: The structured nature of the book and exercises received praise for aiding comprehension, with detailed examples enhancing understanding. 2. Exam Preparation: The exam tasks practiced during the course were beneficial, though there's potential for improvement in actively listening to and incorporating student feedback. 3. Communication Style: Some challenges arise from the lecturer's communication style, exacerbated by distance due to COVID restrictions. Utilizing slides for better visibility and adapting communication methods could address this. 4. Instruction Clarity: Unclear or irrelevant instructions during lectures led to student confusion and dissatisfaction.

5. Project Feedback: Students felt project feedback was overly critical, lacking empathy towards project challenges.

Actionable Feedback Suggestions:

1. Enhance Communication Style: Work on improving communication to cater to all students, possibly through slower speech or visual aids.
2. Clarify Instructions: Ensure instructions provided during lectures are clear and concise to prevent confusion.
3. Offer More Feedback: Encourage early project sharing for better understanding of student challenges and tailored feedback.
4. Utilize Online Resources: Integrate engaging online materials to supplement lectures and boost student engagement.
5. Adjust Seating Arrangements: Where possible, consider seating students closer together during COVID restrictions to mitigate visibility issues with slides.

Addressing these suggestions can foster a more inclusive and effective learning environment for students.

4. EVALUATION OF THE OUTPUTS

A team of three human evaluators rated the model outputs on a five-point Likert scale, considering the three dimensions: Factuality, Actionability and Appropriateness. Overall, there was good agreement between the evaluators, with the majority of evaluations receiving the same or similar ratings on the Likert scale. The process of reviewing divergent ratings revealed interpretation differences on the part of the evaluators, and the process of reconciling these differences identified key themes for the feasibility of this NLP approach.

4.1. Observations regarding Factuality.

Overall, the output of the model was largely agreed to be factually correct—it was indeed a synthesis of the input feedback from the students. The model was consistent in the amount of output it would generate, which presented challenges when dealing with the smallest and largest sets of input data.

For the smallest samples (there are seven courses with only one respondent) the output would reflect the input; but it would also include additional feedback not arising from the input. While these were largely benign in nature, they did not actually reflect factual feedback from the students.

These false positives appear to have mostly been introduced in the second step of the model. The first step summarisation of the inputs seems to be an accurate summary; it is the prompt to provide actionable feedback that triggers the model to generate additional comments not based upon the input.

For the largest samples the model suffered from not having pedagogical expertise, and as such being unable to correctly prioritise which input comments most needed to propagate to the output. This challenge was most pronounced where there were contradictory comments in the dataset. The model could identify that students were positive or negative towards an aspect of the teaching, but it struggled to convey the inconsistency among students, instead often only reporting one of the two sentiments.

4.2. Observations regarding Actionability.

The model was prompted to provide actionable feedback to the instructor, and for the most part the output provided suggestions to the academic based on the summaries. Given that the model had not been specifically trained to the operating context of a Computer Science department, it was somewhat surprising how relevant many of the general suggestions were. The model struggled, however, with specific suggestions for domain specific issues. The model also made a number of suggestions that were not feasible or were outside the control of an individual instructor, such as changing ECTS credit points, or the duration of a course.

The model struggled with making suggestions when there were contradictory inputs. For example, if there were two student evaluations and one student mentioned they liked online teaching and one did not, the model selects only one part of the feedback, mentioning that *all* students liked online teaching. On a more general note, there is a common pattern; when the input to the model is *sparse* (i.e., not many evaluations) the model generates non-actionable items, or in other words, hallucinates new problems. When the input is too *dense* (i.e., many evaluations), we notice that the model has a harder time prioritising which feedback to generate.

4.3. Observations regarding Appropriateness.

Overall the model produced output that was appropriate to share with academics, however there were issues with losing some of sentiment from the student feedback. There were multiple instances of names being included, despite the model being explicitly prompted not to include names. In all such cases the mentions had positive sentiment, so this did not negatively affect the appropriateness of the feedback, but it undermines the trust in the model not to convey negative sentiment outputs in the future.

There were instances in which specific comments with strong sentiment, both positive (e.g., “super helpful”) and negative (e.g., “hopeless”), were not incorporated in the synthesised output. A consequence of this was that the resulting output did not convey the strength of that sentiment, instead seeming much like the output for more mild sentiment inputs. While this meets the objective of providing appropriate output, it undermines the factuality and actionability of the outputs by not conveying to the academics how the students are actually responding to their teaching.

5. CONCLUSION

In this work, we present a proof-of-concept leveraging open-source generative AI to automatically synthesise actionable teacher feedback from student course evaluations. We prompted an out-of-the-box open-source LLM to summarise course evaluations and give actionable feedback based on this summary. The model generates output consistently based on three common formats. Despite the simplicity of the model, our findings suggest the feasibility of using open-source models to generate summarised actionable feedback from course evaluations as a cost-effective approach to supporting teachers' development. However, we believe further improvements are necessary to improve the effectiveness and accuracy of the generated feedback. With continued refinement, integrating generative AI into educational settings could significantly contribute to improving teaching practices and supporting educators' professional growth.

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REFERENCES

Achiam, J., Adler, S., Agarwal, S., Ahmad, L., Akkaya, I., Aleman, F. L., ... & McGrew, B. (2023). Gpt-4 technical report. *arXiv preprint arXiv:2303.08774*.

Alrajhi, L., Alamri, A., Pereira, F. D., & Cristea, A. I. (2021). Urgency analysis of learners' comments: An automated intervention priority model for mooc. In Intelligent Tutoring Systems: 17th International Conference, ITS 2021, Virtual Event, June 7–11, 2021, Proceedings 17 (pp. 148-160). Springer International Publishing.

Aslan, S., Alyuz, N., Tanriover, C., Mete, S. E., Okur, E., D'Mello, S. K., & Arslan Esme, A. (2019). Investigating the impact of a real-time, multimodal student engagement analytics technology in authentic classrooms. In Proceedings of the 2019 chi conference on human factors in computing systems (pp. 1-12).

Bauer, E., Greisel, M., Kuznetsov, I., Berndt, M., Kollar, I., Dresel, M., ... & Fischer, F. (2023). Using natural language processing to support peer-feedback in the age of artificial intelligence: a cross-disciplinary framework and a research agenda. *British Journal of Educational Technology*, *54*(5), 1222-1245.

Botelho, A., Baral, S., Erickson, J. A., Benachamardi, P., & Heffernan, N. T. (2023). Leveraging natural language processing to support automated assessment and feedback for student open responses in mathematics. *Journal of Computer Assisted Learning*, *39*(3), 823-840.

Brown, T., Mann, B., Ryder, N., Subbiah, M., Kaplan, J. D., Dhariwal, P., ... & Amodei, D. (2020). Language models are few-shot learners. *Advances in neural information processing systems*, *33*, 1877-1901.

Chang, Y., Wang, X., Wang, J., Wu, Y., Yang, L., Zhu, K., ... & Xie, X. (2023). A survey on evaluation of large language models. *ACM Transactions on Intelligent Systems and Technology*.

Demszky, D., & Liu, J. (2023). M-powering teachers: Natural language processing powered feedback improves 1: 1 instruction and student outcomes. In Proceedings of the Tenth ACM Conference on Learning@ Scale (pp. 59-69).

Demszky, D., Liu, J., Hill, H. C., Jurafsky, D., & Piech, C. (2023). Can automated feedback improve teachers' uptake of student ideas? evidence from a randomized controlled trial in a large-scale online course. Educational Evaluation and Policy Analysis, 01623737231169270.

Guerraoui, C., Reisert, P., Inoue, N., Mim, F. S., Singh, K., Choi, J., ... & Inui, K. (2023). Teach Me How to Argue: A Survey on NLP Feedback Systems in Argumentation. In *Proceedings of the 10th Workshop on Argument Mining* (pp. 19-34).

Guo, Z., Jin, R., Liu, C., Huang, Y., Shi, D., Yu, L., ... & Xiong, D. (2023). Evaluating large language models: A comprehensive survey. *arXiv preprint arXiv:2310.19736*.

Hattie, J. (2008). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. Routledge.

Jensen, E., Dale, M., Donnelly, P. J., Stone, C., Kelly, S., Godley, A., & D'Mello, S. K. (2020). Toward automated feedback on teacher discourse to enhance teacher learning. In Proceedings of the 2020 chi conference on human factors in computing systems (pp. 1-13).

Kasneci, E., Seßler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., ... & Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and individual differences*, *103*, 102274.

Katz, A., Gerhardt, M., & Soledad, M. (2024). Using Generative Text Models to Create Qualitative Codebooks for Student Evaluations of Teaching. arXiv preprint arXiv:2403.11984.

Kelly, S., Olney, A. M., Donnelly, P., Nystrand, M., & D'Mello, S. K. (2018). Automatically measuring question authenticity in real-world classrooms. Educational Researcher, 47(7), 451-464.

Liang, W., Zhang, Y., Cao, H., Wang, B., Ding, D., Yang, X., ... & Zou, J. (2023). Can large language models provide useful feedback on research papers? A large-scale empirical analysis. *arXiv preprint arXiv:2310.01783*.

Narciss, S. (2008). Feedback strategies for interactive learning tasks. In *Handbook of research on educational communications and technology* (pp. 125-143). Routledge.

Pankiewicz, M., & Baker, R. S. (2023). Large Language Models (GPT) for automating feedback on programming assignments. *arXiv preprint arXiv:2307.00150*.

Romera-Paredes, B., & Torr, P. (2015). An embarrassingly simple approach to zero-shot learning. In *International conference on machine learning* (pp. 2152-2161). PMLR.

Samei, B., Olney, A. M., Kelly, S., Nystrand, M., D'Mello, S., Blanchard, N., ... & Graesser, A. (2014). Domain Independent Assessment of Dialogic Properties of Classroom Discourse. Grantee Submission.

Schwarz, B. B., Prusak, N., Swidan, O., Livny, A., Gal, K., & Segal, A. (2018). Orchestrating the emergence of conceptual learning: A case study in a geometry class. International Journal of Computer-Supported Collaborative Learning, 13, 189-211.

Suresh, A., Jacobs, J., Lai, V., Tan, C., Ward, W., Martin, J. H., & Sumner, T. (2021). Using transformers to provide teachers with personalized feedback on their classroom discourse: The TalkMoves application. arXiv preprint arXiv:2105.07949.

Touvron, H., Martin, L., Stone, K., Albert, P., Almahairi, A., Babaei, Y., ... & Scialom, T. (2023). Llama 2: Open foundation and fine-tuned chat models. *arXiv preprint arXiv:2307.09288*.

Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., ... & Polosukhin, I. (2017). Attention is all you need. *Advances in neural information processing systems*, *30*.

Wahle, J. P., Ruas, T., Abdalla, M., Gipp, B., & Mohammad, S. (2023). We are Who We Cite: Bridges of Influence Between Natural Language Processing and Other Academic Fields. In Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing (pp. 12896-12913).

Wang, R., & Demszky, D. (2023). Is ChatGPT a Good Teacher Coach? Measuring Zero-Shot Performance For Scoring and Providing Actionable Insights on Classroom Instruction. In *Proceedings of the 18th Workshop on Innovative Use of NLP for Building Educational Applications (BEA 2023)* (pp. 626-667).

Wang, R. E., Zhang, Q., Robinson, C., Loeb, S., & Demszky, D. (2023). Step-by-Step Remediation of Students' Mathematical Mistakes. *arXiv preprint arXiv:2310.10648*.

Wei, J., Wang, X., Schuurmans, D., Bosma, M., Xia, F., Chi, E., ... & Zhou, D. (2022). Chain-of-thought prompting elicits reasoning in large language models. *Advances in neural information processing systems*, *35*, 24824-24837.

Xian, Y., Schiele, B., & Akata, Z. (2017). Zero-shot learning-the good, the bad and the ugly. In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 4582-4591).

Zhang, Z., Zhang, A., Li, M., & Smola, A. (2022). Automatic Chain of Thought Prompting in Large Language Models. In *The Eleventh International Conference on Learning Representations*.

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THE DEVELOPMENT OF THE SCALE FOR AUTHENTIC ENGINEERING LEARNING MODEL IN DIVERSE CONTEXTS

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***Conference Key Areas**: Educating the whole engineer: teaching through and for knowing, thinking, feeling, and doing; Curriculum development and emerging curriculum models in engineering*
***Keywords**: Authentic engineering learning model; Authenticity; Scale development; Multicontext; Engineering responsibility*

ABSTRACT

Authentic engineering learning is an educational model emphasizing the construction of knowledge in practical contexts that closely resemble real-life work situations, which is crucial for fostering students' engineering responsibility. This study aimed to develop a reliable scale for assessing the authenticity of Chinese engineering learning projects. Drawing on existing literature and qualitative interview data, we

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created a 14-item scale encompassing four dimensions: task authenticity, process authenticity, collaboration authenticity, and impact authenticity. The scale was validated through exploratory and confirmatory factor analysis using data from Chinese universities. Furthermore, we explored three implementation contexts for authentic engineering learning: teaching tasks, virtual simulation, and industrial sites, each exhibiting unique characteristics. Multiple linear regression analysis confirmed that these four dimensions enhance students' engineering responsibility, thereby supporting curriculum development and innovative educational models in engineering.

1 INTRODUCTION

Humanity faces increasing pressure to find collaborative solutions to global social and environmental challenges, including climate change, biodiversity conservation, and social inequity (Dobson 2007; Scott 2009). This presents a significant challenge for university-level engineering educators, who must help students form personal connections with these topics rather than perceiving direct involvement in global change as too distant, troublesome, or difficult to understand (Lombardi and Sinatra 2012; Helicke 2014). Recent reforms and transformations in engineering education worldwide, such as the Massachusetts Institute of Technology’s New Engineering Education Transformation program, Aalborg University’s Centre for Problem Based Learning in Engineering Science and Sustainability, and the Emerging Engineering Education Plan implemented in Chinese universities, share a common characteristic: the emphasis on authenticity in engineering learning. The authentic learning sciences offer strategies to address this challenge by fostering curricula where students are motivated to learn in rich, relevant, and real-world contexts (Herrington 2005).

2 LITERATURE REVIEW

2.1 Authentic Engineering Learning and Its Components

Authentic engineering learning is a learner-centered, practice-based model that immerses students in experiences mirroring the "real engineering world" across various contexts, including teaching tasks, virtual simulations, and industrial sites, to facilitate knowledge construction and cultivate a sense of responsibility (Herrington and Kervin 2007; Herrington and Herrington 2007). Most existing studies on authentic engineering learning explore the construction of this model, with few empirical investigations. These studies typically focus on the following elements. **(1) Authentic learning environment.** It is essential to provide contexts that reflect real-life application of knowledge. For instance, students can utilize a variety of professional equipment, tools, information, and real data (Levin et al. 2023; Zualkernan 2006). **(2) Authentic learning tasks**. Students have access to expert performances and process modeling and are required to solve complex, interdisciplinary problems or tasks in the real world (Farrell 2020). **(3) Authentic learning individuals.** The model offers opportunities for students to be effective performers with acquired knowledge, crafting polished performances or products. This stimulates their interest, sense of meaning, uncertainty, frustration, reflection, and other emotional experiences (Renzulli 2004). **(4) Authentic learning outputs.** This includes integrated and process evaluations, participation of enterprise personnel in the evaluation process, and validity and reliability with appropriate criteria for scoring varied products (Lowell and Yang 2023; Renzulli 2004).

2.2 Authentic Engineering Learning in Diverse Contexts

This study synthesizes global practices and related literature on authentic engineering learning, focusing on three primary contexts. **The first context is teaching tasks**, which provide students with contextually rich engineering cases. This approach employs innovative teaching methods such as design-based learning, problem-based learning, maker spaces, and pinnacle design courses to enhance students' understanding of core conceptual knowledge and practical skills (Huang Z et al. 2021; Love T S et al. 2023). **The second context is virtual simulation**, which utilizes modern digital technologies to simulate engineering laboratories or dynamically showcase engineering sites online. This method offers highly realistic, visual, and interactive learning content that reflects real engineering processes and scenarios (Salinas-Navarro D et al. 2024; Yang W et al. 2019). T**he third context is industrial sites**, where engineering practice training platforms are established by enterprises, universities, or joint ventures. These platforms provide real equipment, production lines, and research and development projects. Students engage in on-site engineering practices as apprentices, interns, or student engineers, completing relevant engineering designs or production processes to acquire the skills and experiences necessary for actual work (Tisch M et al. 2016; Mandal N K and Edwards F R 2021). Additionally, we observed that with the advancement of engineering education reforms, some mixed scenarios have emerged, which cannot be easily categorized according to the aforementioned contexts.

2.3 Authentic Engineering Learning and Engineering Responsibility

Engineering responsibility is an ethical theory positing that engineers have an obligation and duty to benefit society, the environment, and the economy, given their unique knowledge and the direct public impact of their work (Garriga and Mele 2004; Frederiksen and Nielsen 2013). The literature review reveals two primary pathways to foster students' engineering responsibility: ethical foundations and civic engagement (Frankel-Goldwater, 2022). (1) Ethical foundations encompass topics of positivity and normativity, anthropocentric and biocentric views, and the notion that "right and wrong" can be subjective. Authentic engineering learning integrates learning moments with students' interests and their sense of morality (Robertson D R 2005). (2) Civic engagement involves taking direct action for societal causes, supporting learning through service. Authentic engineering learning activities foster a sense of agency through in-class reflections, shared site placements, and formative connections with socio-ecological issues (Barth M et al. 2007; Lynch and Boulay 2011).

2.4 Research Purpose

The literature review indicates that accurately measuring authenticity in the field of engineering remains a research gap. Additionally, few scholars have investigated the extent to which and how enhancing authenticity in engineering learning helps students become responsible engineers. Consequently, this paper has two primary purposes. Firstly, it aims to clarify the operational definitions of authentic engineering learning and propose appropriate items to form an instrument for measuring internal dimensions. Moreover, it will analyze whether each characteristic exhibits varying degrees of presence across different contexts of authentic engineering learning. Secondly, this study will assess how the authenticity characteristics within the instrument influence students' sense of engineering responsibility and attempt to analyze the underlying mechanisms.

3 METHODOLOGY

The research hypotheses of this paper include: (1) Different contexts of authentic engineering learning will have differential impacts on the dimensions of authenticity, and (2) the dimensions of authenticity will have a significant positive effect on students' engineering responsibility.

This study employed a mixed research design approach. Initially, 16 items from Zhangwei's (2023) measurement tool and 13 items from established studies (Barab 2000; Herrington and Oliver 2000; Herrington and Kervin 2007) were collected to construct a brief authentic engineering learning framework with four dimensions: task authenticity (TA), process authenticity (PA), collaboration authenticity (CA), and impact authenticity (IA). Semi-structured interviews with 5 engineering students provided 11 additional questions to supplement the items. Three engineering professors and four students from Zhejiang University revised and simplified the questionnaire. In the initial testing phase, 132 completed questionnaires were collected for preliminary model fitting, and unclear or problematic items were modified or removed. The final measurement questionnaire comprised 19 items across four dimensions (TA: 4, PA: 3, CA: 3, IA: 4). Subsequent analyses included exploratory factor analysis (EFA), confirmatory factor analysis (CFA), criterion-related validity (CRV), and descriptive statistical analysis, conducted using IBM SPSS Statistics version 27.

4 FINDINGS

4.1 Qualitative Research Findings

Based on established research and interviews with engineering teachers and students, we defined operational terms for task authenticity, process authenticity, collaboration authenticity, and impact authenticity. Task authenticity refers to learning activities that mirror real-world scenarios and are designed to address complex engineering problems (Farrell 2020). Process authenticity pertains to learning activities that replicate real-world industrial processes and procedures (Callison and Lamb 2004). Collaboration authenticity involves activities completed in teamwork, akin to real-world practices (Ashford-Rowe 2008). Impact authenticity refers to the applicability of learning outcomes, such as products or patents, in contexts beyond the school environment (Barab et al. 2000).

Table 1. Items for Measuring the Authenticity in Engineering Learning

Items
The solutions to the problems I face are usually open-ended. (TA1) The engineering problems that I face are complex and interdisciplinary.(TA2) What I need to solve is the complex engineering problem of poor structure.(TA3) I need to solve engineering problems by investigating, collecting, and interpreting complex data information.(TA4)
My study tasks are similar to the challenges in my daily life.(PA1) I can oversee the entire life cycle of the product, including design, manufacturing, production, and other stages.(PA2) I will contact the project stakeholders, such as suppliers and consumers.(PA3)
I need a clear division of tasks among other students.(CA1) We work together to complete the final problem solution.(CA2) I can discuss with my classmates to come up with a solution to the problem.(CA3)
The engineering products I design or create can be applied to real-world engineering situations.(IA1) I need to design or build a complete and valuable product.(IA2) The engineering products I design or create can have a significant impact on the advancement of technology and industry. (IA3) The engineering products I design or create can be widely utilized in the market after enhancements.(IA4)

We also conducted a qualitative study on engineering responsibility, integrating core competence standards for engineering education graduates as defined by the Accreditation Board for Engineering and Technology (ABET) and related research (Zandvoort 2008). We identified six key questions: (1) Consideration of public health, safety, social security, and global factors; (2) Adherence to professional ethics and engineering practices; (3) Evaluation of the impact of engineering solutions on the global economy, environment, and society; (4) Conservation of natural resources, minimization of waste emissions, and prioritization of ecological protection; (5)

Balancing economic development with environmental preservation; and (6) Addressing social issues such as gender equality and poverty through engineering interventions. These questions were then converted into a Likert five-point scale for data collection.

4.2 Exploratory Factor Analysis(EFA)

In this study, we distributed questionnaires to Chinese engineering students and obtained 159 valid responses. The respondents were enrolled in 29 different schools, including prestigious institutions such as Zhejiang University and Peking University, and represented 35 distinct majors, prominently including Mechanical Engineering. The sample composition consisted of 32.5% undergraduate students, 51.4% graduate students, and 15.7% doctoral students. Statistical analyses revealed a Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy at 0.852, surpassing the recommended threshold of 0.70. Bartlett's test of sphericity yielded a value of 911.512 ($p < 0.001$), indicating the dataset's suitability for factor analysis. We conducted principal component analysis with maximum variance rotation to extract factors, yielding factor loadings ranging from 0.602 to 0.845, with a cumulative variance explained of 66.857%. This demonstrates that the factor structure of authentic engineering learning aligns with theoretical expectations.

Table 2. Summary of Factor Loadings in EFA and Cronbach's alpha (α)

Factors	Items	Factor Loading			
TA（α=0.707）	TA 1	.716			
	TA 2	.700			
	TA 3	.703			
	TA 4	.710			
PA（α=0.697）	PA 1			.818	
	PA 2			.602	
	PA 3			.670	
CA（α=0.808）	CA 1		.802		
	CA 2		.845		
	CA 3		.778		
IA(α=0.792)	IA 1				.805
	IA 2				.747
	IA 3				.804
	IA 4				.810

4.3 Confirmatory Factor Analysis(CFA)

In the CFA study, we utilized a distinct sample by re-collecting 243 questionnaires from Chinese engineering students (Zheng X M et al. 2015). These respondents represented a diverse range of schools, majors, and academic levels. The model fit test results in Table 3 indicate that all indicators reached satisfactory or acceptable levels, demonstrating a good fit for the CFA model. Additionally, we examined the

Average Variance Extracted (AVE) and composite reliability (CR) for each scale dimension. The AVE values were mostly above 0.5, and all CR values exceeded 0.7, affirming strong convergent validity and reliability across all dimensions of the authenticity engineering learning scale in this study.

Table 3. Fit Test of CFA Model for Authenticity Engineering Learning Scale

Index	Reference standard	The measured results
CMIN/DF	1-3:excellent，3-5:good	2.475
RMSEA	＜0.05:excellent，＜0.08:good	0.078
IFI	＞0.9:excellent,＞0.8:good	0.931
TLI	＞0.9:excellent，＞0.8:good	0.911
CFI	＞0.9:excellent，＞0.8:good	0.930

Table 4. Convergent Validity and Composite Reliability Test of Each Dimension

Path relationship			Esti-mate	AVE	CR	Path relationship			Esti-mate	AVE	CR
TA 1	<---	F1	0.721	0.499	0.799	CA 1	<---	F3	0.722	0.663	0.854
TA 2	<---	F1	0.654			CA 2	<---	F3	0.908		
TA 3	<---	F1	0.708			CA 3	<---	F3	0.802		
TA 4	<---	F1	0.740			IA 1	<---	F4	0.755	0.565	0.838
PA 1	<---	F2	0.765	0.655	0.847	IA 2	<---	F4	0.711		
PA 2	<---	F2	0.630			IA 3	<---	F4	0.790		
PA 3	<---	F2	0.992			IA 4	<---	F4	0.748		

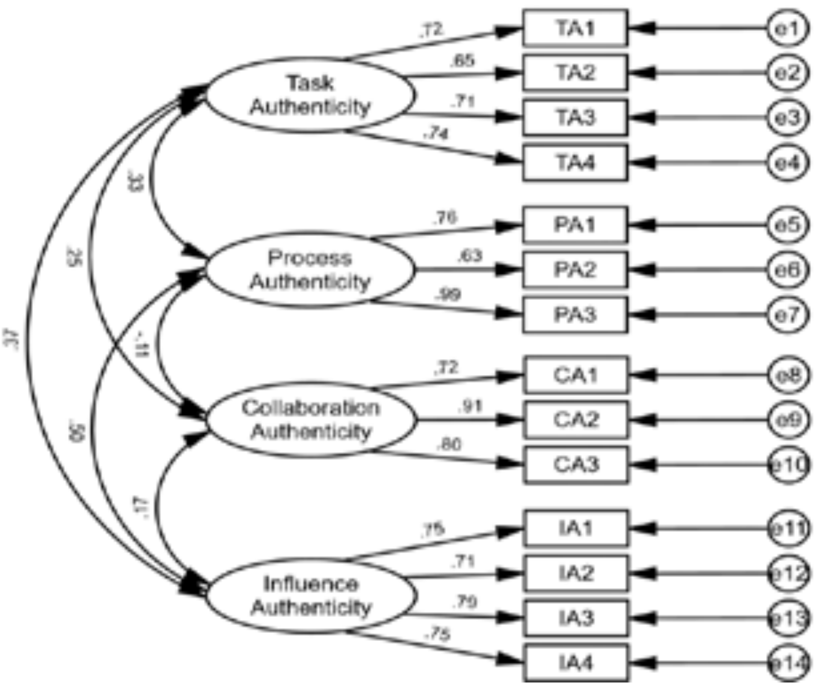

Fig.1. Confirmatory Factor Analysis Model with Standardized Loadings

4.4 Description Statistics and Analysis of Variance

We combined the questionnaires obtained from the EFA and CFA studies, resulting in a total of 402 responses. These respondents were categorized based on their participation in teaching task contexts, virtual simulation contexts, industrial site contexts, and multiple contexts. Descriptive statistical analysis revealed that students experienced the highest CA in the teaching task context, while PA and IA were comparatively low. Students in the virtual simulation context reported low TA and CA but slightly higher PA. Students who participated in the industrial site context or multiple contexts achieved the highest levels of TA and PA.

A one-way analysis of variance (ANOVA) was conducted to investigate the effect of context on the authenticity of each dimension. The results were as follows: TA: F=2.877, p=0.036; PA: F=1.349, p=0.258; CA: F=1.055, p=0.368; IA: F=0.187, p=0.905. A statistically significant difference in TA was found across different contexts (p<0.05).

Table 5. Description of statistics of each dimension of authenticity in different scenarios

Context	TA	PA	CA	IA	Average Authenticity	Average Responsibility
Context1(N1=54)	3.560	2.994	4.049	3.134	3.434	3.941
Context2(N2=26)	3.356	3.090	3.731	3.221	3.349	3.756
Context3(N3=27)	3.852	3.395	3.938	3.278	3.616	3.648
Multiple Context (N4=295)	3.703	3.098	3.950	3.223	3.494	3.869
Total(N=402)	3.671	3.103	3.949	3.215	3.484	3.857

4.5 Multiple Linear Regression Analysis

We calculated the values of engineering responsibility as the dependent variable and conducted a multiple linear regression analysis using the dimensions of authenticity as independent variables. The results indicated that the regression model was significant, without multicollinearity (F=30.268, p<0.001). TA, PA, CA, and IA all positively influenced engineering responsibility and collectively explained 22.60% of the variation in the dependent variable.

Table 6. Results of the Regression Analysis of Responsibility

	B	*β*	*t*	*P*	*VIF*	*F*	Adjusted R^2
TA	0.139	0.152	2.886	0.004	1.430	30.268^{***}	0.226
PA	0.105	0.135	2.290	0.023	1.813		
CA	0.222	0.252	5.226	<0.001	1.203		
IA	0.081	0.113	1.882	0.061	1.863		

5 DISCUSSION

Consistent with previous studies on authentic learning, this study examines variations in perceptions of authenticity across different learning scenarios: teaching tasks, virtual simulations, and industrial sites. ANOVA results indicate significant differences in TA across these contexts, while the other three authenticity dimensions do not show significant differences. This can be attributed to two factors. Firstly, TA refers to activities mirroring real-world scenarios to tackle complex engineering problems. In teaching tasks, students encounter rich engineering cases, perceiving these as solving real-world problems, resulting in moderate TA. In virtual simulations, students use computer-based platforms, perceiving tasks as less connected to reality, thus showing lower TA. In industrial sites, students engage in on-site practices, completing real engineering tasks, leading to the highest TA. Thus, TA varies significantly across contexts. Secondly, with ongoing engineering education reforms, teaching tasks and virtual simulations increasingly integrate industrial site characteristics, creating blended scenarios. Consequently, students perceive similar levels of PA, CA, and IA across these contexts, with no significant differences in these dimensions. Therefore, TA plays a crucial role in crafting authentic engineering learning experiences, especially in teaching tasks and virtual simulations, highlighting the need for its development in these contexts.

Furthermore, this article explores the relationship between authentic engineering learning and engineers' responsibility. The six items of engineering responsibility in the questionnaire encompass aspects such as environmental awareness and social development. Through multiple linear regression analysis, we found that each dimension of authentic engineering learning significantly enhances students' awareness of engineering responsibility, although with relatively low explanatory power. For instance, during the engineering learning process, students feel they are completing real-world tasks, necessitating consideration of public health, safety, social security, and global factors. They perceive their activities as having a genuine impact on the world, prompting them to think about protecting natural resources, minimizing waste emissions, and achieving ecological preservation while promoting economic growth. Experiencing complete and real industrial processes requires them to evaluate the impact of engineering solutions on the global economy, environment, and society. Through collaboration within engineering practice communities, students also recognize the importance of adhering to professional ethics. Therefore, these dimensions of authentic engineering learning contribute to cultivating students' sense of engineering responsibility.

6 CONCLUSION

Pursuing authenticity in engineering education is both a pedagogical and societal imperative, preparing future engineers to address complex global challenges with a strong sense of environmental and social responsibility. This paper introduces a measurement scale for authentic engineering learning, encompassing four dimensions: task authenticity, process authenticity, collaboration authenticity, and impact authenticity. Each dimension contributes to the development of engineers' sense of responsibility. We also identified three primary contexts for authentic engineering learning: teaching tasks, virtual simulations, and industrial sites, while acknowledging the presence of mixed scenarios. And dimensions of authenticity vary across different contexts.

7 LIMITATIONS

As a pilot study, our work had two main limitations. Firstly, in the empirical research section, we collected 402 valid questionnaires. However, the relatively small sample size reduced the robustness of the results. Regression analysis on samples with different authentic learning experiences also yielded unsatisfactory results , likely due to small sample sizes within scenario groups. Therefore, future research should include a broader range of courses and a larger sample size to enhance the generalizability of the findings. Secondly, we did not focus on mixed scenarios, which are common in real life. Future research should scientifically distinguish between different learning scenarios and pay particular attention to mixed scenarios.

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REFERENCES

Dobson A. “Environmental citizenship: Towards sustainable development” *Sustainable developmen*t, 2007, 15(5): 276-285. https://doi.org/10.1002/sd.344.

Scott W. “Environmental education research: 30 years on from Tbilisi” *Environmental Education Research*, 2009, 15(2): 155-164.https://doi.org/10.1080/13504620902814804.

Lombardi D, Sinatra G M. “College students’ perceptions about the plausibility of human-induced climate change” *Research in Science Education*, 2012, 42: 201-217. https://doi.org/10.1007/s11165-010-9196-z.

Helicke N A. “Learning and promoting urban sustainability: environmental service learning in an undergraduate environmental studies curriculum” *Journal of*

Environmental Studies and Sciences, 2014, 4(4): 294-300. https://doi.org/10.1007/s13412-014-0194-8.

Herrington J. *Authentic learning environments in higher education*. 1st ed. Hershey, PA: IGI Global, 2005.

Herrington J, Kervin L. “Authentic Learning Supported by Technology: Ten suggestions and cases of integration in classrooms” *Educational Media International*, 2007,44(3): 219-236. https://doi.org/10.1080/09523980701491666.

Herrington A, Herrington J. *What is an authentic learning environment?* 1st ed. Hershey, PA: IGI Global, 2007.

Levin O, Frei-Landau R, Flavian H, Erez C. Miller. “Creating authenticity in simulation-based learning scenarios in teacher education”. *European Journal of Teacher Education*, 2023: 1-22. https://doi.org/10.1080/02619768.2023.2175664.

Zualkernan I A. “A framework and a methodology for developing authentic constructivist e-Learning environments”. *Journal of Educational Technology & Society*, 2006, 9(2): 198-212.

Farrell C. “Do international marketing simulations provide an authentic assessment of learning? A student perspective”. *The International Journal of Management Education*, 2020, 18(1): 100362. https://doi.org/10.1016/j.ijme.2020.100362.

Renzulli J S, Gentry M, Reis S M. “A time and a place for authentic high-end learning”. *Educational leadership*, 2004, 62(1): 73-77.

Lowell V L, Yang M. “Authentic learning experiences to improve online instructor’s performance and self-efficacy: The design of an online mentoring program”. *TechTrends*, 2023, 67(1): 112-123. https://doi.org/10.1007/s11528-022-00770-5.

Huang Z, Kougianos E, Ge X, Wang S, Chen P. Daniel, Cai L. “A Systematic Interdisciplinary Engineering and Technology Model Using Cutting-Edge Technologies for STEM Education”. *IEEE Transactions on Education*, 2021, 64(4):390-397. https://doi: 10.1109/TE.2021.3062153.

Love T S, Cysyk P. Joshua, Attaluri A, Tunks D. Robert, Harter K, Sipos R.” Examining science and technology/engineering educators’ views of teaching biomedical concepts through physical computing”. *Journal of Science Education and Technology*, 2023, 32(1): 96-110. https://doi.org/10.1007/s10956-022-09996-7.

Salinas-Navarro D, Vilalta-Perdomo E, Michel-Villarreal R, Montesinos L. ”Using Generative Artificial Intelligence Tools to Explain and Enhance Experiential Learning for Authentic Assessment”. *Education Sciences*, 2024, 14(1): 83. https://doi.org/10.3390/educsci14010083.

Yang W, Yuan N, Chinthammit W, Kang B. “A distributed case-and project-based learning to design 3D lab on electronic engineering education”. *Computer*

Applications in Engineering Education, 2019, 27(2): 430-451. https://doi.org/10.1002/cae.22087.

Tisch M, Hertle C, Abele E, Metternich J, Tenberg R. “Learning factory design: a competency-oriented approach integrating three design levels”. *International Journal of Computer Integrated Manufacturing*, 2016,29(10/12). https://doi.org/10.1080/0951192X.2015.1033017.

Mandal N K, Edwards F R. “Student work readiness in Australian engineering workplaces through work integrated learning”. *Higher Education, Skills and Work-Based Learning*, 2021,12(1):145-161. https://doi.org/10.1108/HESWBL-02-2021-0025.

Garriga E, Melé D. “Corporate social responsibility theories: Mapping the territory”. *Journal of business ethics*, 2004, 53(1): 51-71. https://doi.org/10.1023/B:BUSI.0000039399.90587.34

Frederiksen C S, Nielsen M E J. *Corporate Social Responsibility: Challenges, Opportunities and Strategies for 21st Century Leaders.* 1st ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013.

Frankel-Goldwater L. ”Social Responsibility and the World of Nature: an interdisciplinary environmental studies course for inspiring whole system thinking and environmental citizenship”. *Journal of Environmental Studies and Sciences,* 2022, 12:114–132. https://doi.org/10.1007/s13412-021-00720-2.

Robertson D R. “Generative paradox in learner-centered college teaching”. *Innovative Higher Education*, 2005, 29: 181-194. https://doi.org/10.1007/s10755-005-1935-0.

Barth M, Godemann J, Rieckmann M, Stoltenberg U. ”Developing key competencies for sustainable development in higher education”. *International Journal of sustainability in higher education*, 2007, 8(4): 416-430. https://doi.org/10. 1108/14676370710823582.

Lynch K A, Boulay M C. “Promoting civic engagement: the environmental leadership program at the University of Oregon”. *Journal of Environmental Studies and Sciences*, 2011, 1: 189-193. https://doi.org/10.1007/s13412-011-0028-x.

Zhang W, Wang L. “Measuring the Authenticity of Engineering Learning in Community of Practice: An Instrument Development and Validation”. *2023 ASEE Annual Conference & Exposition.* https://doi.org/10.18260/1-2--43584.

Barab S A, Squire K D, Dueber W. “A co-evolutionary model for supporting the emergence of authenticity”. *Educational technology research and development*, 2000, 48(2): 37-62. https://doi.org/10.1007/BF02313400.

Herrington J, Oliver R. “An Instructional Design Framework for Authentic Learning

Environments". *Educational Technology Research and Development*, 2000,48(3). https://doi.org/10.1007/BF02319856.

Callison D, Lamb A. "Key Words in Instruction: audience analysis". *School Library Media Activities Monthly,* Sep 2004, 21(1):34-39.

Ashford-Rowe K. "Applying a design-based research approach to the determination and application of the critical elements of an authentic assessment".*Emerging technologies conference 2008.*

Zandvoort H. "Preparing engineers for social responsibility". *European Journal of Engineering Education*, 2008, 33(2): 133-140. https://doi.org/10.1080/03043790802024082.

Zheng X M, Zhu W C, Zhao H X, Zhang C. "Employee Well-being in Organizations: Theoretical Model, Scale Development, and Cross-cultural Validation". *Journal of Organizational Behavior*, 2015,36(5):621-644. https://doi.org/10.1002/job.1990.

Practice Papers

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BRIDGING THE GAP: EFFECTIVE COMMUNICATION AND PROJECT LEADERSHIP IN CHALLENGE-BASED LEARNING

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ABSTRACT

Engineering students' insufficient work experience, lack of knowledge or misconception about their own abilities to work and communicate efficiently on a complex engineering project, as well as their abilities to manage work efficiently can be a difficult task for lecturers to teach at university. Challenge-based learning (CBL) has been implemented in engineering higher education because it constitutes an active learning pedagogy that provides students with a framework to acquire and develop key transversal disciplinary skills like problem-solving, critical thinking, project leadership or communication skills. The experiential learning that a CBL framework offers allows students to work collaboratively in real-life problems that are challenging to solve. The authors of this paper are involved in integrating the teaching of two important transversal skills, project leadership and management and communication to manage a project and communicate it to different stakeholders for different purposes, into a challenge-based year-long course. In this paper, we report

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on our experience in teaching master engineering students these two transversal skills by means of a pedagogical intervention that is integrated within a course based on challenge-based pedagogy. The pedagogical intervention is described and subsequently students' perceived usefulness of such intervention is explained.

1 Introduction

Innovative teaching practices, such as project-based learning (PrBL) and challenge-based learning (CBL) have become frequent in the context of engineering in Higher Education (Beckett and Slater 2020). Project-based learning is related to action learning and makes students work on real world work assignments on time limited projects (DeFillippi, 2001); it later evolved into CBL. We adhere to Malmqvist et al.'s definition of challenge-based learning (2015) as the identification, analysis, and design of a solution to a sociotechnical problem. The learning experience in CBL usually involves different stakeholder perspectives and aims to find and develop solutions environmentally, socially and economically. Both types share the student-centred and student engagement focus and envision instructors as facilitators, yet CBL differs from PrBL in that students design the problem, and develop and execute the solution, with instructors designing, mentoring and coaching students (see van der Beemt et al., 2023 for a full comparative analysis).

The recent challenge-based pedagogy trend is attributed to the increasingly complex situations that engineers find themselves in, where they are expected to operate efficiently when undertaking actions that require innovative technological and sustainable solutions (Dolougeri et al. 2024). Among transdisciplinary skills that engineers are supposed to develop in their engineering endeavours and projects, we find problem-solving skills, entrepreneurship, collaboration, project management and team building, information gathering skills, critical thinking or communication skills (Tranquillo 2017; Zhao and Watterstone 2021). This brings to the fore the need to take on a holistic stance toward an integral engineering education that includes these transversal skills and disciplinary literacies in the curriculum (Heron et al. 2021; Paretti et al. 2019). In this study, we therefore focus on two such competences, namely, project management and leadership, and communication –missing features in most CBL research, as pointed out by a recent systematic review (Membrillo-Hernández and García-García 2020; Doulougeri et al. 2024).

Both transversal skills are essential for engineers to perform their daily activity effectively, but they stand out as particularly important for engineers working in a project collaboratively with other teams of engineers, sometimes in remote and culturally different countries. It is therefore not surprising to find challenge-based pedagogy implemented in different engineering courses and curricula, as real or quasi-realistic challenges are believed to stimulate self-directed learning by placing students centre stage and pushing them to link new knowledge with prior knowledge (Hadgraft and Kolmos 2020; Dolougeri et al. 2024). Challenge-based pedagogies, however, allow for a wide range of possible designs and implementations, not always equally effective as it comes to student learning (Dolougeri et al. 2022). In this paper, we describe a challenge-based course within a Master's programme that involves external stakeholders and integrates these two transversal skills through multidisciplinary teaching. The educational background, the Master's programme, against which this challenge-based course is taught will be described. In section three the framework and specificities of this course are described in detail as well as students' assessment of the intervention.

1.1 SELECT- Environomical Pathways for Sustainable Energy Systems Master's programme

The emergence of Master's degrees specialised in energy can be traced to the growing global awareness of two interconnected factors. The first is the urgency of the energy transition and refers to the increasing urgency of climate change mitigation and the necessity of shifting from fossil fuel-based energy systems to renewable sources. The second factor relates to the interdisciplinary nature of energy systems, since the complexity of energy production, distribution, and policymaking demands a new generation of graduates equipped with a holistic understanding of technical, economic, social, and environmental aspects of energy.

Among these diverse offerings, the SELECT (Environomical Pathways for Sustainable Energy Systems) Master's program holds a distinct position. SELECT is a collaborative initiative of several European universities. SELECT started as an Erasmus Mundus Program in 2010 and, since 2011 it has been offered within the framework of the European Institute of Innovation & Technology (EIT) InnoEnergy programme. This master's degree originated with the vision of training a workforce capable of accelerating the adoption of sustainable energy technologies and innovations throughout Europe. A core aspect of the SELECT experience is thus its emphasis on international mobility, with students spending semesters at two different partner universities.

Some of the two-year SELECT programme main components are:

- Entrepreneurship and Innovation: SELECT fosters strong entrepreneurial skills and an understanding of how to transform nascent technologies into commercial ventures.
- Global perspective: Through its mobility requirements and diverse student body, SELECT cultivates a nuanced understanding of global energy challenges and opportunities.
- Industry Network: SELECT students build strong connections to the industry through internships, company visits, and EIT InnoEnergy's extensive network.
- Energy Systems Analysis: Besides knowledge in energy engineering, SELECT students acquire deep knowledge about analysis of energy systems, by means of several systems analysis methodologies

The partner universities in SELECT programme are: the Royal Institute of Technology in Sweden (KTH), Politecnico di Torino (PoliTo), Eindhoven University of Technology in the Netherlands (TUE), Technical University of Catalonia in Barcelona, Spain (UPC), Instituto Superior Técnico in Portugal (IST), AGH University of Science and Technology in Poland (AGH), and Aalto University in Finland (Aalto). The first year of the master degree is developed simultaneously in two rooms connected remotely in Barcelona and Stockholm, an approach that can be considered a particular case of blended learning (Valderrama et al. 2018). The three authors work in two of the partner universities.

2 METHODOLOGY

Our primary objective is to present the approach adopted for incorporating Effective Communication and Project Leadership competences into the Project of the Year course, PoY,(12 Ects), a challenge-based course. We draw upon van der Akker's (2003) curricular spider web as a methodological framework. This paper is authored by the course coordinator and the instructors responsible for the two aforementioned competence interventions, so it draws upon the authors' direct experiences.

In March and April 2024 first-year students were asked to give their assessment on the project leadership (PL) and effective communication (EC) seminars that they received at the beginning of the academic year as well as on the guidance, mentorship, and feedback received by the two teachers (Author 1 and Author 3) throughout the Project of the Year (PoY) course.

2.1 Participants

We analysed the engineering students enrolled in the PoY during the second semester of the academic year 2023-24. Although students will submit the final report and deliver the final presentation within a month after the actual writing of the paper (month 5 as per Table 1), students are now at the end of the process and are considered to be entitled to assess and rate the usefulness of the two pedagogic interventions that tackle the transversal skills. The course coordinator (Author 2) sent all students an email asking them to answer the survey on a voluntary basis, specifying it was anonymous, for educational and research purposes only, and that their opinion was to detect and inform possible improvements. A total of 21 students (out of 50) answered the GForm survey.

2.2 Instruments

The GoogleForm survey that was designed and administered to gather information about the students' perceptions consisted of 5 Likert-type quantitative questions, usually complemented with an open-ended question each. Question 5 was excluded from this study because it fell beyond the objective of this study. Below every item, students could choose between 1 (completely disagree) and 5 (fully agree). The open-ended answers in the survey were inductively analysed, arranging the reasons given by students according to broad themes (Saldaña, 2017). The two instructors met to share and discuss the themes they had identified until consensus was found in order to achieve interrater reliability.

1-Project management skills are necessary for a smooth and efficient development of a challenging project like the PoY2- Can you elaborate on your answer and briefly tell us why?

2- Technical Communication skills are necessary for a smooth and efficient development of a challenging project like the PoY - Can you elaborate on your answer and briefly tell us why?

3-Both types of competence are useful not only for the PoY but for our future career as well.

4- Are project management and communication skills necessary for engineers working in multicultural and multilingual engineering projects? What do you think and why?

3 RESULTS

First, we describe the integration of the two transversal skills throughout the year-long project so that the intervention can be, if necessary, replicated. Subsequently, students' perceived usefulness of these competences will be explained.

3.1 Pedagogic intervention to integrate project leadership and communication skills in the challenge-based project

The aims, content, learning activities, teachers' role, materials and resources, grouping, location, time and assessment of the intervention will be described, following van der Aker (Doulougeri et al.2024:6). First, we describe the Project of the Year course, which starts before every group is allocated a company, with its corresponding challenge. Once projects and clients have been assigned, students create teams of 8-10 students to work for one year on a proposed opportunity or need with a significant impact on sustainability. The teams are made of students from different universities, ensuring a diversity of perspectives. One project manager per team is chosen among students in every team to take on the leadership role throughout the project's duration. The challenges always relate to sustainable energy, but the companies freely define the objectives, technologies considered, and scope according to their interests, time, and available resources. The challenge allows for various approaches and solutions, which are negotiated between the students and the company. Each project is supervised by an academic supervisor, a lecturer from one of the partner universities. This provides students with expert guidance and real-world insights. Additionally, students maintain contact with the company that proposed the project, acting as the client. It is important to emphasize that the companies request analyses and proposals that the students develop and complete to meet their specific needs.

The Project of the Year places great emphasis on effective communication and project leadership skills–considered to be key features conducive to success in challenge-based learning (Membrillo-Hernández and García-García 2020). These transversal skills are taught by two instructors, authors 1 and 3 of this paper, who come from different disciplines to avoid disciplinary egocentrism (Doulougeri 2024): management and business administration and English for specific purposes and professional communication. The instructors lead one seminar each at the beginning of the academic year, whose aim is twofold: i) teach students about relevant important factors in project management and professional communication; and ii) allow students to gain practice in a mini project *before* the real PoY starts. Both specialised seminars are given at the beginning of the academic course (months 8-9, see Table 1). The duration is 10 learning hours per seminar, over several days, with the following structure:

- Seminar on project management is based on energy-related mini projects proposed by the students themselves and developed in groups of 3-4 students. This ends in the mini project proposal presentations on the last day. These presentations are recorded.

- Seminar on effective written and oral communication of engineering projects follows. The recorded mini presentations are the starting point of this second seminar by following a teaching strategy that makes the students aware of their weaknesses and improvement needs (Author 1 and Author 3 2023).

When the two seminars finish, the actual PoY starts: students are allocated their company and their challenge starts. Throughout the rest of the year (month 5 to month 10), both instructors become mentors, meeting students at different points throughout the PoY development, to assist students when required and support the actual year-long PoY project. In this way, students put these transversal skills in practice during real-life challenging Project of the Year, receiving feedback and guidance from the instructors and the course coordinator. Examples of the type of guidance given by instructors are:

- The work groups prepare reports on internal group organisation and planning. Possible hurdles and improvement opportunities are addressed in meetings with the coordinator of the whole course and the teacher in charge of the Project Leadership aspects.
- Group and individual assessment and improvement support is provided by the two instructors to streamline their reporting activities, to support students on the difficulties encountered–as voiced by students and identified by the instructors. Every group drafts the report and rehearses its presentation and receives feedback from the EC instructor at least twice during the PoY.

The temporal structure of the Project of the Year and of the activities on effective communication and project leadership skills can be seen below in Table 1.

Table 1. Effective Communication (EC) and Project Leadership (PL) activities within the context of the Project of the Year.

Month	Project phase	EC & PL activities
8	Project allocation	EC + PL instructors give seminars (10 h each). Students practice with a mini-report.
9		
10-11-12	1st Phase: analysis and work plan proposal	PL instructor and PoY coordinator hold meetings with every group separately
1	1st Phase Submission	EC report assessment & feedback during rehearsals. EC instructor meets every group separately before groups submit reports and give oral defence in front of companies
3-4	2nd Phase: project work	PL instructor & PoY Coordinator give assistance on the project and EC instructor meets students when requested.
5	2nd Phase Submission	PL and EC instructors give support before groups submit reports and give oral defence in front of the (client) companies and academic supervisors

3.2 Students' perception

The quantitative results of the survey indicate a high perceived usefulness among students. Around 90.5% of students who answered the survey agreed with the statement that "project leadership and communication are very necessary for the smooth and efficient development of a challenging project like the PoY." Additionally, all respondents (100%) agreed that "both competences are useful not only for the PoY but also for their future careers." To complement this general overview and gain deeper insights into students' thinking, open-ended answers were analyzed. This analysis unveiled that project management skills are perceived as essential because "having so many projects to fulfill, and being the PoY a long run project, it's easy to lose the focus on it. That's why it's mandatory to be organized and good in project management skills to not lose the point on it" (Student 8) and because "project management is needed to be able to effectively choose the needed tasks and properly put them in frameworks that make it easier to work with, track progress, and correctly measure this progress" (Student 6).

As to communication skills, students actually confirm Paretti et al's (2019) findings when they say " it's essential to have good technical communication skills to understand the deliverables requested by the company and put forth our concerns/ requests to the company (...) We are also required to develop a report and give interim and final presentations to explain the work we have done so far. Here, communication skills become important for illustrating our work to a bigger audience" (Student 14) and "as an engineer it is very important not only to have good communication with fellow engineers but also people from different backgrounds and it is very helpful to convey what the challenge is in a broken down manner to make it easier to understand for everyone" (Student 19).

The following excerpt from student 5 summarises the representative answers by students in item 4, when asked about how necessary the skills are for engineers who work in multicultural and multilingual engineering projects:

In multicultural and multilingual engineering projects, engineers must have excellent project management and communication skills. This is because multicultural environments increase the complexity of projects and require engineers to be able to effectively cross cultural and language barriers to ensure that information is accurately communicated and understood. Good communication skills, including sensitivity to cultural differences and mastery of non-verbal communication, are essential to facilitate teamwork and resolve conflicts. Meanwhile, project management skills enable engineers to lead diverse teams, plan and execute projects efficiently, and adapt to the challenges and changes that cultural differences can bring. In addition, these skills help to identify and mitigate risks caused by cultural differences, build trust among team members, and are a key factor in achieving project success. Therefore, for engineers working in diverse contexts, acquiring these skills is not only a necessity, but also a cornerstone to ensure that projects run smoothly and achieve their goals.

Student 21, however, is the only student that, while acknowledging the relevance of the skills, questions their integration into PoY, maybe because of the complexity of the PoY itself: "obviously yes, but I am not sure the current scope of PoY is the best way to assess this".

4 Summary and acknowledgements

Only 21 students replied, maybe due to the fact that students were not given much time to answer the survey. Yet, our case study provides evidence of how two transversal skills were integrated in a year-long challenge-based learning course and how multidisciplinarity was successfully included in the project, as shown by how highly students rate project leadership and communication skills. These preliminary findings also hint that expecting students to acquire transversal skills without any explicit teaching may mean placing too high–and unfair–expectations on them.

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REFERENCES

Author 1 and Author 3 (2023). "Improving Communication Procedures By Means Of Videorecorded Proposals." In the European *Society for Engineering Education* (SEFI). DOI: 10.21427/ST83-J035.

DeFillippi, R. J. (2001). Introduction: Project-Based Learning, Reflective Practices and Learning. Management Learning, 32(1), 5-10. https://doi.org/10.1177/1350507601321001

Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education*, 1–31. https://doi.org/10.1002/jee.20588

Doulougeri, K., van den Beemt, A., Vermunt, J.D., Bots, M. and Bombaerts, G. (2022). Challenge-Based Learning in Engineering Education: Toward Mapping the Landscape and Guiding Educational Practice. In Vilalta-Perdomo, E., Membrillo-Hernández, J., Michel-Villarreal, R., Lakshmi, G. and Martínez-Acosta, M. (Eds.) *The Emerald Handbook of Challenge Based Learning*, Emerald Publishing Limited, Leeds, pp. 35-68. https://doi.org/10.1108/978-1-80117-490-920221003

Hadgraft, R. G., & Kolmos, A. (2020). Emerging learning environments in engineering education. *Australasian Journal of Engineering Education* 25, 3–16. https://doi.org/10.1080/22054952.2020.17135

Malmqvist, J., Rådberg, K. K., & Lundqvist, U. (2015). Comparative analysis of challenge-based learning experiences. Paper presented at the 11th *International CDIO Conference*. Chengdu, China. https://research.chalmers.se/en/publication/218615

Paretti, M.C., Eriksson, A., and Gustafsson, M. (2019) "Faculty and Student Perceptions of the Impacts of Communication in the Disciplines (CID) on Students' Development as Engineers". In *IEEE Transactions on Professional Communication*, 62, 27-42, https://doi.org/10.1109/TPC.2019.2893393

Saldaña, Johnny. (2009). *The Coding Manual for Qualitative Researchers*. Sage Publ.

Tranquillo, J. (2017). The T-shaped engineer. J*ournal of Electrical Engineering & Technology*, 30(4), 12–24.

Valderrama, César, Peter Hagström, and Thomas Nordgreen. "Shared curriculum at KTH and UPC universities: Blended learning experience at the MSc SELECT programme." In *IEEE Global Engineering Education Conference* (EDUCON), pp. 669-676. IEEE, 2018.

Van den Beemt, A.; Vázquez-Villegas, P.; Gómez Puente, S.; O'Riordan, F.; Gormley, C.; Chiang, F.-K.; Leng, C.; Caratozzolo, P.; Zavala, G.; Membrillo-Hernández, J. (2023) Taking the Challenge: An Exploratory Study of the Challenge-Based Learning Context in Higher Education Institutions across Three Different Continents. *Education Sciences* 13, 234.

Van den Akker, J. J. H. (2003). "Curriculum perspectives: An introduction". In J. J. H. van den Akker, W. A. J. M. Kuiper, & U. Hameyer (Eds.), *Curriculum landscapes and trends* (pp. 1–10). Kluwer Academic Publishers.

PSYCHOLOGICAL SAFETY IN PRACTICE: GUIDELINES AND INSIGHTS FOR DIFFERENT STAKEHOLDERS IN HIGHER EDUCATION

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ABSTRACT

Interpersonal dynamics have a major influence on team processes and outcomes. Psychological safety, in particular, is one of the foundations of effective teamwork. While there has been a recognition of the importance of psychological safety in team settings, in particular in organizational and management literature, there has been an underrepresentation of studies addressing ways by which the concept can be operationalized. Recognizing the primacy of teamwork in higher education settings, this paper aims to raise awareness and provide guidelines for incorporating

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interventions centred around psychological safety. We first elaborate on the concept of psychological safety. We then distil and elaborate on three major components of psychological safety: mindful listening, asking questions, and providing and receiving feedback. Next, we review two sample interventions and provide guidelines for developing similar training and learning interventions.

1 Introduction

The collaborative nature of the rapidly changing work environment in the higher education setting is a reality today. From student group projects in a class to research groups led by faculty to work groups in different units, in all those situations, a *supportive learning environment* forms the basis for *individuals working together in groups or teams* to achieve common goals and objectives.

Over time organizational research has shown that three broad factors are essential for organizational learning and adaptability: a supportive learning environment, concrete learning processes and practices and leadership behaviour that provides reinforcement. These factors are considered the building blocks of a learning organization, a concept introduced by Peter M. Senge in the 1990s. “Organizations learn only through individuals who learn. Individual learning does not guarantee organizational learning. But without it, no organizational learning occurs” (Senge, 1990, p. 139). What are the underlying features of a supportive learning environment? Garvin, Edmondson and Gino (2008) describe four distinguishing characteristics: *psychological safety*, appreciation of difference, openness to new ideas and time for reflection. These characteristics are particularly relevant when working in teams.

Individuals working together, whether they are students working on a project or scientists in a research team, share a certain level of interdependence. The higher the level of interdependence in working towards a common goal, the more important it becomes to establish trust and deal with conflicts in a team. Also, Lencioni (2002) stresses the importance of trust as a fundament of successful teams.

Working successfully together in a team is something that people have to learn. It doesn’t come naturally in the competing knowledge economy of today. Edmondson (2012) introduced the word ‘teaming’: “a way of working that brings people together to generate new ideas, find answers and solve problems” (p. 24). Teaming is a verb, an ability, a competence that people can develop.

For teams to function effectively, team members and team leaders have to learn to team and team to learn. This requires interpersonal behaviours. Literature demonstrated different types of competencies that are critical to effective teamwork, including interpersonal skills such as communication and conflict resolution skills (Stevens and Campion, 1994). Developing these interpersonal skills visible in successful teams requires psychological safety. Psychological safety is a collective belief among team members that the team is a safe environment for speaking up, sharing ideas and concerns and taking risks (Edmondson, 1999).

In a recent review of published articles on psychological safety, Edmondson and Bransby (2023) identified the “micro dynamics of conversations” as an important area that has been understudied in the literature. Such an underrepresentation implies that there are no concrete guidelines for designing, developing and facilitating interventions centred around the concept of psychological safety.

The purpose of this paper is to provide practical guidance and ideas on operationalizing the concept of Psychological Safety within teams for different stakeholders in higher education. First, we share the conceptual foundations of psychological safety from leadership, team development and organizational psychology perspectives. Then we translate the concept with a focus on powerful conversations and skills needed and discuss the role of educators and faculty. We share and reflect on our experiences with developing learning interventions for different audiences. To conclude, we provide practical guidelines and insights to invite engineering educators and faculty to design, develop and facilitate activities to promote psychological safety in teams to further develop a learning culture in higher education settings.

2 Conceptual foundations of psychological safety

2.1 Psychological safety as a concept

Prior literature and research discuss the concept of psychological safety within the context of working in teams related to key terms, such as trust, speaking up, sharing ideas and concerns, taking risks and learning from mistakes. While the use of the concept has been growing, in particular in the context of leadership and organizational settings, the accurate meaning has often been misunderstood. Edmondson (2019) addresses some misconceptions related to the concept of psychological safety.

- *Psychological safety is not about being nice*

It is the opposite. It is about frankness, about making it possible for productive disagreement and free exchange of ideas. It is about the willingness to engage in productive conflict for the purpose of learning from different points of view.

- *Psychological safety is not a personality factor*

It is not a synonym for extroversion if people don’t speak up at work. In a psychologically safe environment, people offer ideas and voice their concerns.

- *Psychological safety is not just another word for trust*

Both have much in common though, they are not interchangeable concepts. Psychological safety is experienced at a group level and describes a temporally immediate experience. Trust refers to interactions between two individuals or parties and describes an expectation that someone can be counted on.

- *Psychological safety is not about lowering performance standards*

It is not an ‘anything goes’ environment where people are not expected to adhere to high standards or meet deadlines. This misconception is particularly important in a highly competitive environment, such as higher education institutions.

Psychological safety is connected to another equally important dimension in team and organizational settings, performance standards. Edmondson (2019) illustrates the relation between these dimensions in a 2 by 2 matrix. Only when performance standards and psychological safety are both high, people are in the learning zone. In this zone, people can collaborate, learn from each other, and get complex and innovative work done (Edmondson, 2019).

From another perspective considering foundational aspects of psychological safety, Edmondson (2014) describes the following three pillars for leaders and team members to foster psychological safety in the workplace:

1. Frame the work as a learning problem, not an execution problem

Reframing creates awareness of the uncertainty and interdependency in work. It is helpful to encourage everyone to share ideas and thoughts. It forms the rationale for speaking up and learning.

2. Acknowledge your fallibility

Admitting mistakes and showing areas of uncertainty and vulnerability, invites others to open up. This creates safety for speaking up.

3. Model curiosity and ask lots of questions

Asking questions and seeking to understand stimulates a culture where everyone's input is valued and appreciated. It creates the necessity for speaking up.

By modelling these behaviours, a culture of speaking up and sharing knowledge and ideas freely without fear of failure will be developed.

3 Operationalizing psychological safety

In this section, we share pointers which can help educators and faculty translate and apply the concept of psychological safety into their daily work environment in further developing their pedagogical, leadership and team development competencies. Informed by literature, we explore two main components we identified as the vehicle to operationalize psychological safety: powerful conversations and the critical skills needed for this.

Studies show that the way in which psychological safety affects performance, learning, work experiences and the role of leadership, explicitly or implicitly, is mainly through conversation (Edmondson and Bransby, 2023). Good conversations in interpersonal and team settings share a specific characteristic, a *personalized relationship* between the actors (Schein and Schein, 2018). According to Schein (2013), it is all about building a relationship, a connection to the whole person. This is true for one-on-one and one-to-many conversations in different settings, such as two or more team members talking about a (research) project or a team leader discussing with the team.

A logical question is, how do we build these personalized relationships in conversations as a fundament for psychological safety? One of the answers comes from the Structural Dynamics Theory developed by David Kantor. Structural Dynamics is a theory of how face-to-face communication works and does not work in human systems (Kantor, 2012). It can be seen as a lens on the nature of human discourse. Kantor later refers to this *lens* as the ability to read the room to understand what’s going on when people communicate in small groups or teams, including how the leader him or herself is participating, when the conversation is moving forward, when it may just about to leave the rails, and possibly even how to guide it back on course (Kantor, 2012).

If one masters the skill of *reading the room*, one actively searches for communication patterns and uses conversation cues next to words (verbal communication). Conversation cues, such as tone of voice, facial expressions, and body language, play a significant role in effective communication. They help convey meaning and context that may not be captured by the words alone. Conversation cues give information which allows individuals to *place conscious and targeted interventions* in conversations, in particular on the process of the relations between the speaker and the listener(s) (Kessels & Smit, 2019). Examples of interventions are asking for details, summarizing, providing feedback, creating an atmosphere, reflecting on emotions and confronting.

The ability to read the room and master the art of placing conscious and targeted interventions form the basis of what we call: a powerful conversation. We posit that this ability is critical to the micro dynamics of conversations as mentioned by Edmondson and Bransby (2023).

Which skills are critical in powerful conversations? Moreover, how do these skills contribute to building a psychologically safe environment? In this section, we discuss three skills we see as the most important to further develop in different settings and for different stakeholders involved. We use the terms skills and competencies interchangeably as we would only like to stress the importance and contribution of mastering these interpersonal skills to enhance and facilitate powerful conversations.

3.1 Mindful listening

Giving someone the feeling that they are ‘really’ listened to and to create a personalized relationship, is challenging. In an educational or management setting, educators and team leaders often tell more than they listen, whether that is during a course, working on a project or during a team meeting. Sharmer (2017) illustrates four levels of listening: downloading (habits of judgement), factual listening (noticing differences and perspectives), empathic listening (emotional connection) and generative listening (energetic and with your whole body). For individuals to listen mindfully, they need to reflect on their assumptions, avoid distractions and pay close attention, and understand what has been said from the speaker’s point of view with recognition of thoughts and emotions. Through mindful listening, then, team members can highly contribute to creating a psychologically safe (learning) environment.

3.2 Asking questions

The art of asking genuine and open questions contributes to building a relationship based on curiosity and interest in the other person. Schein (2013) calls this humble inquiry, the fine art of drawing someone out, of asking questions to which you do not already know the answer. Edmondson (2019) talks about proactive inquiry, the purposeful probing to learn more about an issue, situation or person.

What makes a question powerful? Vogt, Brown and Isaacs (2003) identify the following attributes of powerful questions. A powerful question:

- generates curiosity in the listener
- stimulates reflective conversation
- is thought-provoking
- surfaces underlying assumptions
- invites creativity and new possibilities
- generates energy and forward movement
- channels attention and focuses inquiry
- stays with participants
- touches a deep meaning
- evokes more questions.

Using powerful questions in conversations often results in new insights, reflection and learning. When people use open, genuine questions, they demonstrate interest and curiosity about the other person and are intentional to hear and value their perspectives.

3.3 Providing and receiving feedback

Providing constructive feedback stimulates learning, fosters growth and adds to trust and mutual respect. It is an intervention which is key in a higher education setting. Learning from mistakes based on constructive feedback and reflection facilitates taking risks, another element of a psychologically safe (learning) environment. Edmondson (2023) elaborates on *the science of failing well* in her new book which provides practices, skills and mindsets to help us replace shame and blame with curiosity, vulnerability, and personal growth. It is worth noting that mindful listening and asking questions are key skills needed for enhancing feedback literacy.

There are several models for providing constructive feedback used in different settings and contexts. Explaining different models is beyond the scope of this paper.

4 TWO EXAMPLE INTERVENTIONS

Based on the literature and our experiences, engineering educators and scholars can play an important and leading role in building psychological safety. We identify different stakeholders who might have a direct or indirect influence on promoting the concept, for example, student teams (Bachelor and Master students), research teams (PhD students, post-doctoral researchers and scientists), professors and teachers. In the next section, we share two examples of how we used the concept of psychological safety in learning interventions.

4.1 Psychological safety in engineering student teams

One specific example of an intervention centred around psychological safety was a 90-minute module designed for a graduate-level engineering course. For more details about the activity, see Jalali et al. (2024). The goal was to support students in developing conversational skills, more specifically asking questions and listening, to create a safe and open team climate. Incorporating experiential learning and the major constituents of transversal skills development, mainly knowing, experiencing, and learning from experience (Isaac et al. 2023), the session provided several opportunities for practising, reflection, and feedback. Students were first introduced to major features of a skilful conversation, among them showing vulnerability, asking genuine questions, active listening, and reflecting on ways by which they can show genuine interest in others' perspectives (Edmondson, 2019; Senge et al. 1994). Among different components and exercises, an active, experiential element using LEGO bricks was incorporated to practice the skills and reflect on their strengths and weaknesses. Students were asked to create a model of themselves individually as a member of the team they are representing considering the following criteria: i) their background, ii) areas of expertise and skills they bring in connection with the project, iii) skills for improvement, and iv) anything else they could offer to create a better team climate. Then, each team member would share their models and respond to questions from other students in the team. Students were explicitly asked to be mindful of effective listening and asking genuine open questions. Next, to bring the whole team together, students were asked to create one agreed model representing their teams, considering i) team goals, ii) provisional roles, iii) creating a safe and open environment for team learning, and iv) potential risks they would envision. Finally, students reflected specifically on moments, interactions, or comments that increased or decreased their sense of belonging to the team; and how they contributed to creating a safe and open team climate.

Two features of this intervention are worth noting. First, the focus of the intervention was on teams rather than individuals. Prior literature highlighted the importance of delivering team-training interventions on specific knowledge, skills, and attitudes to teams rather than individuals (Mathieu et al. 2008). Second, by incorporating playful elements, learning is intrinsically motivated, immersive, and involves the positive construction of failure (Whitton, 2018). It can specifically facilitate self-expression and discussion of the aspects of the team process that would be more difficult to address outside of such a playful and engaging experience.

4.2 Psychological safety in research teams led by faculty

Leadership behaviour enhances psychological safety, in particular when it comes to leader competency, listening and transparency (Edmondson and Bransby, 2023). This has been one of the insights used for designing the Program 'Building High Performing Research Teams', a leadership journey for Tenure Track Assistant Professors at EPFL.

This blended learning program is designed to provide Tenure Track Assistant Professors with a comprehensive toolbox to address the typical challenges they face in their role as a first-time leader of a research team at EPFL. Always anchored in the daily life in the lab, the program aims to further develop leadership skills by

taking them on an active and explorative journey from self-awareness to sustaining growth in a demanding research environment.

At the end of this learning journey, they can:

- address what is needed to successfully lead and develop a team where all members can reach their full potential
- start building psychological safety as the basis for a high-performing research team

- identify values, motives and drivers within individual team members by asking good questions and by listening effectively in daily conversations
- give feedback to address motivational issues, proficiency gaps or interpersonal tensions, meant to support each team member to grow
- identify obstacles to handling difficult conversations using a method to structure and solve them
- communicate effectively to obtain better results and better relationships in situations where the stakes are high and emotions are involved.

The format of this program is adjusted to their work situation. It includes a blend of short face-to-face sessions, dedicated group coaching, reflection activities and informal round tables to reinforce leadership skills and exchange experiences with experts and peers.

How is psychological safety put into practice in this learning intervention?

The Tenure Track Assistant Professors practice different types of conversations as one of the key elements of the program, whether it concerns one-on-one or group meetings and from mastering daily conversations to handling difficult conversations. The skills covered in these conversations are mindful listening, asking open questions, providing feedback, negotiating and handling conflicts.

By using the key principle *from self-awareness (self-reflection) to growth (fostering fallibility and vulnerability)*, we try to model the behaviour needed for building a psychologically safe learning environment by professors.

So far, the feedback and experiences from everyone involved are promising and motivating to keep working on and promoting psychological safety in research teams.

5 Discussion and conclusion

In this practice paper, we presented how we interpreted and worked on the concept of psychological safety within our institution. While the primacy of psychological safety in enhancing team processes and improving performance has been illustrated for various team settings (e.g., Duhigg, 2016; Gibson and Gibbs, 2006; Nembhard and Edmondson, 2006), there has been an underrepresentation of studies focusing on psychological safety within engineering education literature. Considering the nature of engineering practice and the need for students to develop teamwork competencies, creating contexts where students can function effectively in teams and learn from their experience is critical. A similar argument holds for other team settings in higher education, noticeably research labs, where members of the teams need to feel valued and respected. As noted earlier, a practical challenge is how to operationalize psychological safety and develop meaningful training and learning interventions for different stakeholders. Building on major illustrations of psychological safety, we distilled and elaborated on essential aspects of psychological safety, mainly listening, asking questions, and providing and receiving feedback. Based on our experiences, we share the following guidelines and insights:

- Co-design the learning intervention with the key stakeholders (and future audience if possible). This engages and motivates the audience from the very first start.
- Start simple by using concrete exercises to practice a selected number of skills and explain the reason behind the choice of skills. This makes it manageable and clear.
- Reflect on the experiences with everyone involved. Reflection creates self-awareness, and an open dialogue contributes to creating a supportive learning environment.
- Explore and create an open dialogue around the topic of psychological safety linked to performance standards with key stakeholders. This helps to avoid misconceptions.
- Incorporate major elements of skills development, knowing, experiencing, and learning from experience, when designing activities.

We intentionally focused on three critical skills as we consider these the core skills to build psychological safety in different settings in higher education. We aim to explore further how different stakeholders experience similar learning interventions. We invite all engineering educators and faculty to design, develop and facilitate activities to promote psychological safety in project and research teams to further develop a learning culture within their institutions.

More research on the development, implementation and evaluation of pilot learning interventions is needed to identify and develop an overview of interventions, activities, guidelines and instructions to build psychological safety in different team settings in higher education.

REFERENCES

Duhigg, C. (2016). What Google Learned from its Quest to Build the Perfect Team. *The New York Times Magazine*, *26*(2016), 2016.

Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly*, *44*(2), 350-383.

Edmondson, A.C. (2012). Teaming*. How Organizations Learn, Innovate, and Compete in the Knowledge Economy*. Hoboken, New Jersey: John Wiley & Sons.

Edmondson, A.C. (2014). *Building a psychologically safe workplace*. TEDx Talk, https://www.youtube.com/watch?v=LhoLuui9gX8

Edmondson, A.C. (2019). *The Fearless Organization: Creating Psychological Safety in the Workplace for Learning, Innovation and Growth*. Hoboken, New Jersey: John Wiley & Sons.

Edmondson, A.C. (2023). *Right Kind of Wrong: The Science of Failing Well*. New York: Simon & Schuster.

Edmondson, A.C. & Bransby, D.P. (2023). *Psychological Safety Comes of Age: Observed Themes in an Established Literature*. *Annual Review of Organizational Psychology and Organizational Behavior*, *10*, 55-78.

Garvin, D.A., Edmondson, A.C., & Gino, F. (2008). Is Yours a Learning Organization? *Harvard Business Review, 86(3)*, 109.

Gibson, C. B., & Gibbs, J. L. (2006). Unpacking the Concept of Virtuality: The Effects of Geographic Dispersion, Electronic Dependence, Dynamic Structure, and National Diversity on Team Innovation. *Administrative Science Quarterly*, *51*(3), 451-495.

Isaac, S., Petringa, N., Jalali, Y., Tormey, R., & Dehler Zufferey, J. (2023). Are engineering teachers ready to leverage the power of play to teach transversal skills? *51st Annual Conference of the European Society for Engineering Education (SEFI)*, Dublin, Ireland, September 11-14.

Jalali, Y., Alberink, B., Dehler Zufferey, J., & Mondada, F. (with Isaac, S., Petringa, N., Winzenried, N., and Tormey, R.) (2024). How to support students to cultivate psychological safety in their teams. In 3T PLAY (Eds.), *Teaching Transversal Skills for Engineering Students: A Practical Handbook of Activities with Tangibles*, Centre for Learning Sciences EPFL, Lausanne.
https://doi.org/10.5281/zenodo.11192095

Kantor, D. (2012). *Reading the Room: Group Dynamics for Coaches and Leaders*. Hoboken New Jersey: John Wiley & Sons.

Kessels & Smit, (2019). The Learning Company. *The Communication Pyramid*. Utrecht.

https://www.kessels-smit.com/en/240

Lencioni, P. (2002). *The Five Dysfunctions of a Team: A Leadership Fable*. First edition. San Francisco: Jossey-Bass.

Mathieu, J., Maynard, M. T., Rapp, T., & Gilson, L. (2008). Team Effectiveness 1997-2007: A Review of Recent Advancements and a Glimpse into the Future. *Journal of Management*, *34*(3), 410-476.

Nembhard, I. M., & Edmondson, A. C. (2006). Making it Safe: The Effects of Leader Inclusiveness and Professional Status on Psychological Safety and Improvement Efforts in Health Care Teams. *Journal of Organizational Behavior: The International*

Journal of Industrial, Occupational and Organizational Psychology and Behavior, *27*(7), 941-966.

Scharmer, O. (2017). *Theory U: Leading from the Future as It Emerges*. San Francisco: Berrett-Koehler Publishers.

Schein, E.H. (2013). *Humble Inquiry: The Art of Gentle Asking instead of Telling.* San Francisco: Berrett-Koehler, 2013.

Schein, E.H., & Schein, P.A. (2018). *Humble Leadership: The Power of Relationships, Openness, and Trust.* San Francisco: Berret-Koehler.

Senge, P.M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization*. New York: Doubleday.

Senge, P. M., Kleiner, A., Roberts, C., Ross, R.B., Smith, B.J. (1994). *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization*. Nicholas Brealey Publishing.

Vogt, E.E., Brown, J., and D. Isaacs. (2003). *The Art of Powerful Questions: Catalyzing Insight, Innovation, and Action*. Mill Valley: Whole Systems Associates.

Whitton, N. (2018). Playful Learning: Tools, Techniques, and Tactics. *Research in Learning Technology*, *26*.

Connecting Experience and Expertise: A Service-Learning project to help seniors distinguish statistical errors in publications

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ABSTRACT

This study describes a project in which undergraduate engineering students, from the statistics course, gain practical experience and reinforce their mathematical knowledge by giving lectures on statistics to adult people attending to the University of Experience at the University of Salamanca, Spain. From a group of 53 students from the statistics course, 4 of them selected this project and developed it during the first semester of 2023-2024. The methodologies used by young students are discussed, including the preparation of materials and the effective communication of complex statistical concepts to a non-specialist audience. In addition, the impact of this experience on the development of communication skills, leadership and mathematical understanding of the engineering students is considered. Students feedback underscores the effectiveness and positive impact of the service-learning (SL) concept implemented on campus. Students were highly satisfied with this approach, which integrates academic learning with community service, fostering a sense of social responsibility and civic engagement among participants. Moreover, the feedback highlights the significant growth and development of teamwork and leadership skills throughout the semester. The SErvice LEarning Benefit (SELEB) questionnaire was shared with students that participated in this project and they include the results in a final report. The SELEB scale measures how students view their service-learning experiences covering four areas: practical skills, interpersonal skills, citizenship, and personal responsibility. This allows to get some results from undergraduate degree students participating in a SL activity.

1 INTRODUCTION

The University of Experience, present at several universities with different names, stands as an innovative educational program that offers lifelong learning opportunities to older adults (over 55 or 60 depending on the institution). Through a variety of courses and activities designed specifically for this demographic group, the University of Experience encourages the exchange of knowledge and experiences, thus promoting significant personal and social enrichment. This program enables participants to access quality education, regardless of their age, and provides them with the opportunity to further explore areas of interest and develop skills, thus contributing to a more active and fulfilling life (Cámara and Eguizábal 2008). The University of Experience at the University of Salamanca reflects the institution's commitment to inclusive education and the enrichment of the whole community, regardless of their stage in life.

The activity described in this study took place in a town of 13,000 inhabitants, where the Higher Technical Industrial Engineering School is located.

The integration of methodologies such as service-learning and teamwork in engineering education is essential to prepare students not only in terms of technical knowledge, but also in terms of interpersonal and leadership skills, as well as social awareness and civic responsibility (Pazos et al. 2020). The combination of service-learning and teamwork in the educational methodology provides a comprehensive and enriching experience for engineering students. By participating in community service projects, students not only acquire technical and academic skills, but also develop teamwork, leadership and project management skills. In addition, by working collaboratively with the community, students can better understand real-world needs and challenges, enabling them to more effectively apply their knowledge and skills to make a positive difference in society (Pazos et al. 2020; Queiruga-Dios et al. 2021).

In addition, project-oriented learning develops students' entrepreneurial competence (Crespí et al. 2022; Schmalenbach 2022). Service-learning provides students with the opportunity to apply their knowledge and skills to address real problems in the community, while

fostering a sense of commitment and service to others (Queiruga-Dios et al 2021). Figure 1 shows the diagram of a SL project, which is not a “classical” project, but has some additional phases (Queiruga-Dios et al., 2023): Observation of the social need, preparation of the project that will address that need, action in the community, reflection of the service already done, registration of the development and results, evaluation as part of the course syllabus, and acknowledgement to the persons involved in the tasks.

Fig. 1. Diagram of service-learning with project stages (Queiruga-Dios et al., 2023)

While SL allows students to apply knowledge and skills in meaningful contexts and in service to others,, teamwork enables students to collaborate, communicate and problem solve effectively in a group environment, essential skills for success in the world of work (Ercan and Khan 2017). Teamwork is a fundamental skill that engineering students must develop throughout their academic training and that allows them to apply theoretical knowledge in real-world situations. Recognizing the importance of statistical literacy in today's society, the team set out not only to raise awareness of the prevalence of these errors, but also to provide tools to identify them and critically evaluate statistical information presented in the media. This initiative builds on the growing awareness of the importance of statistical studies today (Pazos et al. 2020; Schmalenbach et al. 2022).

The scientific literature supports the relevance of addressing errors in statistics. Statistical errors in the media can distort public perception of important issues, such as public health or politics. Statistics is not merely a collection of mathematical techniques, but rather a powerful tool for understanding and interpreting data in various real-world contexts. By emphasizing this connection, students are able to appreciate the relevance and applicability of statistics in their everyday lives and in a wide range of fields and disciplines (Gelman and Nolan 2017).

It is important to foster a critical understanding of statistics to counteract the spread of misleading or incorrect information. This research underlines the need for educational programs that enable the population to properly discern and evaluate statistical information presented in the media (Joseph 2011; O'Connor and Wearherall 2019).

Students of statistics acquire several fundamental mathematical competences throughout their education, which go beyond simply manipulating numbers. These competences include mathematical thinking, which involves the ability to approach problems from a logical and analytical perspective. They also develop problem-processing skills, which enable them to break down complex situations into more manageable steps for solving them. Mathematical modelling enables them to represent real-world situations using mathematical concepts and tools, while mathematical reasoning helps them to ground and justify their resolution processes. In addition, students also cultivate skills in mathematical representation, which involves the ability to visualize and present data and concepts clearly and accurately. The use of mathematical symbols and formalisms is essential for expressing mathematical ideas and relationships concisely and accurately. Mathematical communication is another crucial competence they develop, as it enables them to explain, effectively in both written and oral form, their thought processes and the results they obtain (Alpers et al 2013; Niss and Højgaard 2019).

In the context of teamwork, such as giving a talk to older people on statistics, students can apply and strengthen these competencies. Team collaboration allows them to combine their individual skills to plan, prepare and present the talk effectively. In addition, this project encourages the use of mathematical aids and tools, as students can use visual aids, practical examples and technological tools to enhance audience understanding and participation. Finally, this experience not only strengthens the mathematical skills of statistics students, but also enables them to develop interpersonal, teamwork and leadership skills, preparing them to face professional and social challenges in the future (Tishkovskaya and Lancaster 2012).

2 METHODOLOGY

As part of the statistics course, a group of 4 students came together to participate in an innovative project: further exploring service-learning projects and giving a talk to seniors about common statistical misconceptions found in the media, such as television, news and newspapers.

The team was well organized, assigning roles and responsibilities to each member to ensure an effective and cohesive presentation. The engineering students' teamwork involved not only preparing the content of the talk, but also adapting the information to make it accessible and understandable to a non-specialist audience (Anwar and Menekse 2020). As part of the SL project, students observe and prepare for a non-technical audience. Regular meetings were held to discuss the content of the talk, search for concrete examples of statistical errors in the media and devise strategies to make the information accessible and understandable to a non-specialist audience. In addition, visual resources and practical examples were used to illustrate statistical concepts in a clear and concise manner. An interdisciplinary approach combining statistical literacy with effective communication techniques was used to highlight the importance of using innovative pedagogical methods to improve the understanding of statistical concepts in different audiences (Bromage et al. 2022; Kovacs et al. 2021).

In conclusion, the integration of methodologies such as service-learning and teamwork in engineering education is essential to train skilled, ethical and socially committed professionals who can face the challenges of today's world in an effective and responsible way.

The Student LEarning Benefit (SELEB) questionnaire has been designed with the purpose of collecting crucial information about the service-learning (SL) experience and the benefits that participants have gained from this activity. The responses obtained are of vital importance to the ongoing study, as they contribute to a deeper understanding of the impacts of SL on the academic community and society at large (Brown at al 2023; Toncar et al. 2006).

The SELEB questionnaire includes the following 21 topics:

1. Experience personal growth.
2. Ability to work well with others.
3. Enhance my leadership skills.
4. Enhance my communication skills.
5. Gain a greater understanding of cultural and racial differences.
6. Enhance my social responsibility and citizenship skills.
7. Be involved in the community.
8. Ability to make a difference in the community.
9. Apply information learned in the classroom to real-life scenarios.
10. Problem analysis and critical thinking.
11. Apply problem-solving techniques.
12. Build my self-confidence.
13. Conflict resolution.
14. Ability to assume personal responsibility.
15. Learn practical workplace skills.
16. Skills in Learning from Experience.
17. Develop organizational skills.

18. Connecting theory with practice.
19. Establish caring relationships.
20. Empathy and sensitivity to the plight of others.
21. Demonstrate my trustworthiness to others.

To complete the questionnaire, students are asked to indicate how important each of the items in the questionnaire is to them, using a Likert scale ranging from 1, representing “not important at all”, to 7, indicating “very important”. This process allows researchers and educators to accurately assess participants' perceptions and ratings of the different aspects of SL.

By providing this detailed feedback, responses help to identify areas of strength and opportunities for improvement in the implementation of SL, as well as to highlight the tangible and intangible benefits that this experience offers both individually and collectively. In summary, the SELEB questionnaire is a valuable tool for capturing students' perspectives on SL and its impact, providing essential information to inform and enrich future community service initiatives in academia.

Once the service-learning project was finished, students made an oral presentation to their fellows and a written report to the teacher. The qualitative analysis of the responses to the SELEB questionnaire provides a more detailed and enriching insight into the students' experience with older adults. Through these responses, students have been able to express their perceptions and opinions on various aspects related to their participation in this community service activity.

3 Discussion and Results

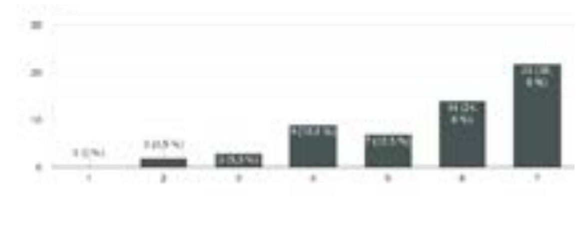
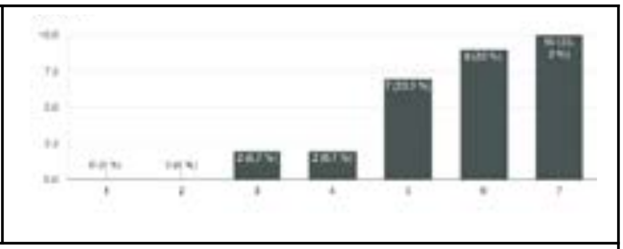
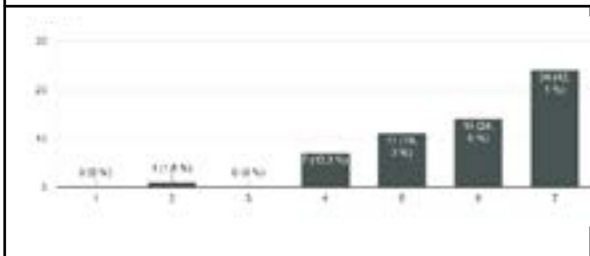
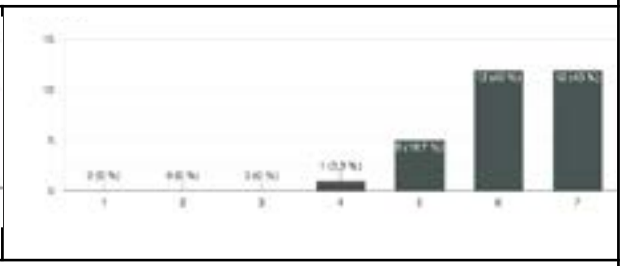
The resulting speech was a successful event and provided the audience with more practical tools to identify and avoid statistical errors in the media (see Figure 2). The students used concrete examples of poorly designed surveys, misinterpretations of data and statistical manipulation to highlight the importance of being critical and cautious when consuming statistical information in the media. In addition, they provided practical advice on how to identify and avoid these errors, equipping the audience with tools to make more informed and evidence-based decisions in their daily lives.

Fig. 2. Presentation of statistical errors in the media to older adults at the University of Experience

This project not only allowed the students to apply their statistical knowledge in a real-life context, but also strengthened their communication, teamwork and leadership skills. By collaborating to address a relevant and meaningful topic, the team demonstrated the transformative power of statistics education and the positive impact that engineering students can have on the community.

Table 1 shows some results from the SELEB questionnaire. No specific statistical analysis was developed because the qualitative analysis was the main part of the results.

Table 1. Some results from the SELEB questionnaire during the 2022-2023 year

	
Question2: Ability to work well with others	
	
Question 4: Enhance my communication skills	

Apart from that, students highlighted the personal growth experienced as a result of their participation in the activity, mentioning an increase in self-confidence and a sense of achievement in sharing their knowledge with others. Many students mentioned that the experience helped them develop skills to work effectively in a team, collaborating with others to achieve common goals. They noted that the activity enabled them to improve their leadership and communication skills by having to explain statistical concepts in a way that was clear and understandable to a non-specialist audience.

The activity provided them with a greater understanding of cultural differences, as they interacted with people from different backgrounds. Students expressed a sense of social and civic responsibility while participating in the activity, highlighting the importance of contributing positively to the community and making a difference in the lives of others. Moreover, they valued the opportunity to apply knowledge acquired in the classroom to real situations, allowing them to see the relevance and practical usefulness of statistics in everyday life and of problem-solving and critical thinking skills when faced with new challenges and situations.

The group of students filled a document with the different stages of a SL project see Figure 3).

Fig. 3. Document prepared by students including their feedback in the SL project stages

In summary, the development of a service-learning project reveals a range of benefits and learning gained by students from participating in the activity. The concept of service learning not only provides students with opportunities to apply theoretical knowledge in real-world contexts but also encourages collaboration, communication, and problem-solving within diverse teams. Through engaging in community projects, students are able to enhance their teamwork skills by working closely with peers towards common goals, navigating challenges, and leveraging each other's strengths.

Furthermore, the service-learning experience serves as a platform for the development of leadership skills among students. As they take on roles and responsibilities within their service projects, students have the opportunity to exercise leadership qualities such as decision-making, initiative, and effective communication. Over the course of the semester, students are likely to see noticeable improvements in their ability to lead and motivate others, as well as in their confidence in taking on leadership roles.

Overall, the positive student feedback regarding service-learning reflects its value in promoting holistic student development, fostering meaningful connections with the community, and cultivating essential skills that are applicable in both academic and professional settings.

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REFERENCES

Alpers, B. A., M. Demlova, C. H. Fant, T. Gustafsson, D. Lawson, L. Mustoe, D. Velichova. “A framework for mathematics curricula in engineering education: a report of the mathematics working group”. In *SEFI Mathematical Working Group Seminar*, Salamanca, 2013.

Anwar, S. A. I. R. A. and M. Menekse. “Unique contributions of individual reflections and teamwork on engineering students’ academic performance and achievement goals”. *International Journal of Engineering Education* volume 36, no. 3 (2020): 1018-1033.

Bromage, A., S. Pierce, T. Reader, and L. Compton. “Teaching statistics to non-specialists: Challenges and strategies for success”. *Journal of Further and Higher Education* volume 46, no. 1 (2022): 46-61. https://doi.org/10.1080/0309877X.2021.1879744

Brown IV, I. D., L. Pointer, C. Smith, and K. Gleason. “The impact of a short duration service-learning project on student learning outcomes”. *Journal of Service-Learning in Higher Education* volume 16. (2023): 4-19.

Cámara, C. P., and A. J. Eguizábal. “Quality of university programs for older people in Spain: Innovations, tendencies, and ethics in European higher education”. *Educational Gerontology* volume 34, no. 4 (2008): 328-354. https://doi.org/10.1080/03601270801897774.

Crespí, P., M. Queiruga-Dios, and A. Queiruga-Dios. “The challenge of developing entrepreneurial competence in the university using the project-oriented learning methodology”. *Frontiers in Psychology* volume 13 (2022): 966064. https://doi.org/10.3389/fpsyg.2022.966064.

Ercan, M. F., and R. Khan. “Teamwork as a fundamental skill for engineering graduates”. In *2017 IEEE 6th International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 2017, 24-28. IEEE. https://doi.org/10.1109/TALE.2017.8252298.

Gelman, A., and D. Nolan. *Teaching statistics: A bag of tricks*. Oxford University Press, 2017.

Joseph, N. L. “Correcting the record: The impact of the digital news age on the performance of press accountability”. *Journalism Practice* volume 5, no. 6 (2011): 704-718. https://doi.org/10.1080/17512786.2011.587670.

Kovacs, P., E. Kuruczleki, K. Kazar, L. Liptak, and T. Racz. “Modern teaching methods in action in statistical classes”. *Statistical Journal of the IAOS* volume 37, no. 3 (2021): 899-919. https://doi.org/10.3233/SJI-210843.

Niss, M., and T. Højgaard. “Mathematical competencies revisited”. *Educational studies in mathematics* volume 102 (2019): 9-28. https://doi.org/10.1007/s10649-019-09903-9.

O'Connor, C., and J. O. Weatherall. *The misinformation age: How false beliefs spread*. Yale University Press, 2019.

Pazos, P., F. Cima, J. Kidd, S. Ringleb, O. Ayala, K. Gutierrez, and K. Kaipa. “Enhancing teamwork skills through an engineering service-learning collaboration”. In 2020 *ASEE Virtual Annual Conference Content Access, Virtual Online*, 2020.

Queiruga-Dios, M., M. J. Santos Sánchez, M. Á. Queiruga-Dios, P. M. Acosta Castellanos, and A. Queiruga-Dios. “Assessment methods for service-learning projects in engineering in higher education: A systematic review”. *Frontiers in Psychology* volume 12 (2021): 629231. https://doi.org/10.3389/fpsyg.2021.629231.

Queiruga-Dios, A., Rasteiro, D. M., Sánchez Barbero, B., Martín-del Rey, Á., & Mierlus-Mazilu, I. “Service-Learning Activity in a Statistics Course”. In *International Conference on Mathematics and its Applications in Science and Engineering*, 2023, 317-324. Cham: Springer Nature Switzerland.

Schmalenbach, C., H. Monterrosa, A. R. Cabrera Larín, and S. Jurkowski. “The LIFE programme–University students learning leadership and teamwork through service learning in El Salvador”. *Intercultural Education* volume 33, no. 4 (2022): 470-483. https://doi.org/10.1080/14675986.2022.2090689.

Tishkovskaya, S., and G. A. Lancaster. “Statistical education in the 21st century: A review of challenges, teaching innovations and strategies for reform”. *Journal of Statistics Education* volume 20, no. 2 (2012). https://doi.org/10.1080/10691898.2012.11889641

Toncar, M. F., J. S. Reid, D. J. Burns, C. E. Anderson, and H. P. Nguyen. “Uniform assessment of the benefits of service-learning: The development, evaluation, and implementation of the SELEB scale”. *Journal of Marketing Theory & Practice* volume 14, no. 3 (2006): 223–238. https://doi.org/10.2753/MTP1069-6679140304.

DEVELOPMENT OF A FORMATIVE ASSESSMENT PRACTICE

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ABSTRACT

Formative assessment during a course promotes a focus on learning rather than performance. We present ongoing work on the implementation of a formative assessment practice in a large physics course. In this feedback practice, both the students and the teacher have an active role. Two-hour sessions take place in an ordinary lecture hall, where the students in the first part work on exercises and hand in answers on a digital platform. During the second part, the feedback practice occurs. Based on the students' answers, the teacher initiates activities such as

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discussions and other instructions to target specific issues where the answers show challenges.

During these sessions, the teacher gains insight into the students' learning process, something that forms not only the second part of the session but can form future teaching. The students gain better insight into their learning process and eventually become self-regulated. Our preliminary results show that the students find the exercises difficult, but report the session has a large effect on their learning and understanding.

1 INTRODUCTION

In formative assessment, the aim is to promote students' learning. This approach, to perceive assessment as learning has a different purpose than summative assessment where the aim is to evaluate learning. Due to the learning effect, it is recommended to use formative assessment as a part of the teaching and learning activities (Ashwin, et al. 2020; Dolin et al. 2018). Formative assessment can give students insight into their learning process through a feedback process. For a good feedback practice, Nicol and Macfarlane-Dick (2006) recommend teachers to follow the seven principles: 1. help to clarify what good performance is (goals, criteria, expected standards); 2. facilitate the development of self-assessment (reflection) in learning; 3. deliver high-quality information to students about their learning; 4. encourage teacher and peer dialogue around learning; 5. encourages positive motivational beliefs and self-esteem; 6. provides opportunities to close the gap between current and desired performance; 7. provides information to teachers that can be used to help shape teaching (p. 205). Using these principles, the authors argue that students may become self-regulated learners (Nicol and Macfarlane-Dick, 2006).

OBJECTIVE

This paper presents work in progress from a project on the implementation of formative assessment in a large course. The overall goal of the project is to develop a formative assessment practice that increases learning, and the students find valuable. The paper aims to describe the development process of the formative assessment practice. We present results from this pilot, where the students' multiple-choice answers inform on their performance and questionnaires give insight into the students' experiences. In addition, observations provide information on the development of the practice.

2 BACKGROUND

The introductory physics course for students in physics at the Norwegian University of Science and Technology is a calculus-based mechanics course (NTNU, 2024). Before the pilot, mandatory activities in this course consisted of calculus exercises, numerical exercises, and laboratory work. These activities took place as group work without the direct involvement of the lecturing teacher. Feedback for the approximately 160 enrolled students was provided by student assistants.

To change this, we initiated this project, where the aim is to introduce new formative exercises that give the teacher insight into the students' achievement during the course and thereby form the teaching. At the same time, the students get valuable feedback on their learning process and hopefully, they experience a better connection between the exercises and the lectures.

3 APPROACH

Inspired by the recommendations of Nicol and Macfarlane-Dick (2006), we planned active learning sessions to take place in a lecture setting. Sessions were designed to start off with an individual part, where the students work on exercises individually. By the end, they hand in their answers on a digital platform. The exercises consist of concept questions and calculus-based calculations, which are relevant for the summative exam by the end of the semester. During the break, the teacher goes through the results and decides on the activities for the second part. During this second part, the feedback practice occurs since the teacher initiates activities such as discussions and other instructions to target the specific issues where the answers have shown challenges. These activities are in line with the peer instruction method described by Mazur (2014).

Because the purpose of the pilot was to study the effect of a specific intervention and not a complete redesign of the course, the number of sessions during the autumn semester of 2023 was limited to two. Data was collected during both sessions. In this paper, the focus is on the data produced during the first session as the two data sets show the same trends, and their few differences arise due to a small reduction in the workload in the second session.

4 DATA PRODUCTION AND ANALYSIS

In total 130 students joined the lecture where the first session took place from which 114 of the students replied to the multiple-choice questions. This data informs the students' level of achievement. To explore the students' experiences, a questionnaire with the Likert scale questions listed in Table 1 together with an open text box for comments was distributed afterwards. In total 96 students answered this questionnaire. Participation in all activities and questionnaires was voluntary and anonymous. This was only possible because the activity was not mandatory during this pilot.

Table 1. Likert scale questions and the open question

Questions: How do you find/assess…	Response s
the difficulty of the exercises?	96
the time available in relation to the workload?	96
the effect on your learning and understanding from the activities:	
● Teacher working out problem	95
● Peer discussion	93

• Hint followed by peer discussion	94
• Hint followed by individual work	93
• Follow-up exercises	93
the activities' overall impact on your learning and understanding	95
Comments for development purposes (open text)	19

In addition, both sessions were observed from two perspectives: the teacher in front of the lecture hall as part of the active lecturing, and from the back passively overviewing what the student audience was doing, taking notes of their behaviour and time registration.

The results of the quantitative questions are presented as average and standard deviation. Data from the open question is used to gain a deeper understanding of the students' experience with the session, some of the quotes are presented as part of the discussion.

5 Results

This section is organized into three themes: the difficulty level of the exercises and students' performance (5.1), the flow of information and the overall structure (5.2), and the students' self-reported effect on learning and understanding (5.3).

5.1 The difficulty level of the exercises and students' performance

During the first part of the session there were six problems to work out. Students answered these in a multiple-choice format. Table 2 shows how many correct answers the 114 students had.

Table 2. Students' number of correct answers

Overall score	0	1	2	3	4	5	6
Number of students	6	26	26	24	19	12	1

The average overall score is 43% correct with a standard deviation of 24%. This result indicates that the exercises had a challenging level. Through the questionnaire, distributed after the session, the students were asked about the difficulty of the exercises and their time available in relation to the experienced workload, see Table 3. On a Likert scale from 1 (very easy) to 5 (very difficult), the average of the 96 answers to the question, regarding the difficulty, the average is 3,6 with a standard deviation of 0,7. No one answered that the exercises were very easy. To the question about the time available in relation to the workload, where the Likert scale ranges from 1 (short on time) to 5 (plenty of time) the average is 2,7 with a standard deviation of 1.

Table 3. The average of students' answers on the level of difficulty

Reported answers	Average	St. dev.
The difficulty, Likert scale of 1 (very easy) to 5 (very difficult)	3,6	0,7
Time available, Likert scale of 1 (short on time) to 5 (plenty of time)	2,7	1

The data on the level of difficulty and the students' performance (Tables 2 and 3) show that very few students completed all exercises. Approximately half the students found the exercises difficult with slightly insufficient time for completion. As the aim of the session is for the students to learn and experience challenges, this level of difficulty might be suitable. In order words, most students have had a learning opportunity during the session. If too many students find the exercises easy, the session becomes redundant.

5.2 Flow of information and the overall structure

From the observations, it is clear that all students were well-informed before the session since by entering the lecture hall, the students knew what they were supposed to do. This includes grabbing the worksheet at the entrance and following the rules for the first part by working individually in a classical exam-like atmosphere. Further, the students knew they were supposed to hand in their answers as multiple-choice answers by the end of the first part. As the break was announced by the teacher, the observer experienced silence being disrupted by loud chatter. Students started to discuss, pointing at their calculations, asking "What did you do?", "I managed...", and "I knew things" while they were smiling and looking at each other's notes. During the second part of the session, the students engaged actively in the different activities initiated by the teacher, of which their self-reported effect on learning and understanding is presented in Table 4, next section.

Overall, the students' collective behaviour indicates that the teacher had prepared the students for the session well in advance. His strategy was: to announce the pilot at the beginning of the term; this was repeated in the weeks before each session; a few days ahead of a session students would receive an email message detailing the structure of a session.

5.3 Students' self-reported effects on learning and understanding

The second part of the session is the central part of the feedback practice, here the teacher initiates activities based on the distribution of the answers and the seven principles for a good feedback practice (Nicol and Macfarlane-Dick, 2006). For example, if the multiple-choice answers show an equal distribution of the five possible answers, the teacher will initiate a peer discussion according to Principle 4 encouraging peer dialogue. Since a variety of perspectives exist among the students, there are aspects for them to discuss. On the other hand, if the multiple-choice answers show that very few students answered correctly, it indicates that most students might have problems or misunderstandings. In this case, a better choice for the teacher is to work out the problem and explain the details, thereby showing what a good performance looks like (Principle 1). Another possibility is for the teacher to give a hint and then let the students discuss or finish the calculations themselves, thereby helping the students close the gap between their current and desired performance (Principle 6). These activities were tested out during the first session. Table 4 shows data on the students' self-reported effects on their learning and understanding of the different activities during the second part of the session, along with the overall impact of the session. The Likert scale used ranges from 1 (very little) to 5 (very large).

Table 4. Self-reported effects on students' learning and understanding

Questions regarding the different activities in part two:	Average	St. dev.
• The teacher works out the problem	4,3	0,6
• Peer discussion	3,7	0,9
• Hint followed by peer discussion	3,9	0,9
• Hint followed by individual work	3,8	0,8
• Follow-up exercises	4,0	0,8
The overall impact on learning and understanding	4,1	0,6

The students have reported the follow-up activity where the teacher works out problems to have the highest learning effect, and activities such as peer discussion, hint followed by either individual work or peer discussion with a lower learning effect.

One might speculate whether the students value the teacher's words higher than their peers and the possibility of a discussion due to an authority effect or simply the fact that most students already had discussed the most demanding things during the break. However, the average of answers to the overall impact of the session was 4,1 which corresponds to a 'large' effect. It is noteworthy that no one answered that the learning effect was 'very little'.

6 Discussion

The session described in this paper was the first attempt to implement a formative assessment practice in an introductory physics course for physics students. The results indicate a significant positive impact on the students' self-reported learning and understanding. There are several reasons. First, the students were well informed about the session, the progress, and what they were expected to do. Second, the difficulty of the exercises seemed to be at the right level. All students were engaged throughout the first part, and not too many had everything correct. However, students' comments on the open question suggest that there might have been too little time available during the first part. As one student writes: '*Very informative. This was a good practice in problem-solving. A suggestion is, to have more time, or fewer tasks, so that one can try all the tasks before going through them'.* To have the full learning potential during the second part, it is essential that everyone has had sufficient time to work on all problems. For the subsequent session, which took place later in the semester, we intentionally reduced the workload, and the first exercises were simpler.

The structure of the session with the two distinctive parts is crucial as in the first part the students realise what they need to study more as commented by a student: '*[I] see, what I need to work on'*. Further, it is important to give feedback while the students still remember the exercises and the problems they experienced, as expressed: '*It's nice to have time to do exercises and then go through everything while one still remembers'*. The second part is also where the teacher implements the feedback principles by Nicol and Macfarlane-Dick (2006).

The fact that the students rate the teacher working out the problem as having the most significant impact on their learning and understanding might be similar to the self-reported perception of learning from traditional lecturing compared to an active learning environment reported by Deslauriers et al. (2019). Their study measured the actual learning from two student groups and compared this to the students' perception of learning. Their results show that students in a traditional learning environment think they learn more compared to those in an active learning environment, but the measure of actual learning shows the opposite. We think, our data shows a similar effect, that the students think they learn more when the teacher works out the problem rather than if they discuss it with their peers. A student's comment confirms this: '*The review [by the teacher] was useful to know whether one had thought correctly'.* This perception is something to address in the future. Perhaps, the results from (Deslauriers et al. 2019) could be a part of the information given to the students in advance.

7 CONCLUSION

Our overall goal of creating learning sessions with teacher feedback was achieved. As a student expressed: '*I think it [the session] was very good in terms of learning, I feel like I learned a lot in a short time. At the same time, it was a shock how difficult the tasks were to solve, especially given the very short amount of time'.* The plan is to incorporate this practice into the mandatory activities and further enhance it by researching students' learning experiences during these sessions.

The feedback practice developed and described here is easy to implement in other courses. It represents a cost-effective and relatively simple method to engage large student groups and provide them with relevant feedback.

REFERENCES

Ashwin, P., D. Boud, S. Calkins, K. Coate, F. Hallett, G. Light, K. Luckett, I. MacLaren, K. Mårtensson, J. McArthur, V. McCune, M. McLean and M. Tooher. *Reflective Teaching in Higher Education*. 2 ed. Bloomsbury Academic, (2020).

Deslauriers, L., L. S. McCarty, K. Miller, K. Callaghan, and G. Kestin. "Measuring Actual Learning versus Feeling of Learning in Response to Being Actively Engaged in the Classroom." Proceedings of the National Academy of Sciences 116, no. 39 (2019): 19251-19257. https://doi.org/10.1073/pnas.1821936116.

Dolin, J., J. Bruun, C. P. Constantinou, J. Dillon, D. Jorde, and P. Labudde*. How to change Practice and in What Direction*. In J. Dolin and R. Evans (Editors) Transforming Assessment Through an Interplay Between Practice, Research and Policy. (2018): 249-278. DOI 10.1007/978-3-319-63248-3_10

Mazur, E. *Peer Instruction: a user's manual.* Pearson, 2014.

Nicol, D. and D. Macfarlane-Dick. Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education* 31, no. 2, (2006): 199-218. DOI: 10.1080/03075070600572090

NTNU, Course description mechanical Physics. Retrieved June 11, 2024, from https://www.ntnu.edu/studies/courses/FY1001#tab=omEmnet.

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Bridging Theory and Practice in Antenna Education: Students Perceptions on Software Based Learning

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Conference Key Areas: *Educating the whole engineer: teaching through and for knowing, thinking, feeling, and doing. Engineering skills, professional skills, and transversal skills*
Keywords: *Electromagnetic teaching, Research-led teaching, Software-assisted learning, Virtual Prototyping*

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ABSTRACT

In the field of engineering education, the traditional approach of solely imparting theoretical knowledge has evolved to emphasise the significance of experiential learning. Providing engineering students with opportunities to learn through hands-on experiences, critical thinking, and analysis has become increasingly essential. This shift is not only beneficial for enhancing students' understanding of theoretical concepts but also crucial for fostering practical skills and preparing them for the challenges of the modern workplace.

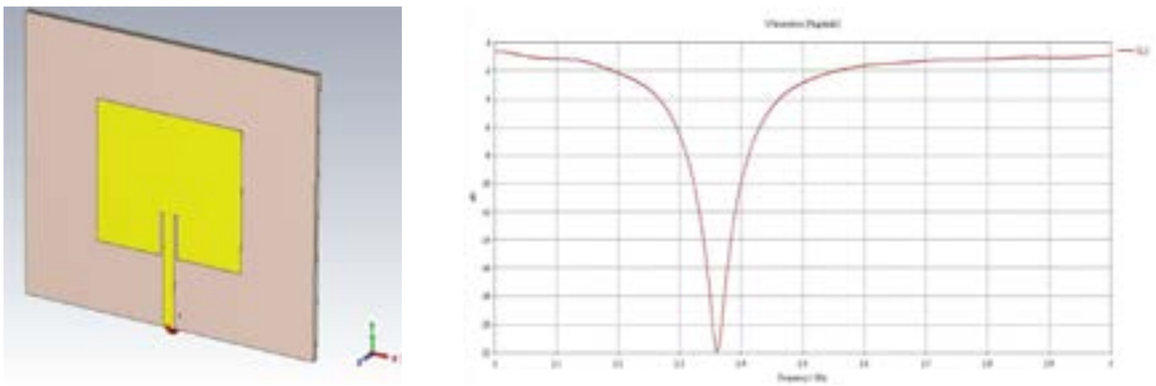
Theoretical modules such as antennas and propagation in electromagnetics present challenges rooted in advanced mathematics and complex theoretical concepts, leading to a notable gap between theory and practice. We implemented computer simulation classes alongside traditional lectures to address this gap and enrich students' learning experiences. These simulation sessions offer students a virtual prototyping environment, guiding them through the complete design cycle - from model creation to generating Gerber files necessary for real-world antenna fabrication. Additionally, the classes incorporate 3D visualisation tools to facilitate understanding of intricate concepts. To reinforce the connection between simulation and real-world applications, each session begins with demonstrations of antenna prototypes. At the conclusion of the semester, a survey was administered to assess student satisfaction with the approach, yielding positive feedback.

1 INTRODUCTION

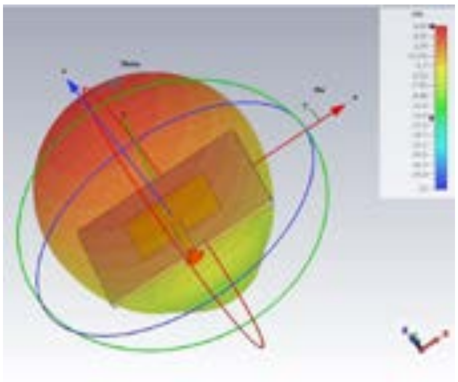
Developing engaging and effective approaches to teaching electromagnetics (EM) and antennas has received considerable attention over the last few decades. Among the numerous suggested approaches is software-aided teaching. Initially, basic free space wire antennas simulations were demonstrated using the mini numerical electromagnetics code “MININEC” (Cole et al.1990, Excell 1993). Subsequently, several software tools were developed under the activities funded by the NSF/IEEE Center for Computer Applications in Electromagnetic Education (CAEME) (Iskander 1993, Fabrega, Sanz and Iskander 1998, De Los Santos Vidal et al. 2002). In addition, an EM field simulator with a graphical user interface (GUI) was used to teach introductory EM (Beker, Bailey, and Cokkinides 1998). The concept of multi-media-based teaching of EM and antenna and a virtual antenna laboratory were introduced (Iskander 2002). Furthermore, Mathematica and MATLAB were adopted to teach EM and antennas (Anderson 2003). Computer-aided-design (CAD) tools were proposed to gauge undergraduate students' understanding (Popović and Giannakopoulos 2005). Moreover, a finite element method (FEM) based customised tool was developed for interactive learning of electromagnetics (Trlep et al. 2006). A stronger students’ retention of electromagnetics was observed when adopting technology-enabled active learning (TEAL) compared to traditional teaching formats (Dori, Hult, and Belcher 2007). On the other hand, several virtual tools were developed and used to reach the right balance between EM theory and computer simulations (Sevgi 2008). EM teaching using electromagnetic field visualisation was demonstrated using COMSOL (Talele, 2014).

This study utilised the teaching model that included asynchronous and synchronous activities to support students' learning. The former included the release of recorded videos every week, followed by a synchronous session involving quizzes in conceptual questions and a recap of the recorded material. Furthermore, the CST simulations represent a key element of synchronous teaching. Through these simulations, students acquire practical experience in antenna design, complementing theoretical knowledge with hands-on skills. Using 3D visualisation tools for electromagnetic field analysis simplifies complex concepts and enhances comprehension, particularly for students facing learning difficulties. Moreover, the widespread usage of the CST package in the industry provides students with valuable employability skills, enriching their antenna learning journey with practical applications. By engaging in 3D simulations and virtual antenna design exercises, students develop a tangible connection between theoretical principles and real-world practices. This connection is further reinforced by presenting students with prototypes of the antennas to be designed in each session. A research-led teaching approach was adopted by embedding practical examples based on the instructors' and others' research in the lectures and simulation sessions. For example, explaining the basic antenna theory and design principles in reference to millimeter-wave and terahertz advanced technologies and challenges associated with these frequencies.

The efficacy of this adopted approach is evaluated through an anonymous student survey, detailed in Section 3 that gauges the effectiveness of the teaching methodology and the extent to which it bridges the gap between theory and practice in antenna education. Figure 1 exemplifies a patch antenna design derived from one of the sessions utilising CST Microwave Studio software. The figure displays the proposed antenna structure alongside analysis of relevant parameters post-simulation, encompassing return loss and far-field radiation pattern assessments.



(a) (b)



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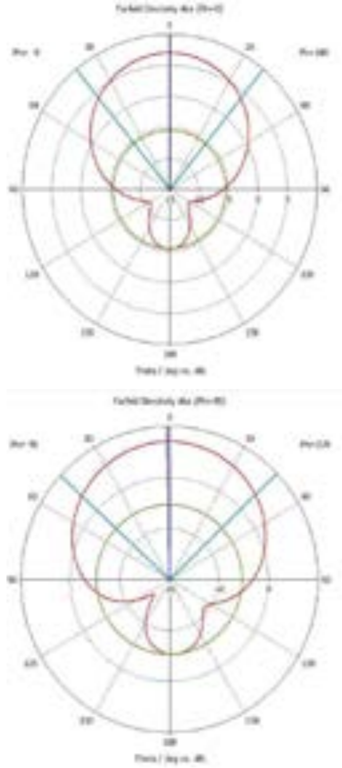

(d)

Figure 1. Antenna design created in CST Microwave Studio (a) Patch antenna modelling (b) Return loss analysis, (c) 3D radiation pattern, and (d) 1D far-field pattern

2 METHODOLOGY

The antenna module in question comprised 18 timetabled in-person lectures, with 6 sessions dedicated to simulations. These simulation sessions were strategically integrated into the curriculum, following the delivery of relevant theoretical content. For instance, after a lecture on a specific antenna type, students engaged in a simulation session focused on the same topic to explore modelling and evaluating the antenna performance characteristics as well as think through the design process.

During the hands-on session, students are encouraged to work within a small group. Students are given the time and opportunity to independently think about the antenna design steps and model using the available commercial software (CST). Then, students are shown an actual prototype of the antenna to be designed, which helps to place the learned theory in the practical context. Subsequently, students received guidance on configuring parameters such as frequency, boundary conditions, and mesh type and size as they followed step by step to model the antenna of interest. Under the instructor's supervision, students created the virtual antenna geometry and initiated the simulation process.

Upon completing the simulation, students are encouraged to analyse the radiation characteristics and compare them to the theoretical principles discussed in previous lectures. Following this, students are encouraged to reflect on their antenna modelling experience and the corresponding obtained performance indicator results (return loss, and radiation pattern). Each session concludes with a demonstration of generating a Gerber file, essential for practical antenna fabrication.

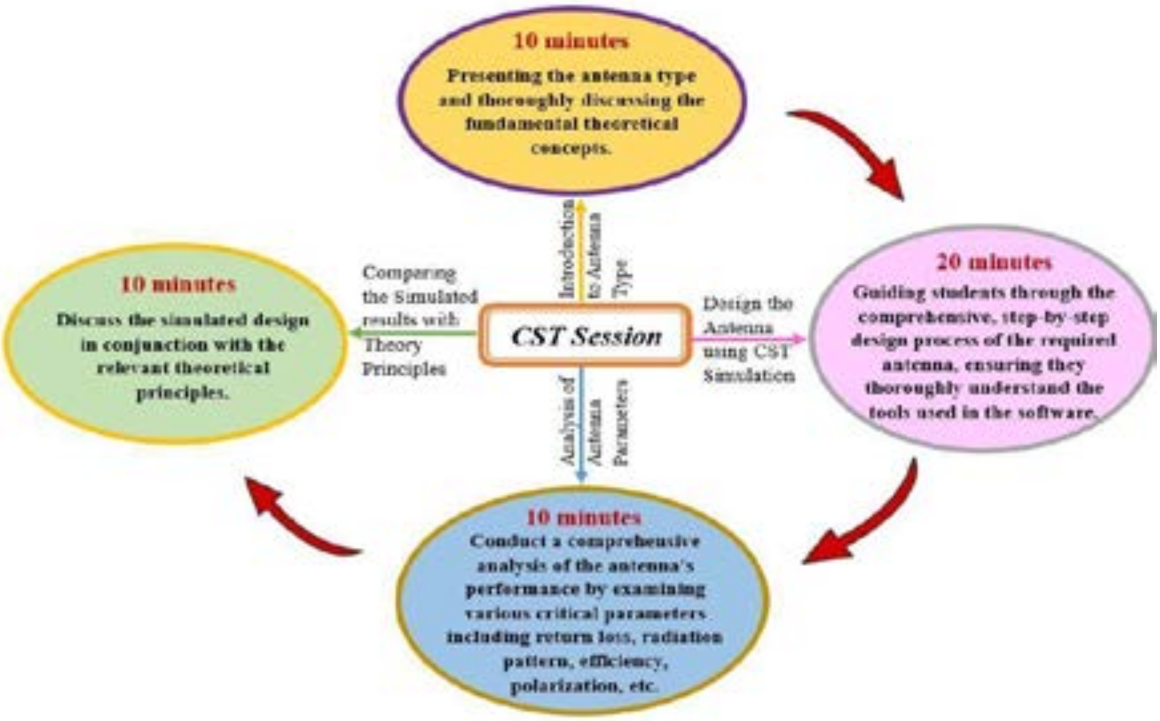

Figure 2. Structure of the CST hands-on session.

Figure 2 illustrates the CST hands-on session structure. The session starts with a 10-minute overview of the antenna type to be analysed and its fundamental theoretical concepts. Next, students spend 20-minute to follow a guided step-by-step approach to apply their knowledge and model an antenna. Then they spend 10 minutes engaging in discussions analysing the design antenna performance with a focus on critically evaluating key design parameters such as return loss and radiation patterns. In the final 10 minutes students engage in making the connection between the resulting simulation performances and the theory discussed earlier.

Historically, the antenna module was taught from a theoretical perspective, taking students through lengthy derivations of Maxwell's equations to derive electric and magnetic fields from first principles, followed by applications to dipole antennas, monopoles and an array of isotropic sources. Students' knowledge of antenna design was limited to understanding the operation of dipoles. Further, students were assessed on remembering and calculating antenna problem-solving problems. Using this blended model of teaching and learning, with a focus on application to electromagnetics and antenna principles, has elevated the scope for students to explore in-depth design and optimisation of various prototypes, dipoles, patch antennas, slot antennas, monopoles, loop antenna, linear arrays, and phased arrays.

We wanted to remove the complexity of theory and focus on real application to support students in developing knowledge and skills favourable to industry.

On reflection, these sessions offer students a holistic view of the antenna design process, mirroring real-world engineering practices and preparing them for future careers. Furthermore, students gain valuable simulation experience, enhancing their employability prospects. Ultimately, the well-structured blended teaching activities embracing the complexity of the theory in a practical setting have increased students' understanding of the subject renowned for its complexity. This is reinforced by the fact that students' attendance increased, and they demonstrated increased interest in the subject by asking creative questions and attempting the quizzes with more than 70% answering the questions correctly.

3 RESULTS

By adopting this technique in teaching, it was observed that students' attendance to the lectures and the subsequent hands-on sessions has increased as compared to other modules taught by the instructor that were delivered using a traditional teaching model. Furthermore, students could make immediate sense of the theory as teaching progressed from discussing simple antennas, such as dipoles, to complex antenna arrays. This instant feedback has given us confidence in the effectiveness of this teaching approach, and we proceeded to design a survey to explore students' opinions and feelings about how they perceived this teaching method. Additionally, students were prepared for their formative assessment through Blackboard asynchronous activities, in-class quizzes, and in-person workshops on CST using antenna design principles to deepen students' understanding. Formal assessment is done in two stages where students sit an online multiple choice and calculation questions text - this aims to examine their basic understanding of the concepts taught in electromagnetics and antennas. This is followed by an in-person invigilated exam where students address problem-solving questions that examine their understanding and engineering skills to design and evaluate antenna performance.

Therefore, an ethically approved survey was administered to a cohort of 102 graduate students, yielding responses from 32 participants. The survey was given to students towards the end of teaching in week 12. It was anonymous, and students were informed that this would not influence their final outcomes in the module. In addition, the survey was sent to students of all abilities, and given it was anonymous, the authors had no influence on who responded or not. When asked whether the hands-on CST simulation session has complemented the traditional lectures, 56.3% of students positively responded that CST simulations significantly enhanced the lectures, attributing their improved understanding of the subject to the 3D visualisation capabilities, as shown in Figure 3. However, 15.6% of the respondents have chosen "To some extent" to answer the same question. This can be improved by mentioning in the lecture how the upcoming simulation activity is relevant to the covered topic.

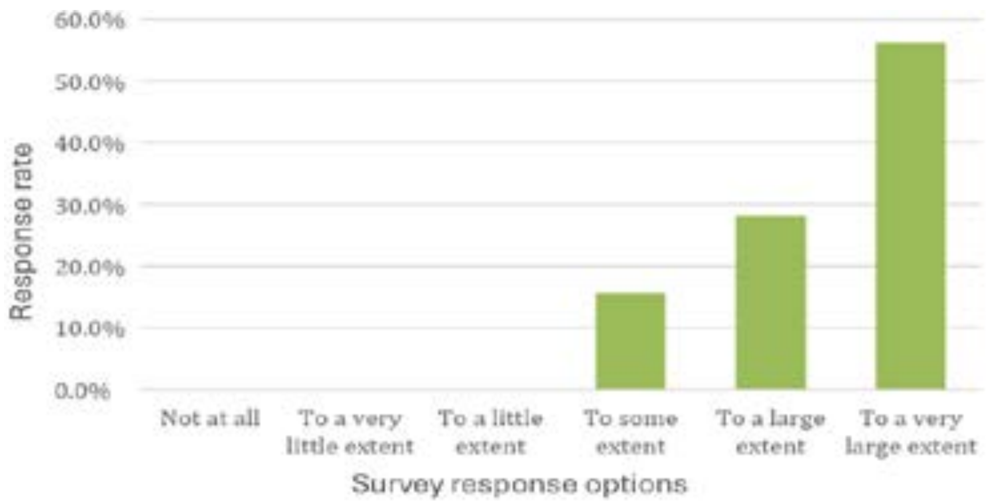

Figure 3 Student's response to the question, "To what extent did you find the CST simulation sessions complement the lectures?"

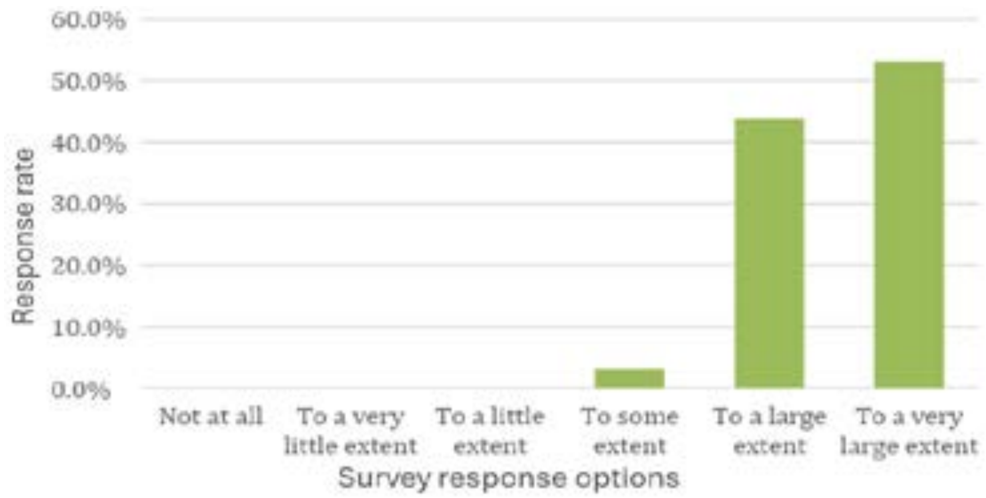

Figure 4. Students' response to the question, "Learning commercial computer simulation skills is a valuable skill for my future career pathway."

Furthermore, exploring students' anticipation on the value of learning a commercial simulation tool within their degree programme, from an employability perspective, a significant majority of respondents, accounting for 97%, affirm the critical importance of the simulation skills acquired during the course to boost their technical and transferable skills and enhance their future professional endeavours, as shown in Figure 4. It was reassuring to ensure that students continue receiving the best teaching and learning value to meet their expectations and career goals.

In the authors' experience, students avoided antenna-based design projects in the past due to the topic's complexity. However, after adopting a research-led teaching approach educating students to design methodologies of antennas in relation to cutting edge technological challenges, in which computer simulations represent a crucial element, students started to take the initiative in requesting antenna design topics for their MSc final year projects, as observed by the authors of the paper. The CST simulation sessions boosted the students' confidence and improved their practical experience with antenna design techniques. A few students took a further step by pursuing PhD studies on antennas. This is confirmed by the responses to a survey question on whether introducing the CST training session within the module has increased students' confidence in pursuing antenna design projects, as demonstrated in Figure 5, where 84.4% of the responses agree to a large, or very large, extent. However, 12.5% agree to some extent, and 3% agree to a very small extent when asked the same question. In the future, additional support will be offered to students who feel less confident with the simulations.

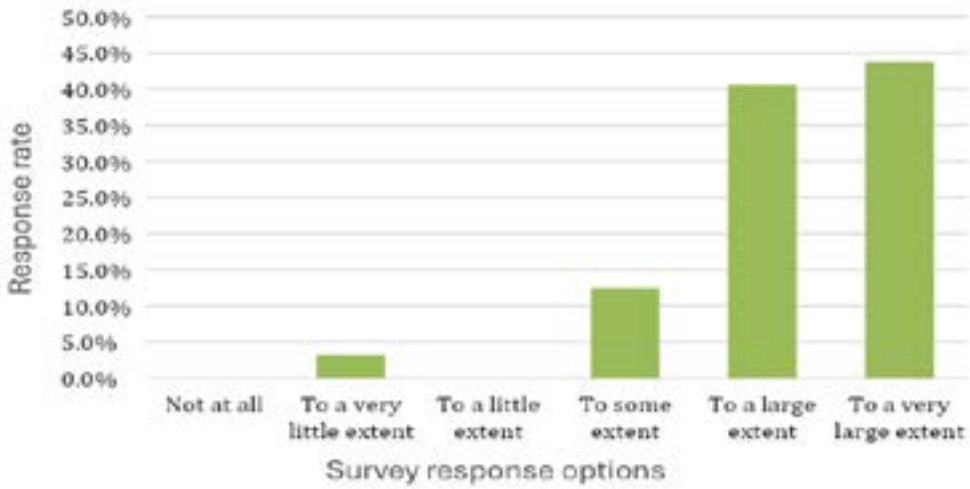

Figure 5 Students' response to the question, "The CST training has made me more confident to conduct antenna related projects."

In addressing the survey question, "Can you provide feedback on the most beneficial or engaging aspect of the CST demonstration sessions?", a prevalent response highlighted the value of the step-by-step guidance provided throughout the sessions. This was frequently cited as instrumental in facilitating comprehension and engagement. Additional comments highlighted the effectiveness of the simulations in clarifying theoretical concepts, fostering interactive learning experiences, and imparting practical skills. As for the question, "What knowledge or skills did you gain from CST antenna visual prototyping?" respondents agreed on acquiring the ability to imagine the radiation from an antenna, deepening their understanding, and linking theory to practice, in addition to offering a different perspective to students with limited 3D imagination capabilities.

4 Summary and acknowledgements

This study demonstrates the efficacy of integrating computer simulation sessions, particularly utilising the CST Microwave Studio, into antenna teaching for postgraduate students. By incorporating these sessions alongside traditional lectures, and immersing students in activities that involve designing, constructing, and analysing antennas, they gain a deeper understanding of complex theoretical principles. Moreover, engaging in hands-on experimentation and problem-solving tasks allows students to bridge the gap between theory and practice, thereby solidifying their comprehension and retention of electromagnetic concepts. The utilisation of 3D visualisation tools aids in simplifying complex concepts, fostering deeper understanding, and enhancing student engagement. The survey results indicate a positive response from students, with the majority acknowledging the value of simulation-based learning in improving their confidence and employability prospects in antenna-related projects. Additionally, feedback from students highlights the importance of step-by-step guidance during simulation sessions and the acquisition of skills in imagining antenna radiation patterns, further underscoring the effectiveness of this teaching approach in bridging the gap between theory and practice.

Furthermore, transforming teaching methodologies to integrate theory with practice yields profound benefits beyond academic realms. By cultivating a learning environment that emphasises application and real-world relevance, students develop technical engineering skills and invaluable transferable skills such as critical thinking, problem-solving, and teamwork. These skills are indispensable for success in the workplace, where engineers are required to navigate complex challenges and innovate solutions effectively.

We sincerely appreciate the graduate students who participated in this study and offered invaluable feedback. Their input played a pivotal role in shaping the development and execution of the computer simulation sessions. Additionally, we gratefully acknowledge the support and guidance provided by Dr. Salam Khamas throughout the entirety of the sessions.

REFERENCES

Anderson, N. "A New Approach in Teaching Electromagnetism: How to Teach Electromagnetics to All Levels from Freshman to Graduate and Advanced-Level Students." In Proc. Of the 2003 American Soc. For Eng. Edu. Annu. 8.82.1- 8.82.17

Beker, B., D. Bailey, and G. J. Cokkinides. "An Application-enhanced Approach to Introductory Electromagnetics." IEEE Transactions on Education 41, no. 1 (January 1, 1998): 31–36. https://doi.org/10.1109/13.660785.

Cole, R. W., E. K. Miller, S. Chakrabarti, and S. Gogineni. "Learning About Fields and Waves Using Visual Electromagnetics." *IEEE Transactions on Education* 33, no. 1 (January 1, 1990): 81–94. https://doi.org/10.1109/13.53631.

De Los Santos Vidal, O., R. M. Jameson, M. F. Iskander, A. Balcells, and J. C. Catten. "Interaction and simulation-based multimedia modules for electromagnetics education." *FIE Proceedings*, December 24, 2002. https://doi.org/10.1109/fie.1996.567758.

Dori, Y. J., E. Hult, L. Breslow, and J. W. Belcher "How Much Have They Retained? Making Unseen Concepts Seen in a Freshman Electromagnetism Course at MIT." *Journal of Science Education and Technology* 16, no. 4 (August 10, 2007): 299–323. https://doi.org/10.1007/s10956-007-9051-9.

Excell, P. S. “Computational Electromagnetics in Education at the University of Bradford, England.” *IEEE Transactions on Education*, May 1,1993.

https://doi.org/10.1109/13.214703.

Fàbrega, J. M., S. Sanz, and F. I. Magdy. “New software packages and multimedia modules for electromagnetics education.” *Proc. IEEE Antennas and Propagat. Soc. Int. Symp*, November 27, 2002. https://doi.org/10.1109/aps.1998.701767.

Iskander, M. F. “Computer-based Electromagnetic Education.” *IEEE Transactions on Microwave Theory and Techniques* 41, no. 6 (January 1, 1993): 920–31.

https://doi.org/10.1109/22.238505.

Iskander, M.F. “Technology-based Electromagnetic Education,” *IEEE Transactions on Microwave Theory and Techniques* 50, no. 3 (March 1, 2002): 1015–20, https://doi.org/10.1109/22.989985.

Popović, M., and D.D. Giannacopoulos. “Assessment-based Use of CAD Tools in Electromagnetic Field Courses.” *IEEE Transactions on Magnetics* 41, no. 5 (May 1, 2005): 1824–27. https://doi.org/10.1109/tmag.2005.846493.

Sevgi, L. “A New Electromagnetic Engineering Program And Teaching Via Virtual Tools.” *Progress in Electromagnetics Research B* 6 (January 1, 2008): 205–24. https://doi.org/10.2528/pierb08031103.

Talele, S. “Teaching Electric Field Topic With Computer Visualization.” *International Conference on Education and New Learning Technologies*, January 1, 2014, 3647–50, https://researchcommons.waikato.ac.nz/bitstream/handle/10289/9287/1868.pdf;sequence=1.

Trlep, M., A. Hamler, M. Jesenik, and B. Štumberger. “Interactive Teaching of Electromagnetic Field by Simultaneous FEM Analysis.” *IEEE Transactions on Magnetics* 42, no. 4 (April 1, 2006): 1479–82.

https://doi.org/10.1109/tmag.2006.871437.

IMPROVING ACCESS AND PARTICIPATION of WOMEN TO ENGINEERING RESEARCH

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***Conference Key Areas**: 1) Diversity, equity and inclusion in our universities and in our teaching and 2) The attractiveness of engineering education*
***Keywords**:* women in engineering, equality, diversity, inclusion

ABSTRACT

Research and innovation thrive on diversity, enhancing collective performance (UKRI, 2023). The All-Party Parliamentary Group (APPG) on Diversity and Inclusion in STEM highlighted that the STEM workforce is less diverse than the broader workforce, leading to underrepresentation of minoritized groups such as Black people, women, disabled individuals, and those from the LGBTQ+ community (British Science Association, 2021). According to Engineering UK's Equality, Diversity, and Inclusion (EDI) strategy, only 12% of the engineering workforce is female, compared to 51% of the working-age population (Engineering UK, 2019). At the University of Warwick, our data analysis revealed that females at the postgraduate research (PGR) level are underrepresented in engineering, though the gender balance is more equitable at the postgraduate taught (PGT) level. To address this disparity, we launched the "Improving Access and Participation in Engineering Research (IAPER)" project. This internship program targeted undergraduate and

PGT female students to enhance their participation in engineering research, aiming to improve gender balance in PhD and postdoctoral populations. We offered research internships to 20 female students, who completed an 8-week program under the mentorship of leading academics (IAPER interns, 2023). Additionally, we hosted three events featuring successful women in industry and academia, who shared their experiences and success stories with the UG and PGT female students (IAPER Lecture Series, 2023). Student feedback was collected through video snippets and project reports, with a reflective section on their internship experiences. The feedback was overwhelmingly positive, with strong recommendations to continue such programs in the future (IAPER overview, 2023).

1 INTRODUCTION

Engineering serves as the cornerstone of innovation and invention. In 2021, women accounted for 16.5% of the engineering workforce in UK, marking a notable increase from 10.5% in 2010 (Engineering UK, 2020). However, when we compare this figure to the overall workforce, where women comprised 48% (Engineering UK, 2022), it becomes evident that substantial efforts are required to attain gender parity within the engineering field. Notably, the highest proportion of women in engineering were observed in the category of 'Associate Professional and Technical Occupations' at 32%, gradually decreasing with seniority to 22% in 'Professional Occupations' and 15% in 'Managers, Directors, and Senior Officials’ (Engineering UK, 2022).

In an Education Development Trust report (EDT, 2023), it was emphasized that while significant progress has been made since the days when explicit social and gender-based barriers limited women's opportunities, there are still prominent gender-related disparities in practical outcomes. For instance, despite more women now participating in higher education (HE), men still constitute 80% of students in technology and engineering fields at this level. It was acknowledged that careers information, advice, and guidance alone cannot be seen as a panacea for rectifying these imbalances. However, this should be integrated into the overall strategy for addressing these disparities. It was also mentioned for the active involvement of career professionals starting from early years education and continuing throughout the education system. This involvement would serve the purpose of ensuring that young individuals are aware of the diverse opportunities available to them and creating more pathways for young women (EDT, 2023).

Female under-representation in engineering is not unique to the UK but it is a global issue. The World Economic Forum's Global Gender Gap Report (Piaget et. al. 2024) indicates that, based on LinkedIn data, women's representation in STEM and non-STEM workforces has grown since 2016. However, women still remain underrepresented in STEM roles, making up only 28.2% of the STEM workforce compared to 47.3% in non-STEM sectors. Overall, women's workforce representation is below men's across almost all industries and economies, with women constituting 42% of the global workforce and 31.7% of senior leaders (Piaget et al, 2024).

A study by (GenderInSITE , 2021) surveyed 120 national science academies and disciplinary associations globally, revealing persistently low female representation in science from 2015 to 2020. In the U.S., although women's representation in the

National Academy of Sciences increased from 13% to 19%, women still make up less than one-fifth of its members.

To address the growing demand for engineers in the future, it is imperative that the engineering workforce becomes more diverse and attracts a greater number of women to the field. A rapid evidence review (RER, 2023) has highlighted various strategies to enhance the aspirations and interest of girls in STEM careers. These strategies range from the presence of relatable role models to fostering a nuanced understanding of the limitations associated with the binary concept of gender. Similarly, the American Association of University Women (AAUW, 2021) has listed some problems indicative of the underrepresentation of women in STEM:

1. Gender Stereotypes: STEM fields are frequently associated with masculinity, leading teachers, and parents to underestimate girls' mathematical abilities from a very young age, often starting in preschool.
2. Male-Dominated Cultures: Reflective of the lack of female representation, patriarchal cultures tend to dominate both STEM education and professions. Such cultures result in an environment that is not conducive to supporting or attracting women and minority individuals.
3. Limited Role Models: Young women have access to fewer role models who can inspire their interest in STEM disciplines. There are few examples of female scientists and engineers to be found within contemporary popular culture, including on social media. Notably, the representation of Black women role models in mathematics and science is particularly scarce.
4. Maths Anxiety: Many teachers struggle with maths anxiety, which they inadvertently transmit to their young female students. This can result in girls receiving harsher grading than boys for equivalent work under the misguided belief that girls must exert more effort to achieve parity with boys.

Considering the literature and the statistics the paper authors proposed an internship programme specifically targeted at female undergraduate (UG) and postgraduate (PG) students. This Programme was entitled “Improving Access and Participation to Engineering Research (IAPER)”. The main aim of IAPER programme was to provide opportunities for young women students to experience first-hand what it is like to take part in ‘real-life’ research projects; the aim was to improve the gender balance across Engineering & Applied Science PhD and Post-Doctoral populations.

The paper is arranged in the following order, Section 2 explains the methodology, Section 3 includes the comments given by IAPER interns followed by the lesson learnt. The summary and acknowledgements are presented in Section 4.

2 METHODOLOGY

The first stage of the project involved completing background research that comprised a statistical analysis of student-data pertaining to the PGT, PGR and UG populations. This initial analysis evidenced the arguments regarding gender imbalances and a lack of female representation amongst our student body. The results of this analysis revealed that the difference in the proportion of male and female PGT students is more balanced than at PGR level (Figure 1) confirming that the Internship Programme was not only timely, but it was also much needed to improve the gender balance in the engineering departments. The percentages in Figure 1 are derived from Figure 2, which details the exact numbers of white and BAME (Black, Asian, and Minority Ethnic) male and female students across WMG and School of Engineering(SoE) departments. Figure 2 highlights that BAME representation in PGT programs is significantly higher than that of white students. However, since this study focuses on gender balance, we combined the male and female populations of UG, PGT, and PGR students (regardless of ethnicity), as shown in Figure 1.

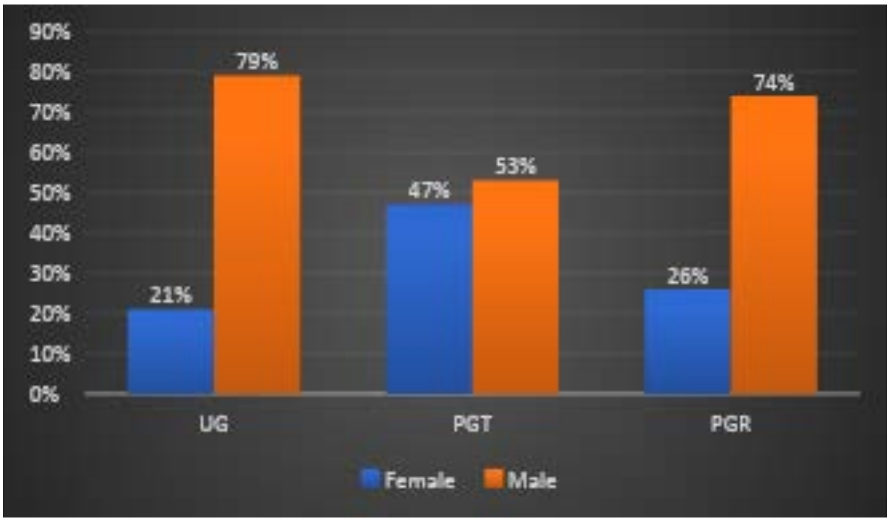

Figure 1: Percentage split by gender for UG, PGT and PGR students enrolled in academic year 21/22, collectively in both WMG and School of Engineering

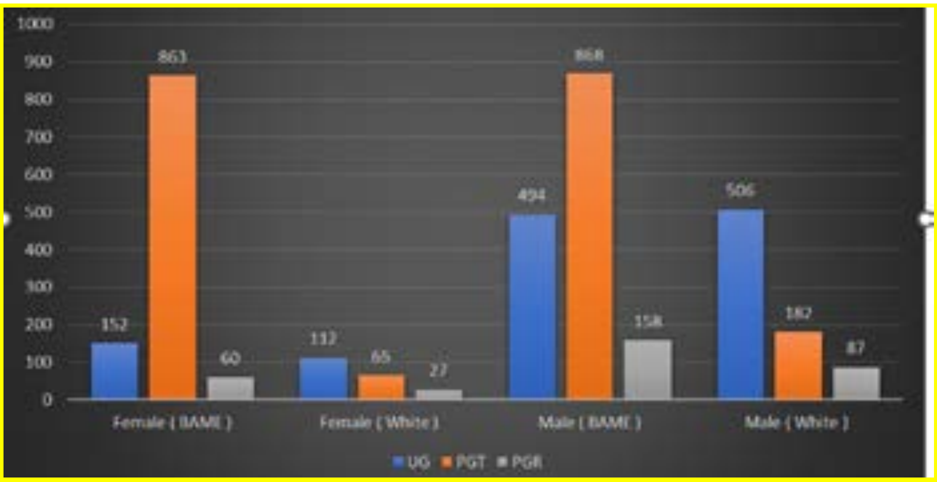

Figure 2: Exact number of male and female students by gender and ethnicity for UG, PGT and PGR students enrolled in academic year 21/22, collectively in both WMG and School of Engineering

In accepting students onto the IAPER Programme precedence was given to female students from low socio- economic backgrounds or who had a learning or physical disability. We gathered this information via the application process of the internship and made this field optional, so that if someone was comfortable to give more information about themselves, they could do.

The IAPER Internship scheme offered 20 research internships of 8 weeks total duration between April-July 2023 to UG and PGT female students from the Faculty of Science, Engineering, and Medicine (SEM). Internship carried a stipend of £1750 per intern. The initial step was to invite project supervisors in both engineering department at the University of Warwick (School of Engineering (SoE, 2024) and Warwick Manufacturing Group (WMG, 2024)) research groups to propose project ideas. The internships were all linked to or relevant to actual research projects being undertaken within these groups and cover broad areas from sustainability to systems engineering and machine learning. Some of the projects include: 1) Role of life cycle assessment in achieving circular economy, 2) Learning to manufacture electric machines- industry workshops development, 3) Systems engineering tools for next generation engineering biology and 4) Implementation and deployment of machine learning algorithm on edge devices (IAPER projects, 2023).

A window of 1.5 months was allocated for prospective interns to apply. The application process involved students uploading their CV, explaining their research interest, and (optionally) providing a statement about why they identify as underrepresented in engineering The Internship Management Team reviewed the applications to ensure the criteria for application were met. Project supervisors made a final choice on who to award the internship for their project, based on those who have selected the project and have met the application criteria.

The recruited interns, who were studying in several different disciplines including Mathematics, Computer Science, Physics and Engineering, were all given an engineering-focused, research-based internship. Completion of the internship was flexible to fit with students' academic workloads (e.g. one day per week during term time, with full time attendance during vacation periods).

2.1. Raising the Profile of Women in STEM

In parallel with the internship scheme, we organized a series of invited guest lectures, with speakers from underrepresented backgrounds who each shared their journey in engineering (and associated) research careers. The lecture series was open to all SEM Faculty students and staff, impacting IAPER's reach beyond the 20 interns. Four events were held over a six-month period concluding in the summer of 2023:

- **Speaker 1**: An award-winning data leader currently working in the Technology and Artificial Intelligence (AI) space. This speaker is the Senior Director of Advanced Analytics at an AI-driven company that fuels intelligent customer engagement in the life sciences industry. She provided excellent examples of how resilience and hard work can help anyone to excel in the career.
- **Speaker 2:** A Chemical Engineer working in the Climate Change and Environment Studio this speaker leads on Circularity and Sustainable Supply Chain ventures: building innovation concepts, pilots and corporate ventures across startups, accelerators, and private sector to decarbonize manufacturing and supply chains. She provided an in-depth account her experience during field work which was dominated by men and how she tackled the obstacles and took actions to make workplace inclusive.

- **Speaker 3:** A Senior Consultant and a Chartered Mathematician working across a major UK Construction Management s Advisory Services Portfolio. Specializing in data in the civil engineering sector and transport-related asset management across 10 years in the engineering sector. Her career journey was inspiring on one end but given she delivered the talk while she was on maternity leave showed audience her commitment towards her field and her continuous effort to help others.
- **Speaker 4:** A Defense Innovation Consultant who previously headed up the industry, technology and innovation team at a public policy think tank. A member of the IET design and manufacturing policy panel, the speaker was a member of the UK manufacturing symbiosis network plus advisory board and Make UK equalities working. She gave interesting perspective as in how one can engage with policy makers by explaining the tips and tricks to ensure voice is heard.

The speakers, all women from ethnic minority backgrounds, have not only navigated workplace politics but also confronted societal stereotypes often attached to women from disadvantaged backgrounds while advancing in their careers. The lecture series attracted not only students but also staff members, all of whom found the insights shared by each speaker valuable.

3 IAPER: LONGTERM OUTCOMES

Following the internship students were asked to reflect upon their internship and their future aspirations, particularly in relation to whether they might consider engaging in research in future. In this section, the views of the interns have been divided into four main themes: soft skills, technical skills, inspirational talks and career aspirations. Each section also includes verbatim quotes from the evaluation.

Soft Skills development:

The majority of the students have said that research internships improved their soft skills. Intern 1 stated that her professional skills and communication skills were improved through completion of set tasks, delivering presentations, and developed understanding of the workplace environment through observation and interaction with those around her. Intern 2 mentioned that internship helped her to understand the operation of real-life projects and how they are managed (workplace dynamics, inspiration and tips), particularly through the opportunity to sit in on Weekly Catch-up Meetings. Intern 2 also found that internship helped her to experience how to document and keep up to date on different aspects of the project through using a tracker and the importance of bringing people who may not be directly involved but are knowledgeable on the subjects and have additional expertise to aid in the project's development. Intern 3 stated that the internship has helped her to improve herself confidence in terms of her ability to produce work and that she can excel in STEM research. Majority of students mentioned that imposter syndrome and self-doubt are some of the feelings they have been combatting during their time in the university and this internship has shown them that they can indeed excel in the workplace and that they had the capabilities to do so. Similarly, Intern 4 stated that she was able to explore those fields using internships which wouldn't have otherwise crossed paths and the internship has made her more inclined to apply to similar opportunities, building both skillset and confidence.

It is important to note that despite the technical nature of the internships, it was clearly observed that all of the interns were able to develop several transferable skills from participating in the programme. .

Technical Skills:

One of the aims of this internship programme was about the exposure to state of art technical labs and facilities so that they can see for themselves what a research career would look and felt like. By working in such facilities, students were able to develop technical skills.

The student interns on variety of projects and developed technical capabilities in their interest. Intern 1 stated that although her degree is in physics, she was able to learn about electric machines and how they work. This has increased her knowledge about the electrical and electronic side of research and science. This student also noted that whilst completing the internship, the intricacies of delving into data, identifying trends, and drawing meaningful conclusions piqued her curiosity and passion.

Intern 2 described how she has managed to learn a new 3D printing technique in some depth. She also talked about how gaining hands-on experience, whereby she had the opportunity to dive into the exciting field of computer graphics and digital twins, she learned much.

Intern 3 had the opportunity to delve into the realm of sustainability and environmental impact assessment as part of the internship. As a computer sciences student, sustainability was initially unfamiliar to this intern, but she quickly realized its significance and relevance in today's world. She gained a comprehensive understanding of the challenges faced by these countries in collecting, managing, and utilizing data for sustainable decision-making. The literature review broadened her horizons and introduced her to various concepts, methodologies, and strategies employed in LCA research.

Inspirational talks:

Guest lectures played a key role in enabling students to make connections to the successful women in academia and industry. The majority of the students enjoyed the inspirational guest lecture series and described how they took away many positive points. Intern 1 shared that hearing the inspirational talks of incredible women from different stages in their career journey was enlightening. Intern 2 told how she was really encouraged by how each guest speaker overcame their challenges and worked towards finding opportunities to further develop their capabilities and skills. Similarly, Intern 3 mentioned that beyond her individual research project, the remarkable impact of the IAPER scheme was that is fostered an inclusive and empowering environment through its guest lectures and emphasis on community.

Career aspirations:

Most of the students mentioned that they have decided to pursue research as a career as an outcome of the internship programme. Intern 1 recalled how the internship provided her with a great insight to the running of a real-life project; she continued to discuss how the programme made her aware of what a career related to research may be like giving her better knowledge of the potential pathways she can take in the future. Likewise, intern 2 stated that after the internship, she is considering further study and career options related to research. This is something she has never previously considered it as she thought it was something one could only do after a few years in industry. She found the environment of learning and intellectual growth to be enjoyable as the focus was to improve oneself rather than just deadlines and results.

Intern 3 also described how she has learned that industrial research is more interesting and that it's practical nature means it can be applied in the next few years.

Intern 4 discussed how she learnt a lot about prioritisation and flexibility whilst working on a research project. She started research internship during the final term of her first year at the University, a time when she had exams and coursework to attend to. In this scenario, a research project like this provided her with the opportunity to adapt to the coming pressures and priorities, but also taught her that work cannot be left for a few weeks before the deadline to be completed.

Intern 5 shared the following: *"This internship was unlike anything else I have done before. I applied for this because I was intrigued to learn a different side to my scientific degree, I would like to continue to explore a future in research. I think there are many exciting projects and opportunities that research presents that other jobs do not, and the ability to create something really appeals to me. I plan to look for further internship posts, focusing on more mechanical engineering-based roles, so I can explore how my degree can connect to research.*"

Lessons Learnt and Conclusion

If this project were to be undertaken again, it would be advisable for students to showcase their project through either a poster presentation or a video summarizing the project outcomes and their reflections. Utilizing a poster or video format could enable them to effectively communicate their findings and experiences to a broader audience compared to a traditional written report.

The project team also intends to assess the viewpoints of the supervision and research groups in the future to determine if this project has influenced any stereotypes, biases, or attitudes within those groups. Additionally, the team observed that 25% of the interns were postgraduate (PG) students, while 75% were undergraduate (UG) students. Consequently, efforts will be made to devise strategies to attract more postgraduate students in future endeavours.

For the wider engineering education sector, the project team recommend that developing curriculum materials which are inclusive and highlight the contributions of women in engineering throughout history can help make engineering more relatable and accessible to young women. Also providing opportunities for young girls to engage with engineering concepts from an early age can help spark interest and confidence. This could include activities like coding classes, robotics clubs, or STEM-focused extracurricular programs. Providing scholarships and financial support specifically for female engineering students can help offset the cost of education and make engineering programs more accessible. By implementing these strategies and fostering a culture of inclusivity and equity, the engineering community can work towards improving access to engineering for female from all backgrounds, including those from working-class or poorer backgrounds.

4 Conclusion and Acknowledgements

This paper summarized the methodology and results of a project that was aligned to gender equality, diversity, and inclusion agenda at the University of Warwick. As a result of this project, 20 students identifying as female in the Faculty of Science, Engineering and Medicine at Warwick University were able to participate in research internships and got exposure to state of art engineering facilities present in both departments. As a long-term result of this initiative, we aim to achieve an increased number and diversity of students choosing to pursue engineering research at the University of Warwick. Also, we hope this scheme may be extended across the institution and potentially increase the diversity of those entering research.
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REFERENCES

American Association for University Women (AAUW). (2021), The STEM Gap: Women and Girls in Science, Technology, Engineering and Mathematics, .https://www.aauw.org/resources/research/the-stem-gap/

British Science Association (July 2021), Equity in the STEM workforce.,

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.britishscienceassociation.org/Handlers/Download.ashx?IDMF=3d51130a-458b-4363-9b2b-d197afc8382a

Engineering UK (2019), Equity, Diversity and Inclusion.

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.engineeringuk.com/media/232364/edi-strategy-final.pdf

Engineering UK (2021), Women in Engineering: trends in women in the engineering workforce between 2010 and 2021.

women-in-engineering-report-extended-analysis-engineeringuk-march-2022.pdf

Engineering UK (2022), Early perception and underrepresentation of women in engineering.,

https://www.engineeringuk.com/blog/early-perceptions-and-the-underrepresentation-of-women-in-engineering/

Education Development Trust (EDT). (July 2023). , APPG on Women and Workhttps://www.edt.org/news/edt-at-the-uk-s-all-party-parliamentary-group-on-women-and-work/

GenderInSITE (September 2021), Gender Equality in Science: Inclusion and Participation of Women in Global Science Organizations. Results of two global surveys.chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://genderinsite.net/sites/default/files/GenderEqualityInScience_TwoGlobalSurveys.pdf

IAPER interns. (July 2023).

https://warwick.ac.uk/fac/sci/wmg/education/internships/wmg_research_internships/iaper_internships/interns/
IAPER lecture series. (July 2023).

https://warwick.ac.uk/fac/sci/wmg/education/internships/wmg_research_internships/iaper_internships/guestspeaker/

IAPER overview.(July 2023)

https://warwick.ac.uk/fac/sci/wmg/education/internships/wmg_research_internships/iaper_internships/

IAPER projects. (July 2023).

https://warwick.ac.uk/fac/sci/wmg/education/internships/wmg_research_internships/iaper_internships/2023_projects/

P. Piaget, S. Baller, and S.Zahidi (June 2024), Gender gap report, World economic forum, https://www.weforum.org/publications/global-gender-gap-report-2024/digest/.

Rapid evidence review (RER). (2023), STEM Clubs and their ability to increase students aspirations for engineering and technology careers. https://www.engineeringuk.com/research-policy/provision-outreach/rapid-evidence-reviews/

School of Engineering (SoE). Feb 2024https://warwick.ac.uk/fac/sci/eng/

UKRI (July 2023). Addressing under-representation and active participation,

https://www.ukri.org/what-we-do/supporting-healthy-research-and-innovation-culture/equality-diversity-and-inclusion/addressing-under-representation-and-active-participation/

Warwick Manufacturing Group (WMG). (Jan 2024), https://warwick.ac.uk/fac/sci/wmg/

“*I’VE LEARNED THAT BEHIND EVERY HEADLINE THERE IS A HUMAN WITH THEIR STORY*”: GEARING UP ENGINEERING DESIGN PROJECTS FOR NURTURING EMPATHY

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***Conference Key Areas**: Educating the whole engineer: teaching through and for knowing, thinking, feeling, and doing; Engineering skills, professional skills, and transversal skills.*
***Keywords**: empathy, design, project-based learning, multidisciplinary, intercultural.*

ABSTRACT

Engineers are not only problem solvers but also individuals with social responsibilities and ethical considerations. Incorporating empathy into engineering education goes beyond imparting technical skills; it involves fostering the holistic development of individuals. In this practice paper, three courses tailored to their unique institutional and subject contexts yet unified by a shared objective of fostering empathy through design education are described: two courses offered at one higher education institution in North America and one course offered in Europe. The courses are centred on the principles of design thinking and project-based learning, providing students with a structured framework to tackle complex societal challenges. Taken together, the courses demonstrate the wide adaptability of this pedagogical approach across educational levels, institutions, countries, themes, and disciplines.

1. Background and rationale

1.1 Empathy

Empathy is the ability to understand and share the feelings of others. It involves putting oneself in someone else's shoes, seeing the world from their perspective, and experiencing their emotions as if they were one's own (Davis 1994), “the ability to understand people by perceiving or experiencing their life situations” (Segal 2011, 267). This capacity for empathy is fundamental to human connection and lies at the heart of meaningful relationships, communication, and understanding. It allows individuals to recognize and respond to the needs of others, fostering compassion, kindness, and cooperation in both personal and social contexts.

In the realm of education, empathy plays a crucial role in creating a supportive and inclusive learning environment. When educators cultivate empathy within themselves and encourage its development among students, they promote a sense of belonging and mutual respect within the classroom (Borba 2018). By understanding students' diverse backgrounds, experiences, and emotions, teachers can tailor their instruction to meet individual needs and provide appropriate support. Moreover, empathy helps educators to address conflicts and behavioural issues with patience and understanding, rather than resorting to punitive measures (Kohn 1996). In this way, empathy fosters a positive and nurturing educational atmosphere where students feel valued, understood, and empowered to learn and grow. Additionally, by modelling empathetic behaviour, educators instil in students the importance of empathy in their interactions with peers and in their future endeavours, preparing them to become compassionate and socially responsible members of society (Noddings 2013). Thus, empathy serves as a cornerstone of effective teaching and learning, nurturing not only academic success but also the holistic development of individuals as empathetic and empathic beings (Hoffman 2000).

1.2 Empathy in Engineering Education

Empathy is an essential skill in engineering education that goes beyond technical expertise. Moreover, it is a learnable skill, a practice orientation, and a professional way of being (Walther, Miller and Sochacka 2017). As engineers design solutions to address real-world problems, they must understand the needs, perspectives, and experiences of the individuals and communities they serve (Rasoal, Danielsson and Jungert 2012). Empathy enables engineers to approach challenges with a human-centred mindset, considering not only the technical feasibility of their solutions but also their impact on people's lives (Dym and Agogino 2005). By empathizing with end-users, engineers can design products, systems, and technologies that are more inclusive, accessible, and responsive to diverse needs and contexts (Cross, 2011).

In engineering education, fostering empathy involves integrating interdisciplinary perspectives, social awareness, and ethical considerations into the curriculum. Through project-based learning, collaborative activities, and engagement with stakeholders, students can develop a deeper understanding of the societal implications of engineering solutions and the importance of empathy in the design process (Hess and Fila 2016; Crespí, García-Ramos and Queiruga-Dios 2022). Additionally, incorporating case studies, role-playing exercises, and experiential learning opportunities can help students cultivate empathy by immersing themselves in the lived experiences of others. By emphasizing empathy alongside technical skills, engineering education prepares future engineers to tackle complex challenges with compassion, empathy, and a commitment to creating a positive social impact.

1.3 Empathy and educating the whole engineer

Teaching empathy to engineering students is not merely about instilling a technical skill; it is about nurturing the development of the ‘whole person’. By incorporating empathy into engineering education, we recognize that engineers are not just problem solvers but also individuals with social responsibilities and ethical considerations (Noddings 2013). Empathy education encourages students to engage with the world around them in a holistic manner, fostering qualities such as compassion, humility, and cultural sensitivity. As engineering projects increasingly intersect with diverse communities and global challenges, empathy equips students to navigate complex socio-technical landscapes with a deeper understanding of human needs and values. By educating the ‘whole person’ through empathy, we empower engineers to create innovative solutions that are not only technologically sound but also ethically grounded and socially impactful (Bairaktarova, 2022). Moreover, empathy skills are transferable skills that students can apply across various domains, enriching their personal and professional endeavours beyond the realm of engineering.

2. Education contexts

In this paper we present three contexts in which empathy education was integrated into existing courses offered during the academic year 23-24 at two higher education institutions in North America and Europe: 1) Foundations of Engineering, 2) Create! Ideation and Innovation, and 3) Biomedical Engineering. Each of the three courses is tailored to its unique institutional and subject context yet unified by a shared objective of fostering empathy through design education and educating the ‘whole engineer’. Embracing a project-based approach, all courses centre on the principles of design thinking (Brown 2009; Elmansy 2021), providing students with a structured framework to tackle complex challenges. Central to this methodology is the recognition of stakeholders' perspectives, which are integrated into the design process to ensure solutions are both inclusive and responsive. This approach encourages students to actively reflect on the impact of engineering design on the community (Ropers-huilman, Crwile, and Lima 2005) and has been widely promoted in service learning in engineering education (Hess and Fila 2016). Activities aimed at fostering empathy are woven throughout the curriculum, emphasizing perspective-taking exercises to encourage students to empathize with diverse user experiences and needs.

Moreover, the courses adopt a solution-oriented approach, guiding students towards the creation of tangible outcomes that address identified challenges while also considering the broader societal context. Through this practice paper, we aim to illuminate commonalities and differences in the implementation of empathy-focused design education across diverse institutional and subject contexts, shedding light on effective pedagogical strategies for nurturing empathetic, whole engineer practitioners.

3. Design projects – courses curricula

3.1 Foundations of Engineering – First-year engineering course (USA)

Foundations of Engineering is a project-based course in which students explore different parts of the design process and different software tools used in engineering work. The project is tailored to help students develop various engineering skills and utilize tools to solve design problems. Through working on the semester-long project students build on their proficiency in implementing the engineering design process (Dym et al., 2005) and communicating engineering decisions to technical managers, along with contributing effectively to an engineering team and evaluating the ethical implications of engineering solutions. Working in a team of four to deliver a tangible solution on a “choose your own adventure project” students are enabled to apply the design process practically and innovatively, setting the stage for the kind of real-world challenges they will encounter in their engineering career. While the challenges provided through the open-ended project are designed to ignite students’ creativity, the main challenge students face lies in conceptualizing something profoundly personal or globally impactful. For this, building on the skill of empathizing in the design process becomes a medium in this course. Students engage with empathy during the semester in structured activities, such as 1) Empathy Walks: Students spend time in public spaces, such as the campus or their local community. Observing everyday challenges faced by various individuals can lead to enlightening design opportunities; 2) Talk to Others: Students engage with potential users or peers, understanding their daily struggles or unmet needs. Direct conversations can often highlight pain points overlooked in everyday life; 3) Gap Analysis: Students investigate existing solutions in the team’s area of interest. What is lacking? What could be improved or streamlined? Finding these gaps can lead to significant innovation; 4) Cross-industry inspiration: Students realize how a method or technology from one domain might be ground-breaking in another. Can the team repurpose a strategy or tool from an entirely different field to create something novel?; 5) Current Events & Global Goals: Students explore contemporary issues, news, or the United Nations' Sustainable Development Goals. Designing solutions to address these urgent challenges can be both impactful and fulfilling. At the end of the semester, students present their project deliverables to a variety of the projects' stakeholders.

3.2 Ideation and Innovation – Undergraduate multidisciplinary course (USA)

This course is part of an Innovation Minor and is designed to lead students through the process of creative inquiry, design, and collaboration to explore the intersection of art, science, and design. To identify these ties, students engage in activities that build participation and questioning strategies for workshops and lectures, problem finding, analogical and metaphorical thinking, and collaboration in multiple formats. The students work in teams of four on a semester-long project where the instructor chose to challenge the teams with the intricacies of addressing global issues without the allure of tangible (physical) outcomes. As the purpose of the course is to improve quality of life through collaborative, integrative, innovative design, the instructor deliberately designed the course to challenge traditional boundaries, urging students to delve deeper into interdisciplinary collaboration and navigate the complexities of global issues (e.g., earthquakes, floods, geopolitical conflicts, inequality employment issues). Empathy in this course is a core value and students engage in empathy activities through a structured curriculum. For example, every class time, there is an activity focused on fostering empathy towards the user (e.g., Human-Face activity, empathy map, data gathering, etc.) and students are tasked weekly to reflect on these activities and how their learning of empathy techniques applies to their project and their daily life. With this structured curriculum, the instructor aims to equip students with skills that transcend disciplines and empower students to tackle challenges with empathy, creativity, and collaboration – the essence of the course. Representatives of the local town community and the general education faculty and administration attend the final presentations at the end of the project and act as judges to select the top three project solutions.

3.3 Biomedical Engineering – Master course (Belgium)

Biomedical Engineering is a project-based course which focuses on design thinking in the field of biomedical engineering. The students work in teams of three to five during seven full-day sessions spread out over a semester. This setup allows the students to build up a strong team bond and allows for sufficient incubation time between the sessions for the topic to mature. The project revolves around a real-world problem chosen from a bank of research questions that were submitted to the university by civil society stakeholders. For instance, in '23-'24 the manager of a horse owners' association raised their grave concerns about an equine chronic liver disease that is assumedly caused by ragwort poisoning and asked the students to come up with solutions. Students first familiarize themselves with diverse perspectives on these authentic issues through various learning activities. After identifying, analysing, mapping and prioritizing all stakeholders involved (Taylor and Bancilhon 2019), the students develop personas ('avatars') for each stakeholder group. In this way it is no longer sufficient to consider stakeholders in the abstract; instead, students get into a character, and they gain an insider ('emic') understanding of how the issue at hand can impact individual members. They also engage directly with various representatives from the work field and conduct an in-depth study of the scientific state-of-the-art. This phase of the course encourages teams to look at the challenge from various perspectives before converging on their specific problem statement. This initiates a new ideation phase in which each team thinks up multiple approaches for addressing the problem by putting themselves in the stakeholders' shoes, using perspective dialogue techniques (Hermsen, van Dommelen, and Hueso Espinosa 2023), such as figure storming, in which students brainstorm from the perspective of a stakeholder persona, and lateral thinking, for instance through the 'six thinking hats' activity (de Bono 1986). After selecting their specific design objectives, students create and recreate low-fidelity prototypes of their tangible solutions. Through user feedback, stakeholder interactions and cross-team discussions, students are given the opportunity to assess their initial prototype and (re-)create a modified version. In the final session of the course, students are invited to present their solutions to invited stakeholder representatives and engage once more in dialogue with them.

A comparison of the three courses' curricula, their shared similarities, and differences, is presented in Table 1.

Table 1. Comparison of the three courses' curricula

Features	Foundations of Engineering	Create!	Biomedical Engineering
Similarities	▫ Project-based course structured along design thinking process. ▫ Project outcomes are tangible. ▫ Instructors integrate empathizing activities in a scaffolded and purposeful way throughout the course. ▫ Culturally diverse student body. ▫ English is the medium of instruction.		
Differences	Compulsory course for all engineering majors. Bachelor level (first year). Class size: +/- 75. Dominantly male. Empathy is not an explicit theme.	Elective course taken by some engineering majors. Bachelor level (all years). Class size: +/- 30. Evenly distributed. Empathy is an explicit theme.	Compulsory course for biomedical engineering option. Master level. Class size: +/- 20. Evenly distributed. Empathy is an implicit theme ('professional competences').

	Physical Prototype.	Tangible outcome but not physical outcome.	Both – prototype and tangible outcome.

4 Discussion on the alignment of the three courses geared towards nurturing empathy

The alignment of the three courses towards nurturing empathy is evident through the inclusion of empathy-related activities and practical guidance on promoting empathy within the learning environment. Each course, catering to first-year, undergraduate, and graduate students, demonstrates a commitment to fostering empathy as an essential skill for engineering professionals. The courses provide practical guidance on how to cultivate empathy through various explicit and implicit means, such as role-playing exercises, case studies, and reflective discussions on real-world issues. This approach ensures that students not only understand the concept of empathy but also learn how to apply it effectively in their personal and professional lives.

Moreover, the adaptability of the work to diverse contexts is apparent since the activities can be easily tailored to the background and educational stage of the students, making it readily applicable in classrooms, universities, and other learning environments throughout the curriculum. The courses' emphasis on empathy also transcends disciplinary boundaries, making them suitable for international and interdisciplinary contexts. Whether students are studying engineering, social sciences, or humanities, the principles of empathy remain universally relevant and applicable.

Furthermore, the impact of incorporating empathy into engineering education is profound and far-reaching. By intentionally integrating empathy into project-based learning and design thinking courses, students develop a deeper understanding of human needs and perspectives. This not only enhances their ability to collaborate effectively but also equips them with the transversal skills needed to address complex societal challenges with empathy and compassion. Additionally, by fostering a culture of empathy within the engineering education community, these courses contribute to creating more inclusive and socially responsible engineering professionals, ultimately enriching the field of engineering.

5 Summary

In integrating empathy into the curriculum of engineering students, we transcend the mere imparting of technical skills to educate the whole person. By emphasizing empathy alongside technical expertise, we acknowledge the importance of emotional intelligence, ethical decision-making, and interpersonal skills in engineering practice. Engineering education becomes more holistic, nurturing students' abilities to understand and empathize with the diverse needs and perspectives of end-users, communities, and stakeholders. This approach fosters well-rounded professionals who are not only proficient in their technical field but also compassionate, culturally competent, and socially aware. The fact that we as an authoring team ourselves embody a multiplicity of disciplinary, professional, linguistic, and other sociocultural backgrounds has reaffirmed our belief in what can be gained as professionals from purposefully considering a diversity of perspectives in what we undertake.

Moreover, in the three courses, students engage in hands-on learning experiences where they work on real cases with real stakeholders and individuals directly affected by their solutions. By immersing students in real-life contexts, they are exposed to authentic challenges and gain a deeper understanding of the impact their work has on real people and communities. Through interactions with stakeholders and individuals affected by their solutions, students not only apply technical knowledge but also develop empathy by listening to real stories and understanding diverse perspectives. This experiential approach not only enhances students' problem-solving skills but also cultivates empathy by fostering connections with the human aspects of engineering challenges. As a result, students graduate with a heightened sense of responsibility and a deeper appreciation for the ethical and societal implications of their work, better preparing them to address complex problems in the real world with empathy and compassion.

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REFERENCES

Bairaktarova, Diana. 2022. "Caring for the Future: Empathy in Engineering Education to Empower Learning." *Journal of Engineering Education* 111, no. 3: 502–7. https://doi.org/10.1002/jee.20476.

Borba, Michelle. 2018. *UnSelfie: Why Empathetic Kids Succeed in Our All-About-Me World*. Touchstone.

Crespí, Paula, Jose Manuel García-Ramos, and Marián Queiruga-Dios. 2022 "Project-Based Learning (PBL) and Its Impact on the Development of Interpersonal Competences in Higher Education." *Journal of New Approaches in Educational Research* 11, no. 2: 259–276. https://doi.org/10.7821/naer.2022.7.993

Cross, Nigel. 2011. *Design thinking: Understanding how designers think and work*. Berg.

Davis, Mark H. 1994. *Empathy: A social psychological approach.* Westview Pres.

de Bono, Edward. 1986. *Six Thinking Hats*. Viking.

Dym, Clive L., Alice M. Agogino, Ozgur Eris, Daniel D. Frey, and Larry J. Leifer. 2005. “Engineering Design Thinking, Teaching, and Learning.” *Journal of Engineering Education* 94, no. 1: 103–20.

Elmansy, Rafiq. 2021. “The Double Diamond design thinking process and how to use it. Designorate.” Designorate, February 9, 2021. Retrieved from: https://www.designorate.com/the-double-diamond-design-thinking-process-and-how-to-use-it/

Hermsen, Pleun E. A., Sjoerd van Dommelen, and Paula Hueso Espinosa. “Reflection on Your Personal Perspective Through the Perspective of Others. A Step in Dealing with Wicked Problems.” Paper presented at *SEFI Annual Conference: Engineering Education for Sustainability – Reflecting on the role of engineering and technology education for a sustainable world, Dublin Technical University, Ireland, 11-14 September 2023* https://arrow.tudublin.ie/sefi2023_wkshp/11/

Hess, Justin L., and Nicholas D. Fila. 2016. “The manifestation of empathy within design: findings from a service-learning course.” *CoDesign* 12, no.1-2): 93–111. https://doi.org/10.1080/15710882.2015.1135243

Hoffman, Martin L. 2000. *Empathy and Moral Development: Implications for Caring and Justice*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511805851.

Noddings, Nel. 2013. *Caring: A Relational Approach to Ethics and Moral Educati*on. University of California Press.

Rasoal, Chato, Henrik Danielsson, and Tomas Jungert. 2012. “Empathy among students in engineering programmes.” *European Journal of Engineering Education* 37, no. 5:1-9 https://doi.org/10.1080/03043797.2012.708720

Ropers-huilman, Becky, Laura Carwile, and Marybeth Lima. 2005. “Service-Learning in Engineering: A Valuable Pedagogy for Meeting Learning Objectives.” *European Journal of Engineering Education* 30, no. 2: 155–65. https://doi.org/10.1080/03043790410001664363

Segal, Elizabeth A. 2011. “Social Empathy: A Model Built on Empathy, Contextual Understanding, and Social Responsibility That Promotes Social Justice.” *Journal of Social Service Research* 37, no. 3: 266–77. https://doi.org/10.1080/01488376.2011.564040.

Taylor, Alison, and Charlotte Bancilhon. 2019. *Back to Basics: How to Make Stakeholder Engagement Meaningful for Your Company*. BSR. Retrieved from https://www.bsr.org/en/reports/stakeholder-engagement-five-step-approach-toolkit

Walther, Joachim, Shari E. Miller, and Nicola W. Sochacka. 2017. “A Model of Empathy in Engineering as a Core Skill, Practice Orientation, and Professional Way of Being: A Model of Empathy in Engineering.” *Journal of Engineering Education* 106, no. 1: 123–48. https://doi.org/10.1002/jee.20159

INTRODUCING AI TOOLS IN THE ENGINEERING CURRICULUM

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Keywords: *AI in the Curriculum, Curriculum innovation*

ABSTRACT

Recent advances in Artificial Intelligence (AI) coupled with public access to related tools have influenced every aspect of human life and society. Engineering education

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has already experienced numerous related effects raising many questions regarding the appropriateness and effectiveness of integrating AI. The purpose of this project is to examine introducing AI tools into the Mechanical Engineering curriculum and use the results to guide a wider integration of AI into the curriculum. During this project, students in different courses and stages in the curriculum experienced utilizing AI tools available to the public, such as Chat-GPT, to assist in their educational tasks. Students were allowed, or requested, to utilize AI tools while performing different educational active-learning tasks such as report writing, homework assignment solving, and tasks within comprehensive design projects. In parallel, students were requested to provide information explaining how they used these AI tools to complete the different educational tasks as well as their feedback regarding these experiences. Meanwhile, assessment and reflections from the instructors were taken into consideration. Multiple methods were implemented to carry out the project, collect data, and analyse results to draw conclusions that will inform plans to implement AI in entire curriculum. Results show that students and instructors experienced and reported learning both the potential benefits, limitations, and requirements of using AI tools, as well as how it can be handled reasonably in assisting education while avoiding potential flaws. Meanwhile, instructors gained insight into the requirements, limitations, and expectations related to integrating AI in the curriculum.

1 INTRODUCTION AND BACKGROUND

Countless changes to engineering education and practice have recently taken place due to the integration of Artificial Intelligence (AI) in numerous aspect of the profession. The explosive expansion of AI can be felt by indicators such as the number of related publications in English and Chinese surveyed by Stanford University and reported to have reached half a million by 2021 (Stanford, 2023). It is no surprise that engineering and STEM fields were the most engaged areas in AI because they represent both the developers and the first implementers of AI into technology that will benefit humanity. Engineering led in benefiting from AI with the advancement of computational power and the digital world in parallel with direct application to research and education. An example of such engagement came as a response to the COVID pandemic, where utilization of digital tools for almost everything related to education and communication, including engineering education and practice, expanded exponentially, resulting in more opportunities to utilize AI for many reasons, starting with improving efficiency (Barakat et al, 2021). These were additions to the continuous changes in engineering education and practice stemming from the dynamic nature of interdisciplinarity and diversity which is a vital part of engineering. Any engineering endeavour would not even start without the integration of many expertise and dimensions. These changes in the nature of engineering, particularly the parts related to the integration of software or AI, continue to confront engineering, and STEM, academics and practitioners with an evolving set of questions on the best utilization of AI and associated potential risks, especially the parts focusing on the preparedness of both engineering researchers and practitioners to effectively integrate and use AI in their profession.

Meanwhile, academia has already been implementing AI in a multitude of ways related to almost all aspects of education and research. To set the tone for AI implementation in education, a report by UNESCO (UNESCO, 2023) stated that using AI in higher education should target improving human capabilities and protect human rights through effective human-machine collaboration in different life needs such as learning, work, and sustainable development. These goals are perfectly aligned with the general goals of engineering endeavours. As a result, many literature reports discussed implementing AI in engineering education, and some have presented results of early testing of AI in supporting learning, teaching, and assessment (Zawacki-Richter et al, 2019) and (Bates et al, 2020). Salim et al. reported utilizing AI to monitor students' learning and provide rapid feedback for potential intervention at different levels to improve their academic progress (Salim et al, 2022). Furthermore, many students and instructors are currently using Chat-GPT to help with assignments and grading, with the aim of time saving, improved accuracy, and timely feedback (Dempere et al, 2023). Learning management systems (LMSs) such as Canvas and Blackboard are now starting to integrate AI based functions assisting in assessment and data analytics (Aldahwan and AlSaeed, 2020). Meanwhile, multiple issues have already emerged in parallel with these developments such as upholding academic integrity and the need for continuous professional development of instructors to be able to handle and integrate appropriate parts of AI in the curriculum. This in addition to issues related to better planning of AI integration to optimize its effect on the educational process. These issues present an opportunity and a need for higher education entities to establish policies and regulations allowing the expanded utilization of AI in the most effective, fair, and ethical manner, especially when this process is still in its infancy across higher education around the globe, and before sporadic skewed results generate unbalanced resistance at the decision-making levels to the entire idea of improving engineers' competency by educating them on utilizing AI tools.

This paper includes a description of a project that constitutes the initial stage in a larger plan aiming to introduce AI-based tools into the Mechanical Engineering (ME) curriculum at UNIVERISTY. To achieve the goal of gaining insight and learning from the experience, from both students and instructors, active learning tasks were selected to implement AI tools. Moreover, AI-based tools were utilized in different courses to examine supporting multiple aspects of interactive learning at different levels in the curriculum. Results were collected from the different courses while implementing various assessment methods to measure the effects of these changes. Findings were evaluated to draw conclusions that will help guide the next stage of the plan to integrate AI into the Mechanical Engineering curriculum.

2 RESEARCH PURPOSE AND QUESTION

The purpose of this study was to investigate the effects of introducing AI-based tools into an Engineering curriculum and evaluate the results for the ultimate goal of informing future plans for to widely integrate AI tools across an entire Mechanical Engineering curriculum. The research questions were:

1. What would be the effect (advantages and disadvantages) of introducing AI tools to selected parts of the curriculum on the education process?
2. What would be needed to integrate AI into the curriculum for an improved educational experience?

3 METHODOLOGY

Different aspects of the curriculum could be selected to introduce AI tools and study their effect on the educational process. However, areas where the impact of change would be widely felt are those where students take an active role. Active learning engages both students and educators. During active learning, students tend to look for tools to help them accomplish the required task while carefully monitoring time savings and effort, especially time needed to learn a new tool. Meanwhile, educators can assess students' experiences and provide feedback that includes their own observations. Therefore, three major areas of active learning were targeted within a Mechanical Engineering curriculum at University of Texas at Tyler (UT Tyler) to introduce AI. These areas are:

1. Technical Report Writing.
2. Technical problem solving assigned outside the classroom (Homework).
3. A technical problem in a project such as a senior capstone design project.

Four different required courses were selected to include the targeted areas with student populations from the sophomore, junior, and senior levels. Direct and indirect assessment methods were implemented to provide feedback from both students and the instructors. Table 1 presents details of the selected courses and related learning outcomes that were targeted to examine introducing AI tools.

Table 1: Details of courses and student groups in curriculum areas targeted for AI inclusion.

Curricular area / Selected Course	**Student Population composition**	**Targeted Course Learning Outcome**
Technical Writing: **Material Science and Manufacturing (MSM)– Sophomore level**	Sophomore = 8 Junior = 14 Senior = 14 Total = 36	CLO: Perform mechanical testing and metallographic procedures to report material properties and microstructures of various metal alloys in laboratory reports.
Homework assignments: Mechanics of Materials (MoM) – Junior level	Junior = 13	CLO: Use various external loads to determine internal forces and related stress and deformation for a variety of structures.
Homework assignments: Thermodynamics (Thermo) – Junior level	Junior = 33	CLO: Perform analysis of thermodynamic cycles.
Senior Capstone Design Project (SCD) – Senior level	Senior = 5 (One group among 52 seniors in the course)	CLO: Apply knowledge and skills acquired in the undergraduate engineering curriculum in an integrated culminating design project experience to articulate and solve a complex engineering problem.

4 PROCEDURE AND INSTRUMENTS

4.2 Technical writing (Material Science and Manufacturing Course - MSM):

Technical writing is learned along a thread in the Mechanical Engineering curriculum. It usually takes place in the lab part, guided by a dedicated learning outcome. MSM lab included individual short reports and group full reports. In the group full reports, the instructor provides specific guidelines on components of each section of the report and each student in a group contributes their section to the final assembled report of the group. At the beginning of the course, AI was allowed in technical report writing without any prior training. The only requirements were to include a statement declaring that AI was used to assist with writing this report, information about the AI tool used, and the intended purpose of using AI.

Towards the last quarter of the semester, students were formally introduced to AI-assisted technical report writing with instructions and a goal to reduce human effort in the writing process. At this stage, a pre-report survey was distributed to students to capture their expectations and perspectives. After submitting the reports, direct assessment data was collected in addition to results from a post-report survey of the same ten attributes in the Pre-report survey. The survey questions were:

Using Chat-GPT or similar AI programs will help me achieve the following:

1. Start a report that later requires my input to make it an excellent report.
2. Improve a report if I started it and gave it to the software.
3. Produce an excellent report without errors.
4. Produce an excellent report without the need for multiple iterations.
5. Produce a report without committing plagiarism just by stating that I have used Chat- GPT.
6. Improve my own report writing skills.
7. Improve my own report writing skills and slowly not needing to use the software.
8. Improve my report writing grade but not my related skills.
9. Save time on writing my report.
10. Learn how to write a report properly.

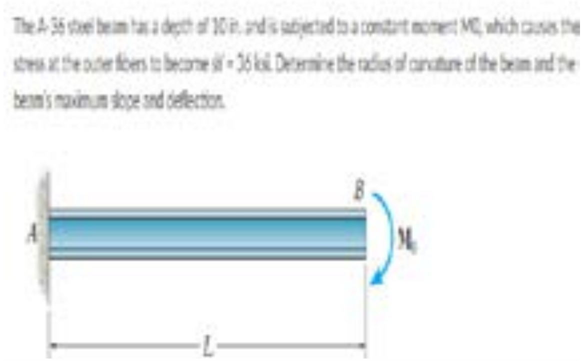

Figure 1: Technical problem assigned as homework within the Mechanics of Materials Course (MoM) and used for AI testing.

Indirect assessment results from all surveys were based on a 5-point Likert scale as follows: 1 = strongly disagree, 2 = disagree, 3 = n3utral, 4 = agree, 5 = strongly agree.

4.1 Solving Technical Problems - Mechanics of Materials (MoM) and Thermodynamics (Thermo)

In these two foundational courses, students learn and practice applying concepts by solve specific technical problems, per course learning outcomes. One of the assigned problems was selected for this experiment in each course. In MoM students were asked to determine changes in the dimensions of a cantilever beam under load, as shown in Figure 1. In Thermo, students were asked to determine the absolute value for exergy with different conditions, as shown in Figure 2. Answers were requested manually, then again using AI tools. In addition to direct assessment of the submitted work, students' reactions were surveyed after completing all tasks using the following seven questions:

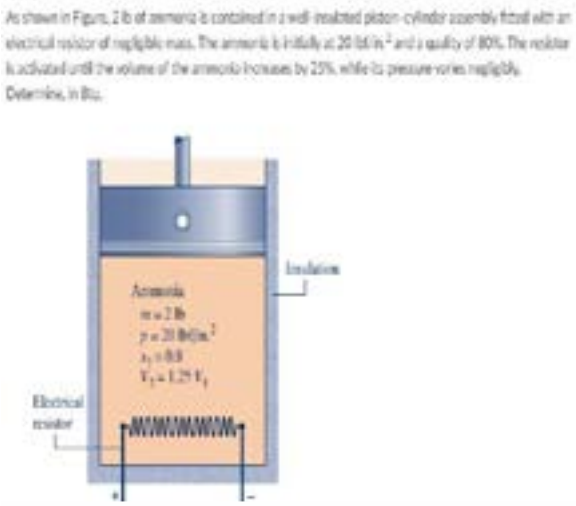

Figure 2: Technical problem assigned as homework within the Thermodynamics Course (Thermo) and used for AI testing.

1. I found AI results to be accurate.
2. Using AI to solve this problem was difficult.
3. AI helped me save time in solving this problem.
4. AI could help me learn topics related to this problem.
5. I will use AI again to solve engineering problems.
6. I recommend AI as a learning tool for MoM / Thermo.
7. I recommend using AI as a tool to assist in engineering design.

4.2 Senior Capstone Design Projects (SCD)

In these two consecutive courses, teams of students solve a complex engineering problem within a real-world industrial project. A team of five students was assigned a project to automate a pick-and-place process of multiple parts that could be presented in random orientation and position. The team designed and built a system based on using a camera with a classic vision software to assist a robotic in the process. A rough industrial environment of operation augmented the challenge of random parts' placement and orientation. The vision system required extensive training time and effort to enable an acceptable rate of accuracy. The team of students explored an AI tool that is based in MATLAB to solve this issue and employed it as part of the project. Training to accomplish a very high rate of accuracy was completed in few minutes.

5 RESULTS AND OBSERVATIONS

Table 2 presents direct assessment results of students' products with and without inclusion of AI tools, in all courses involved except for SCD project due to its unique nature and treatment.

Table 2: Direct assessment results of students' products with and without the inclusion of AI tools from curriculum areas.

Conditions	Grade (%)	Technical Writing (MSM)		Technical Problem Solving	
		Individual short reports	Group full reports	MoM – HW	Thermo - HW
Without AI	Average	82.60	83.90	94.50	92.59
	St. div.	7.90	7.90	1.44	3.92
With AI	Average	82.60	80.80	82.50	26.21
	St. div.	5.20	5.30	6.08	3.45

Results from the technical writing area (MSM) included 125 submissions without AI and 13 submissions with AI, as individual short reports for multiple lab activities. Meanwhile, there were 14 submissions of group full reports without AI and 2 submissions with AI. The self-reported purpose for using AI by students was mainly to improve the language aspects and presentation aspects of the report, compared to very low use for assistance with technical content. Instructors in both MoM and Thermo observed that most solutions with AI included correct formulae and solution steps but did not lead to a complete or correct final solution. In fact, the majority of AI-based solutions using Chat-GPT stopped short of providing a numerical answer.

In the SCD project, a process that would have taken weeks, and frequent calibration, based on data from previous use of the selected vision software, was reduced to minutes using an AI tool, with increased adaptability to accommodate new parts with high efficiency. Input from the SCD student team was collected and summarized in the following anecdotes:

1. At first, students were worried of the possibility to fail when using AI tools because their lack of familiarity of it.

2. AI tool helped students address intricate programming tasks such as object detection, resolving a common challenge among students with low to medium programming skills.

3. AI tools are instrumental in saving students time, enabling them to dedicate their efforts towards enhancing the project.

Comments from the instructor of the SCD project were along the same lines, with the addition of emphasizing that AI tools should be used carefully to empower students and improve their learning and time management while ensuring that AI does not hinder students' development of critical thinking, creativity, and problem-solving skills.

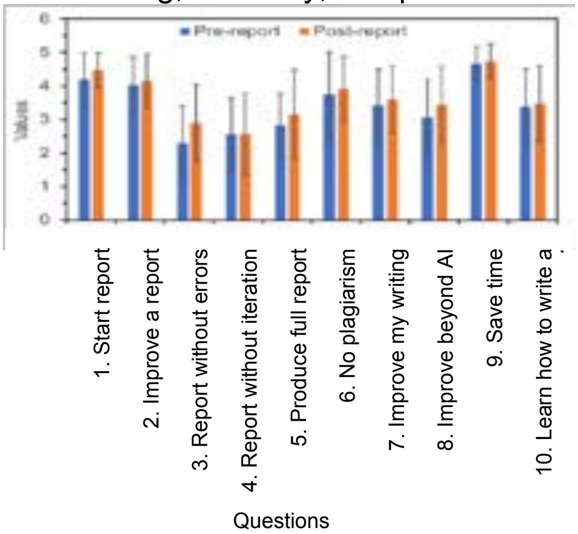

Figure 3: Survey results from students conducting technical writing regarding AI implementation.

6 DISCUSSION

Introducing AI within active learning areas in the ME curriculum to improve the educational process allowed expanded opportunities for students' engagement using commercially available tools.

In technical writing, it was insightful that very few students chose to use AI tools to improve their reports (13 of 125 and 2 of 14). The instructor observed that even the small number of 13 diminished quickly from nine to three, to two, and to zero consecutively. Additionally, those using AI were mainly aiming to improve the language and writing aspects of the report, not the technical content of the report. This helps in understanding the direct assessment results in Table 2 showing almost no change between reports with or without AI. However, these results do not provide sufficient information about the effectiveness of AI implementation in the technical writing area. Checking indirect assessment results of students' perspective on the usefulness in technical writing, as summarized by Figure 3, it can be noticed that receiving instructions on how to use AI tools resulted in increased agreement that AI could improve learning. The highest agreement was on AI helping to start a technical report, which later required input from the author for improvement, and on time saving during writing. The lowest agreement was on AI's ability to produce excellent reports without errors and without multiple iterations. Collectively, this points out issues related to knowledge of, and training on using, AI tools, as well as trust that AI will produce what is desired quickly and efficiently. After providing instruction on using AI tools the biggest change in agreement was seen in students' perspectives regarding trusting AI to help produce an excellent report without errors. These results and the diminishing use of AI tools by students were influenced by the fact that Chat-GPT was mostly used to help with this task. This software is limited by training data and performs as a natural language processor which reduces its ability to handle technical tasks. Students realized that as requirements and expectations of the written reports became more specific, using a general AI tool would be disadvantageous, especially with unchanged grades received for their shorter reports while taking extra time to write the report.

Table 2 shows lower scores in direct assessment of solutions to technical problems in MoM and Thermo using AI tools, compared to solutions without AI. The instructor noticed that in most AI-based solutions students arrived at the correct formulae but ended with the wrong final answer. Figure 4 shows related indirect assessment where students agreed mostly that AI saved them time and could help them learn related topics, as well as recommended using AI in engineering design. The lowest level of agreement was on AI providing accurate solutions and on using AI to learn the specific topic in question. Figure 4 also shows almost similar results of high agreement that AI helps to save time and could help to learn related topics. However, this population was almost neutral regarding the accuracy of AI results. The least agreement was on AI being a candidate for use in engineering design. Notice that indirect assessment results MoM did not provide strong agreement or disagreement but rather a band of answers between some disagreement and some agreement. The band was even narrower around the neutral line in the Thermo course. Direct results were more helpful in showing contrasts. These results confirm the existence of issues related to students' knowledge of AI capabilities and best utilization. When AI tools provided the correct formulae to solve the problem at hand, it was perceived as very helpful and time saving, but when the final answers needed refinement which required time and effort from the student, this perception was retracted due to lower expectations and trust. In addition to confirming the findings from the technical writing area, these results pose questions of suitability of the selected AI tool for the task.

Using AI tools to solve an industrial problem in SCD provided the most positive reactions. A dedicated suitable tool was implemented which enabled students to overcome barriers and embrace a new technology. As a result, students have gained confidence in utilizing AI tools which they could implement across various subjects.

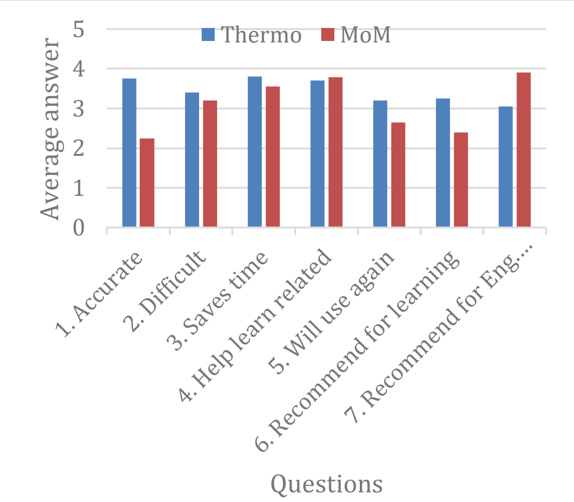

Figure 4: Survey results from students attempting technical problem-solving using AI tools within MoM and Thermo.

7 Conclusion

This project aimed to examine the integration of AI tools into a Mechanical Engineering curriculum to enhance student learning. AI-based tools available to students were utilized in active learning tasks such as technical writing and technical problem solving as well as a senior project within required courses. Various assessment methods were implemented for feedback. Evaluation of the results emphasized the importance of training of both instructors and students on AI tools and their limitations to allow proper integration of this new technology in the curriculum as part of continuous improvement. Understanding AI and proper training on its tools is critical to curriculum innovation without compromising the foundations as well as ensuring engineers are properly equipped to address societal needs.

REFERENCES

Nouf S. Aldahwan, Nourah I. Alsaeed . Use of Artificial Intelligent in Learning Management System (LMS): A Systematic Literature Review. International Journal of Computer Applications. 175, 13 (Aug 2020), 16-26. DOI=10.5120/ijca2020920611.

Barakat, N., Al-Shalash, A., Biswas, M., Chou, SF., Khajah, T. (2022). Engineering Experiential Learning During the COVID-19 Pandemic. In: Auer, M.E., Hortsch, H., Michler, O., Köhler, T. (eds) Mobility for Smart Cities and Regional Development - Challenges for Higher Education. ICL 2021. Lecture Notes in Networks and Systems, vol 390. Springer, Cham. https://doi.org/10.1007/978-3-030-93907-6_105.

Bates, T., Cobo, C., Mariño, O. *et al.* Can artificial intelligence transform higher education?. *Int J Educ Technol High Educ* **17**, 42 (2020). https://doi.org/10.1186/s41239-020-00218-x.

Dempere J, Modugu K, Hesham A and Ramasamy LK (2023) The impact of ChatGPT on higher education. *Front. Educ*. 8:1206936. doi: 10.3389/feduc.2023.1206936.

M. B. Salim, A. AlShalash, O. AlShalash, O. AlSmairat and N. Barakat, "Early Detection of Metacognition Disparity Using a Fuzzy-Logic Based Model," *2022 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden, 2022, pp. 1-5, doi: 10.1109/FIE56618.2022.9962425.

Stanford, 2023, https:\aiindex.stanford.edu\wp-content\uploads\2023\04\HAI_AI-Index-Report_2023.pdf (Accessed: 8 June 2023).

UNESCO report: https://www.iesalc.unesco.org/en/2023/09/06/primer-addresses-harnessing-the-era-of-artificial-intelligence-in-higher-education/

Zawacki-Richter, O., Marín, V.I., Bond, M. *et al.* Systematic review of research on artificial intelligence applications in higher education – where are the educators?. *Int J Educ Technol High Educ* **16**, 39 (2019). https://doi.org/10.1186/s41239-019-0171-0.

THE ARTEFACT PROJECT'S RECIPE FOR INTERDISCIPLINARY SUCCESS

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Conference Key Areas: Educating the whole engineer: teaching through and for knowing, thinking, feeling, and doing. Engineering skills, professional skills, and transversal skills.
Keywords: Soft and technical skills, Engineering education, Student-led learning, Project-based learning

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ABSTRACT

The Artefacts Project presents a unique, self-guided, 12-week practical where second-year materials students analyse the materials of everyday objects (e.g., razor blades, irons etc.) to unravel their properties, processing, and applications.

This project fosters a dynamic learning environment where students take ownership of their research. Guided by discussions with an interdisciplinary teaching team, they develop their own hypotheses, aims, and objectives. The students actively consider each member's strengths and interests throughout the project, ensuring an inclusive and effective research experience and building strong team-working skills. Literacy is also integrated seamlessly. Dedicated workshops equip students with essential skills for crafting impactful presentations, posters, and communicating science effectively.

The presentation will delve into the successful Artefacts Project, outlining the steps that guide students towards formulating their own research questions. We'll outline the stages and the project methodology. In the first five weeks the students concentrate on the fundamental soft skill development (crafting talks, creating posters, and fostering successful teamwork). During the last six weeks student teams disassemble their assigned artefacts and analyse the materials' properties putting into practice the technical skills they have acquired throughout their two years of practical studies. Finally, the presentation will showcase how the project brings materials science to life, demonstrating its application in the everyday objects that surround us.

This project offers an innovative educational approach for engaging students in real-world materials science, fostering essential practical and soft skills, and igniting their curiosity and passion for research.

1. INTRODUCTION

The Artefacts Project presents a unique, self-guided, 12-week practical where the second-year Materials Engineering students analyse everyday commercial objects (bike brakes, phones, toasters, etc.) from a point of view of materials development, processing, and properties. The student groups are given two objects (old/new or expensive/cheap) and are guided to use their creativity and knowledge to decide upon an action plan, the experimental process, and set their own research questions they want answered at the end of their project.

This project is adopted as a core learning approach that allows better alignment of course learning and assessment activities with the two-year undergraduate program's learning outcomes, including active learning, technical analysis skills, research methods and teamwork.

This project is designed to challenge students' implicit notions of learning and to develop their self-efficacy by giving them creative freedom to work in a supported, collaborative, practical process. We want the students to foster professional skills alongside technical skills, supporting innovative, student-led learning in the applied materials engineering curriculum, which can improve students soft and technical skills in ways that teacher-led, lecture-style learning does not (Tell and Hoveskog 2022).

There are different studies on how to address in practice a more student led learning in the curriculum (Rodriguez et al. 2021). Various learning models have been developed in recent decades such as, for example, problem-based learning (PBL)

(De Graaf and Kolmos 2003), Experiential Learning (ExL) (Kolb 1984) and the Conceiving, Designing, Implementing and Operating (CDIO) approach that focuses on all phases of a product, process, or system lifecycle. They all have their own emphasis with the general purpose of engineering education is to provide the learning required by students to become successful engineers – technical expertise, social awareness, and a bias towards innovation.
The Artefacts Project leans more towards the CDIO model and incorporates multiple technical learning outcomes. The 'Conceive-Design-Implement-Operate' (CDIO) movement of engineering education reform emphasises project-based, experiential learning and the development of professional skills such as teamwork, collaboration, and design (Crawley et al. 2007). It addresses the gap between classic engineering education programs and industry needs. Researchers have strongly supported this approach in their call for a change in the traditional, teacher-led engineering curriculum.

1.1. Professional skills

The term 'professional skills' (also called 'soft', 'transferable', 'transversal' or even '21st Century' skills), has come as a requirement for accreditation engineering programs for years (Picard et al. 2021). There is an overall agreement that engineering education should not only address science and engineering but also social, ethical, and organisational aspects of engineers' practices and responsibilities (Winberg et al., 2020). Furthermore, they should also have the abilities needed to solve "complex technical challenges along with being able to work in interdisciplinary teams and dealing with social and cultural issues" (Rodriguez et al. 2021).

A lot of engineering programs today focus narrowly on the technical skills (i.e., the hard skills). Assessments can be seen as puzzles that have one pre-determined correct answer requiring analytical skill but no integrative or creative capability (Edström 2018).

The aim of the Artefacts Project is to address aspects of the 'soft' skills looking at teamwork, communication, and project management. As a possible organizing scheme, Table 1 presents our framework of four categories of soft skills that we have addressed with the Artefact Project as derived from three papers in the soft skills engineering literature (Tell and Hoveskog 2022).

Table 1. Soft skills addressed by the Artefact Project as described in previous research.

Soft skills	Shakir (2009)	Chamorro-Premuzic et al. (2010)	Rodriguez et al. (2021)
Creativity	Critical thinking and problem-solving skills	Critical thinking; attention to detail, planning and organizing skills	Problem solving skills – time and project creativity and management
Cooperation	Teamwork, leadership skills communication skills	Interpersonal and emotional intelligence	Interpersonal skills – social interaction, and leadership

Self confidence	Life-long learning and information management skills	Self-management; insight maturity	Intrapersonal skills: self-direction and the ability to prioritize
Commitment	Entrepreneurship skills	The ability to work under pressure; willingness to learn; imagination/ creativity and initiative	Meta-cognitive skills – willingness to learn, critical/ analytical and innovative thinking

1.2. The Importance of Teamwork and Instructional Support

Several studies highlight the importance of teamwork as an engineering ‘soft’ skill (Costa et al. 2019). To foster this skill, we designed the Artefact project where student teams have freedom to explore their own questions related to materials of their artefact. It is crucial to differentiate between teamwork and group work. While often used interchangeably, these terms have distinct purposes. **Group work** is a pedagogical approach where students collaborate to achieve specific learning objectives. It's a common teaching method. **Teamwork** is formed for a long-term, common goal requiring a high level of interdependence and collaboration, such as a project-based report. Teams exhibit a stronger sense of shared responsibility compared to groups, which often work towards separate goals with a related interest (Davies W.M. 2009).

One of the main challenges we have faced was integrating diverse students into successful teams. Different motivations, expectations, task and role ambiguity and academic disparity can become unpleasant experiences if not managed effectively. Previous studies (Oakley et al. 2004) emphasize the importance of instructor interaction and feedback, alongside collaborative learning, in fostering professional competencies like group skills and problem-solving.

Our strategy for effective teamwork is building on the importance of guidance (Isaac and Tormey 2015) and implementation of specific strategies to ensure a positive learning experience. We divided students into small groups, provided coaching sessions, and incorporated self and peer assessment throughout the 12-week project. We provided feedback on the project’s progression, support on issues or conflicts arising from teamwork, and communication regarding the project due dates. Recognizing the challenges of varying skill and presentation levels, we allowed students to choose presentation roles that maximized their strengths. Confident presenters could handle the main presentation, while others could focus on the poster or support preparation. Our observations suggest that students with lower initial motivation benefit more from working alongside high-achieving peers compared to working independently implying that using individual heterogeneity is an advantage (Torres et al. 2017). This was achieved by providing constant supervision and guidance across the Project indicating that training students in teamwork was crucial (Aranzabal et al. 2022).

1.3 Technical Skills

The aim of the Artefact project is to combine professional and technical skills. The engineering students should not only work in interdisciplinary teams and deal with social and cultural issues but also have the abilities needed to solve “complex technical challenges” (Cukierman and Palmieri 2014).

Project-based learning provides a platform to practice valuable technical skills, the students can put into practice operation procedures, data collection techniques, and analysis methods. Analysing materials on everyday objects may lead to unexpected data, requiring students to troubleshoot, analyse their approach, and potentially adjust their methods or test parameters. This process encourages critical thinking and problem-solving skills that are essential in any field of work, not just Engineering.

A strong foundation in technical skills, also known as hard skills, is the bedrock of engineering education and can be achieved using a joint learning method, example-based learning (EBL) and problem-based learning (PBL) (Sanchez-Gomez 2022). Through coursework, labs, and projects, the 2nd year Materials students gain the ability to utilize relevant software and technologies for the Artefact project at the end of their second year of study. We believe that this technical proficiency is essential for applying engineering principles to real-world challenges and fostering innovation across various engineering fields.

2. METHODOLOGY

The 12 weeks Artefact project is divided into two parts. In the first five weeks, students in their assigned groups study the fundamentals of crafting and delivering talks, creating effective posters, and fostering successful teamwork. The following six weeks focus on applying technical skills honed throughout the past two years of study as students analyse their artefacts and prepare for the final presentation and poster in week 12. A crucial aspect of the project's launch (week one) involves familiarizing students with the course's learning outcomes:

1. To examine real life application of materials design, selection, and application to product design
2. To develop and apply practical laboratory skills.
3. To examine the potential health and safety issues surrounding a practical investigation and manage them accordingly.
4. To develop scientific presentations skills and use them in presenting the project work.
5. To understand what makes a good poster and apply this to design of research poster.
6. To develop team working skills and project planning abilities.

2.1. Weeks 1 to 5 – Skills Development

The first five weeks focus on honing presentation and poster creation skills. Students work collaboratively in groups, utilizing a blend of group discussions, lectures, and workshops.

2.1.1 Developing Presentation Skills:

- *Identifying a Key Paper:* Students select a research paper from the prestigious journal Nature to analyse and present.
- *Crafting a Compelling Presentation (7 minutes):* Presentations should follow a clear structure, including:
    - Introduction: Highlighting the paper's significance
    - Results: Summarizing key findings and discussing potential limitations
    - Conclusion: Exploring potential future applications

To equip students for impactful presentations, an introductory lecture delves into key concepts:

- *Pre-Planning Considerations:* Defining the topic, choosing a captivating title, and conducting relevant research.
- *Structuring the Presentation:* Establishing a clear flow with a beginning, middle, and end, incorporating visuals, and identifying key points
- *Storytelling Techniques:* Structuring a compelling narrative for optimal audience engagement.

Presenting before the project's experimental phase offers several advantages:

- *Practice Makes Perfect:* Students gain valuable presentation experience.
- *Identifying Areas for Improvement:* Self-reflection allows students to pinpoint areas for further development.
- *Skill Sharpening:* Students refine their presentation skills before the final project showcase.

2.1.2 Crafting Effective Posters:

Moving on from presentations, students turn their focus to creating impactful posters. Through group discussions, they analyse a poster from a previous year's report, identifying strengths and areas for improvement. This exercise helps them grasp the key elements of a successful academic poster, including:

- *Tailored Communication*: Considering the unique needs of the target audience.
- *Accessibility and Clarity:* Ensuring the poster is clear and easy to understand.
- *Concise Messaging:* Delivering key information using minimal text and effective visuals.

Following this interactive session, a lecture unpacks the core principles of poster design, incorporating elements like discussions and workshops.

- *Visual Storytelling:* Students learn to strategically select diagrams that enhance their narrative and support key points.
- *Engaging Titles and Keywords:* Choosing clear, concise titles and keywords to grab attention.
- *Effective Use of Images:* Understanding how to present images that inform and guide the audience's interpretation.

Mirroring the structure of a research article, the final portion of the session focuses on organizing poster content, where students learn to:

- *Divide Text by Topic:* Break down the information into clear sections.
- *Essential Elements:* Include an introduction, methodology, results, analysis, discussion, and conclusion.

2.1.3 Team Performance:

To enhance the team performance, the students are asked to divide the activities into these stages:

1. *Familiarisation*. This is the stage when the individual members of the group get to know each other and begin to understand the task they need to undertake.
2. *Planning and preparation*. This is the stage when the group should plan exactly what needs to be done, how it needs to be done, and who should do what. The students should divide the different tasks and the responsibilities among the group. They should make the most of the individual expertise and finally make an action plan.
3. *Implementatio*n. The students should work on an effective communication by establishing regular meetings and sharing contact details to facilitate contact between everyone in the group.
4. *Completion*. As the final stage of the project, it may require a different approach. The students may need to regroup at this stage to agree a new action plan to tie up loose ends and review the whole project rather than discrete part of it.

2.2 Weeks 6 to 11- Artefact Analysis

The Artefact project has two key objectives. First to develop teamwork skills where students collaborate in groups to create oral presentations and impactful posters, fostering teamwork and communication skills. Second to apply knowledge in practice: Students can apply the theoretical and practical knowledge acquired throughout their two years of Materials Science and Engineering studies.

During this phase, student teams disassemble their assigned artefacts and analyse the materials' properties. This analysis focuses on understanding, but it is not limited to, Mechanical Properties, how strong and ductile the material is; thermal properties, within which temperatures a material works at its best; chemical and microstructure compositions, which the students can use to explain materials properties and applications.

The project encourages exploration beyond conventional testing methods. Past students have analysed bicycle brakes using UV-Vis light and moisture to study degradation. They have investigated corrosion in iron plates by ironing lab coats with hard water. Also, they have studied bacterial growth on razor blades under varying conditions.

Students have the freedom to choose specific components of their artefacts to analyse and determine the most suitable analytical techniques. However, this freedom comes with the responsibility to conduct thorough risk assessments and obtain Control of Substances Hazardous to Health (COSHH) approval for any proposed activities. This fosters resilience, creativity, and the responsible application of their knowledge, while focusing on their poster and presentation delivery.

3. RESULTS

The Artefact project fostered a deep sense of discovery in students. The independence granted during the research and experimentation phase was highly valued. Unsupervised access to lab equipment boosted their confidence and proficiency in utilizing a variety of techniques. This is exemplified by their independent use techniques such as X-ray diffraction and infra-red spectroscopy to analyse the chemical composition, crystalline and molecular structure of the components of their chosen artefacts. Crucially, students interpreted the data themselves, leading them to explore limitations of the techniques and delve into robust analytical methods.

The project actively encouraged students to consider techniques beyond the confines of the main laboratory and seek collaboration with staff from other labs. For instance, in the "Razors" project (2023), they investigated bacterial growth on razor handles in simulated bathroom environments. While the metal handles of the "cheap" razors showed minimal bacterial growth, the plastic handles of the "expensive" razors, with their intricate designs and crevices, demonstrated the potential for harbouring bacteria. Similarly, the "Brakes" project (2021) saw groups utilize the chemical and biological processing laboratories to design and test their own corrosive solutions. These projects highlight the ingenuity and real-world applications fostered by the students during the Artefact Project.

The project culminates with a student-led presentation and poster showcasing their work to peers, department members, and an industry panel. This open-ended approach ignited students' imaginations, leading to a broad spectrum of research questions and results. In the "Irons" project (2022), groups explored themes such as material selection and sustainability. One particularly creative group investigated chemical corrosion by hard water by ironing lab coats for five weeks! (Figure 2) Another group encountered health and safety limitations that prevented direct skin shaving, so they found alternative approach using a surrogate material (kiwi) with similar properties to employ (figure 2).

This diverse range of projects encompassed chemistry, sustainability, and materials engineering, fostering student enthusiasm while simultaneously developing their soft skills and understanding of industrial applications and expectations.

Fig. 1. 2022 poster – Effect of hard water on irons

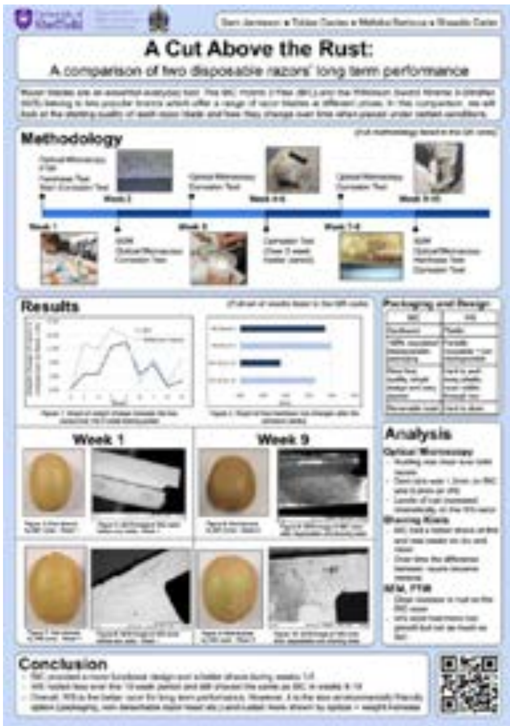

Fig. 2. 2023 poster – Innovative way of shaving

4. CONCLUSION

We have demonstrated that the Artefact project empowers second-year materials students by granting them the freedom to explore the materials within a commercial artefact using technical and literacy skills. This approach fosters a sense of discovery, as students relished the independence during the research and experimentation phase.

The project's two-pronged approach of presentation and poster development proves successful. While collaboration remained crucial to maintain thematic cohesion between the deliverables, dividing the tasks ensures a more equitable workload distribution. This approach built upon the initial emphasis on effective teamwork, equipping students with valuable organizational and collaboration skills. Evidence of this was their proactive scheduling of meetings, task documentation, and fostering open communication within their groups.

Overall, the Artefact project achieves its primary goal of fostering student technical and soft skills using independence and exploration. However, the discussion of student self-reflection highlights an opportunity to further emphasize the broader applicability of the acquired technical skills within various career paths. In today's competitive environment, success is not solely defined by technical ability. The teams that thrived during the Artefacts project were those who could effectively combine their technical expertise with the power of soft skills. By fostering a strong correlation between these two essential skill sets, the students empowered themselves to navigate the complexities of modern work and achieve remarkable results.

REFERENCES

Aranzabal A., E. Epelde and M. Artetxe. “Team formation on the basis of Belbin’s roles to enhance students’ performance in project based learning.” *Education for Chemical Engineers* 38 (2022): 22–37

Costa, A. R., M. Ferreira, A. Barata, C. Viterbo, J. S. Rodrigues and J. Magalhães. “Impact of Interdisciplinary Learning on the Development of Engineering Student’ Skills.” *European Journal of Engineering Education* 44 (2019): 589–601. https://doi.org/10.1080/03043797.2018.1523135.

Chamorro-Premuzic, T., Arteche, A., Bremner, A., Greven, C. and Furnham, A. “Soft skills in higher education: importance and improvement ratings as a function individual differences and academic performance.” *Educational Psychology* 30, no. 2 (2010): 221-241.

Cosgrove, T. and O’Reilly, J., “Theory, practice and interiority: an extended epistemology for engineering education.” *European Journal of Engineering Education* 45, no. 1 (2020): 38-54.

Crawley, E., Malmqvist, J., Östlund, S. and Brodeur, D. *Rethinking Engineering Education – The CDIO Approach*, Springer, New York, NY, 2007

Cukierman, U.R. and J. M. Palmieri. “Soft skills in engineering education: a practical experience in an undergraduate course.” Paper presented at *International Conference on Interactive Collaborative Learning (ICL)*, 2014

Davies M.W.. “Groupwork as a form of assessment: common problems and recommended solutions." *High Educ* 58 (2009): 563–584

De Graaf, E. and A. Kolmos, “Characteristics of problem-based learning.” *International Journal of Engineering Education* 19, no. 5 (2003): 657-662.

Edström, K. “Academic and Professional Values in Engineering Education: Engaging with History to Explore a Persistent Tension.” *Engineering Studies* 10, no.1 (2018): 38–65.

Sanchez-Gomez C.A., “Implementing a joint learning method (PBL and EBL) to innovate the development of mechanical engineering technical and non-technical skills”. *International Journal of Mechanical Engineering Education* 50, no. 1 (2022):176-196. https://doi.org/10.1177/0306419020950751

Isaac, S., and R. Tormey. "Undergraduate Group Projects: Challenges and Learning Experiences.” Paper presented at *In Engineering Leaders Conference on Engineering Education* 2015, 19. Hamad bin Khalifa University Press (HBKU Press). 2014. https://doi.org/10.5339/qproc.2015.elc2014.19.

Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development*, Prentice-Hall, Englewood Cliffs, NJ. 1984

Oakley, B., R. Felder, R. Brent, I. Elhajj. Turning student groups into effective teams. *J. Student Centered Learn*. 2 (2004): 9–34.

Picard, C., C. Hardebolle, R. Tormey, and J. Schiffmann.” Which professional skills do students learn in engineering team-based projects”. *European Journal of*

Engineering Education, 47:2, (2021): 314-332
https://doi.org/10.1080/03043797.2021.1920890

Rodriguez, C., M. Vazquez, M. Fernandez, A. Llamas Nistal, M. Fernandez Iglesias, M. Tsalapatas, H. Heidmann, C. Vaz de Carvalho, J. Triinu, T. Jaanus and L. Sørensen. "Teaching soft skills in engineering education: an European perspective." *IEEE Access* 9 (2021): 29222-29242, https://doi.org/10.1109/ACCESS.2021.3059516.

Shakir, R. "Soft skills at the malaysian institutes of higher learning." *Asia Pacific Education Review* 10, no. 3 (2009): 309-315

Tell, J., M. Hoveskog. "Applied engineering education for soft skills in the context of sustainability and mobility." *International Journal of Sustainability in Higher Education* 23, no. 8, (2022): 324-336. https://doi.org/10.1108/IJSHE-07-2022-0202

Torres, M. F., A. J. Sousa, and R. T. Torres. "Pedagogical and Technological Replanning: A Successful Case Study on Integration and Transversal Skills for Engineering Freshmen." *International Journal of Technology and Design Education* 28 (2017): 573–591. https://doi.org/10.1007/s10798-017-9399-y

Winberg, C., M. Bramhall, D. Greenfield, P. Johnson, P. Rowlett, O. Lewis, J. Waldock and K. Wolff. "Developing Employability in Engineering Education: a Systematic Review of the Literature." *European Journal of Engineering Education* 45 (2020): 165–180. https://doi.org/10.1080/03043797.2018.1534086.

EXAMINING THE EFFECTIVENESS OF A SUMMER SCHOOL TO EQUIP ENGINEEERING STUDENTS WITH COMPETENCES REQUIRED TO ACHIEVE THE SDGS

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***Conference Key Areas**: Teaching the knowledge, skills and attitudes of sustainable engineering; Teaching social and human sciences to engineering and science students*
***Keywords**: Summer School, Engineering Education for Sustainable Development, SDGs, Active Learning, Intercultural Skills*

ABSTRACT

In today's landscape of global challenges, the role of the engineer is experiencing a significant transformation. The expectations of engineers are no longer confined to traditional technical expertise; they are increasingly acknowledged as key players in driving sustainable development agendas on a global scale. As nations endeavour to achieve the ambitious targets outlined in the United Nations Sustainable Development Goals (SDGs), it becomes imperative to equip engineers with a diverse skillset capable of addressing increasingly intricate and multifaceted projects, often characterised as "wicked" problems. The PROFESS 12 research project was conceived to address the gap between traditional and required skills by piloting a summer school which sought to expose students to opportunities where they can develop some of the required skills. This paper describes the design of the summer school and provides evidence from student feedback of its value and effectiveness in addressing learning outcomes. The resources from the design of this summer school can be used by educators who wish to contribute to activities to enhance skills in engineering students.

1 INTRODUCTION

The context in which the engineering profession operates has undergone significant transformation since its inception, now necessitating collaboration within diverse, multidisciplinary international teams. The requisite skills for success now extend well beyond technical prowess (Byrne and Mullally 2014; Craps et al. 2017; Kolmos and Holgaard 2019). Seminal studies on skill requirements for sustainable development in particular (Wiek et al. 2011; de Haan 2010; Rieckmann 2012) have presented a spectrum of competencies that engineers must possess. Recent investigations, such as those conducted under the Erasmus+ project, ASTEP-2030, particularly in the context of achieving the SDGs, have further identified a multitude of skills (53 in total) including Sustainability Awareness and Intercultural Skills (Beagon et al. 2022). The UNESCO (2017) report "Education for Sustainable Development Goals – Learning Objectives" also provides educators with a framework to enrich their curricula, thereby equipping students with the skills essential for the future. Whilst the lists of skills requirements are a useful starting point, many educators encounter challenges in implementing what is termed Engineering Education for Sustainable Development (EESD) initiatives in the classroom. Successful implementation of EESD necessitates a holistic and transformative approach, entailing the integration of novel strategies and appropriate pedagogical methods into engineering curricula (de Haan 2010). Kolmos et al. (2016) summarise three response strategies to EESD: (1) the add-on strategy, involving the inclusion of sustainability subjects into the curriculum at the micro-level, (2) the integration strategy, encompassing content and values at the meso-level, necessitating program modification, and (3) the re-building strategy, entailing a paradigm shift in education by accentuating values, identity, and commitment at the macro-level. The add-on strategy predominates in EESD however, typically entailing the introduction of new courses or topics (Thürer et al. 2018). The use of situated learning and the importance of self directed learning is espoused as critical to provide motivation for students to learn about sustainable development (de Haan 2010). One extracurricular, add on strategy which has been implemented is the use of summer schools, to enhance innovation and entrepreneurship (Qosaj et al. 2023) and multidisciplinary skills (Larsen et al. 2009).

1.1 Background

The project was a joint initiative between Ulster University in Northern Ireland, which is part of the UK and TU Dublin in Ireland. Funded by the Higher Education Authority, its aim was to improve cultural relationships and build connections between researchers, academics and students in each jurisdiction. Hence the summer school was designed with ten student participants from each university and was hosted in each location with travel and accommodation fully funded by the project.

2 METHODOLOGY

2.1 Cocreation exercises (Jan/Feb 2023) and Launch Day (March 2023)

Two co-creation exercises were undertaken with engineering students to test ideas and gather information as to what they would expect or hope to achieve from the summer school. The outcome of the co-creation exercises determined the learning outcomes for the summer school (shown in Table 1) and the types of teaching pedagogies to be utilised. Applications and interviews enabled the team to select ten engineering students from each university, being mindful of diversity in gender, age, university course and year of study. There were concerns that students may not commit to a five-day summer school and so the team organised a Launch Day to engage students in the project at an early stage and to allow them to meet each other before committing to the main five-day event. The Launch Day was organised to coincide with the World Engineering Day for Sustainable Development. Staff and students met at an Area of Outstanding Natural Beauty (AONB) halfway between the two Universities where we had arranged a mountain walk in the morning to remind us of the importance of maintaining our natural environment. The afternoon session included a guest speaker on sustainable manufacturing and a rousing call for action from a climate action activist with the National Youth Council of Ireland.

2.2 Five Day Summer School (May 2023)

The design of the summer school was carefully planned to ensure that students had the opportunity to meet the learning outcomes as well as enjoy the experience itself. A Summer School Toolkit is available on the project website with full details of the itinerary, detailed descriptions of each activity and workshop and a student handbook which was circulated one week before the summer school began PROFESS 12 website. A simplified schedule is included in Figure 1 outlining the main activities and workshops. In line with the literature on the most appropriate methods for EESD, many of the activities were formed around the concepts of active learning, self directed learning, situated learning, future thinking and role playing (de Haan 2010; Thürer et al. 2018; Chernyshova and Tokmylenko 2020). The activities were student centred, with lecturers acting as facilitators.

	Monday	Tuesday	Wednesday	Thursday	Friday
AM	TRAVEL	Circular Economy	TRAVEL	Site Visit	Personal Impact Celebrate
Lunch					
PM	Intro to SDGs	Intercultural – Majoria Minoria	Site Visit	TITANIC MUSEUM	TRAVEL
Dinner					TRAVEL
Evening	ESCAPE ROOM	GUINNESS STOREHOUSE MUSEUM			

Fig. 1. Schedule for five-day summer school

2.3 Feedback on Summer School

The research team wanted to better understand if the summer school was effective in reaching the aims of the PROFESS 12 project and also to gather information and feedback which would help refine the design of a future iteration of the summer school. Therefore, research questions included:

- How effective was the Summer School from the students' perspective?
- What can we learn from the experience to provide feed forward advice for the next iteration of the project at an international scale?

The data was collected from students in three strands; two reflective exercises which included a voice/text submission from each student interrogating their reflections on the site visits and summer school in general and an online survey which was circulated a week after the summer school ended. The students were asked to either provide responses as voice notes or text-based responses (typed or handwritten) – any of these formats were acceptable in line with Universal Design Principles (Novak & Bracken, 2019). For the purposes of considering the effectiveness of the summer school, responses to the student survey are presented. The team are also proposing to thematically analyse the reflective responses to better understand the overall student experiences, but due to length limitations, these will not be included in this paper.

3 FINDINGS

Students were invited to answer questions relating to their overall experience of the summer school and how it was organized, their views on whether they had met the learning outcomes and also on which skills they have developed during the school. Responses to these questions used a 5-point Likert scale with possible responses which ranged from "Strongly Disagree" to "Strongly Agree". Figures 2 to 3 indicate the overall responses from nineteen students involved in the programme who responded.

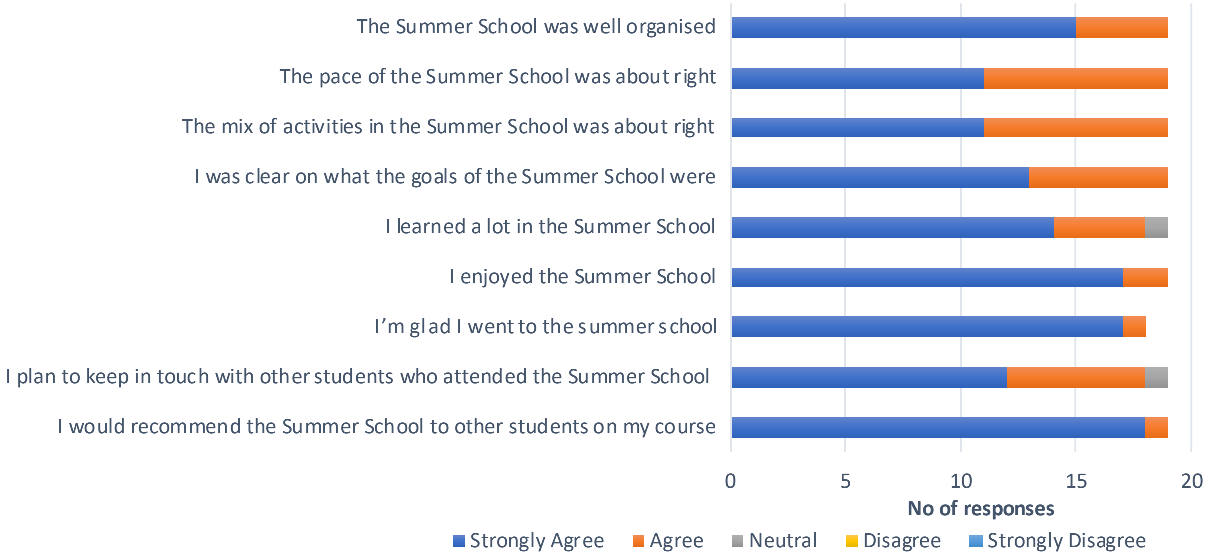

Fig. 2. Responses to survey questions on organisation of summer school and overall experience. (Note one student did not answer one question)

It is clear that the overall feedback from the summer school is positive, with students mainly strongly agreeing or agreeing that the summer school was well organised. There were some indications that the pace and the mix of activities were not ideal for all students, however, nineteen (eighteen ("strongly agree") and one ("agree")) students would recommend the summer school to others. Overall students enjoyed the summer school and were clear on what its goals were. Eighteen out of the nineteen students who responded indicated that they had learned a lot in the summer school with one student remaining neutral on this response.

For the most part, students felt they had achieved the nine learning outcomes associated with the summer school, with a "strongly agree" or "agree" rating for five of the learning outcomes as shown in Table 1. It is worth noting that across all learning outcomes, the majority of students broadly "agree" or "strongly agree" that they achieved them. Further, no student indicated "disagree" or "strongly disagree" for any of the learning outcomes. Two learning outcomes had the highest number of "strongly agree" responses: the appreciation of similarities and differences of different cultures and the learning outcome relating to collaborating with students from diverse backgrounds.

Table 1. Student response scores on achievement of learning outcomes

Learning Outcome	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Explain the SDGs and the principles of sustainable development	11	8	0	0	0
Describe SDG 12 and the concepts of sustainable consumption and production	13	6	0	0	0

Appreciate the importance of R&D in developing solutions for carbon-neutral transport technologies	11	5	3	0	0
Apply the concept of the circular economy to an engineering problem	13	6	0	0	0
Calculate my carbon footprint.	11	5	2	0	0
Better communicate and present	13	4	2	0	0
Collaborate with students from diverse backgrounds	15	4	0	0	0
Appreciate the similarities & respect differences in how people from diverse cultures perceive things	15	4	0	0	0
Be more aware of my reactions in conflict and communication style	11	7	1	0	0

Only four learning outcomes received any neutral response as to whether the students felt they had achieved the learning outcome. These related to: appreciating the importance of R&D, calculating a carbon footprint and better communicating and presenting and being aware of reactions in conflict and communication. The research team discussed the findings seeking to unpack why these few neutral responses were provided. Two site visits were organized to companies which are working on research design and manufacture of carbon neutral technologies (real world experiences). One of the site visits included a long tour around a large manufacturing facility and it was difficult to hear the tour guide discuss the technologies at certain times. It may have been better to organize a short presentation from the company prior to the tour, in order to emphasise the company approach to research and development of technologies. A presentation was provided in the second tour, which was appreciated by students and noted in their reflections. The exercise to calculate one's own carbon footprint (thinking and acting for the future) was undertaken on Friday morning at the end of the week and was only allocated 1 hour. The research team considered that perhaps the students were tired at this point and going forward, it is recommended that either this activity is moved to a different time in the week or removed completely.

The final survey question related to student perceptions of being able to develop their skills. Overall, there is a positive indication from students that the summer school was effective in developing all five of the skills noted, particularly an increased awareness of intercultural skills and developing skills to work in a team as shown in Figure 3.

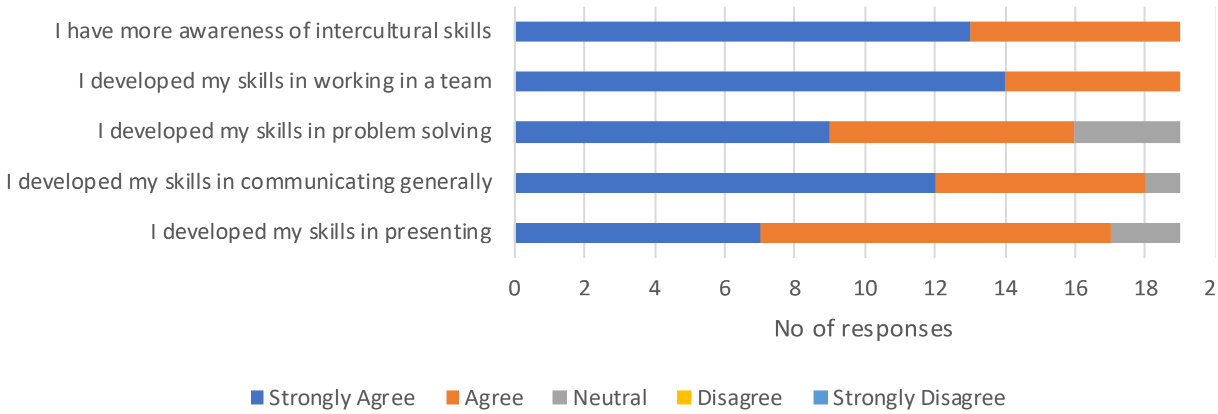

Fig. 3. Responses to survey questions on "What was your experience of being able to develop your skills during the summer school?"

The majority of responses were very positive (either "Strongly Agree" or "Agree"). A small number of neutral responses were received for the skills: problem solving, presenting and communicating generally. This may be explained by the fact that students were permitted to volunteer for presentation opportunities so perhaps not everyone availed of that opportunity through the duration of the summer school. There were no negative responses ("Disagree" or "Strongly Disagree").

4 DISCUSSION AND CONCLUSIONS

In response to the overall research question, "how effective was the Summer School from the students' perspective?", we can draw several conclusions. Students thoroughly enjoyed the summer school, felt it was well organised and would recommend it to their fellow students. They felt the pace and mix of activities on the programme was about right. There is evidence that the majority of students felt that all of the learning outcomes had been met, but particularly noteworthy were the learning outcomes related to understanding the SDGs, SDG 12, the circular economy and aspects of working with students from diverse backgrounds and appreciating intercultural differences. Learning outcomes which were slightly more difficult to achieve for all students related to "Appreciate the importance of R&D in developing solutions for carbon-neutral transport technologies", "Calculate my carbon footprint" and "Better communicate and present". Detailed instructions on how the summer school was designed and facilitated are included on the PROFESS 12 website and are freely available for use.

The evaluation exercise also provided feed forward advice for the next iteration of the summer school. Whilst the overall outcome of the summer school was successful, there are some areas for consideration in designing summer schools in general.

- Energy levels were low at the end of the week and students were not as receptive to learning due to tiredness or overstimulation. The recommendation for the next iteration is to allow some down time for students to rest or explore the local areas in their own time to enhance their cultural understanding.
- An introductory presentation on the nature of site visits and the work of the company, outlining what students are likely to see during the visit is invaluable.

- We identified some barriers to engagement for women who were restricted from attending due to childcare responsibilities or work commitments. In future, considerations should be given to providing some funding towards childcare arrangements or to explore the possibility to attend on a part time basis or participate in some elements remotely (i.e. daytime only or non-residential options). This may necessitate that some aspects of the school are designed as core and mandatory.

The research questions sought to examine the effectiveness of the summer school and provide feed forward advice for the next iteration, however it is also interesting to reflect on how a summer school initiative such as this can influence further change within a University. It is clear that systemic change at the organisational level is required in order to fully address the gaps in our engineering educational system (Kolmos et al. 2016), however, it is acknowledged that systemic changes encounter challenges. The three curriculum response strategies, “add on strategy”, the “integration” strategy” and the “rebuilding strategy”, all require different levels of engagement with university management, external companies and society (Kolmos et al 2016). This pilot project is an example of the “add on strategy” as it was an elective for interested students without academic credit. Further, it was initiated by interested academics, early adopters hoping to lead change within the department. However, it is recognised that systemic change requires support from a top down and bottom up approach. Recent strategic plans in both Universities recognise the importance of Education for Sustainable Development (top down influences) and it is intended that piloting of the summer school will give confidence to the lecturers involved to become change agents and to incorporating these activities more widely in the curriculum (bottom up influences). The challenge lies in transforming the learning opportunities from this summer school into reimagining the entire curriculum within each University.

It is also interesting to reflect on the effectiveness of the different pedagogies used in the school. Students appreciated the site visits where they were able to engage with real world experiences and the workshops where they had the opportunity to investigate aspects of sustainability themselves (self directed learning). Of particular note in student reflections, were two activities: the circular economy workshop and the Majoria Minoria activity. In the circular economy, students were introduced to the topic and asked to reimagine and design a product (food packaging, makeup container, desk chair) using circular economy principles. This was an example of situated learning which is oriented towards behavioural change as a result of reflecting on the experience of activity (Chernyshova and Tokmylenko 2020). Several students reflected on how this exercise made them think about and take note of how everyday things are manufactured (future thinking).The Majoria Minoria exercise was a role play in which members from a rich country and a developing country needed to negotiate. This activity was also identified by students as being very effective in developing an awareness and better understanding of different perspectives. Thürer et al. (2018) highlight in their systematic review that lecturers should develop approaches to learning and teaching that consider the role of values and assumptions in decision making and this role play is a good way to engage students in that type of activity.

Finally, Thürer’s et al. (2018) systematic review raised a further research question: How can faculty be motivated to integrate sustainability into the curricula? Our intention in the design and roll out of this summer school was to pilot this initiative on a small scale to build confidence in our design and delivery and to ignite a wider integration of EESD into the overall curriculum. We hope that the resources provided on our website can be used by other educators to ignite similar reform strategies in order to move from small to large scale implementation, or rather from an add on strategy to an integration, or full-scale rebuilding strategy to enhance engineering curricula to prepare our students to solve the sustainable development challenges we currently face.

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REFERENCES

Beagon, U., Kövesi, K., Tabas, B., Nørgaard, B., Lehtinen, R., Bowe, B., Gillet, C. & Monrad, C. 2022."Preparing engineering students for the challenges of the SDGs: what competences are required?, *European Journal of Engineering Education*, 48,1, 1-23. https://doi.org/10.1080/03043797.2022.2033955

Byrne, E. P. & Mullally, G. 2014. "Educating engineers to embrace complexity and context". I*n Proceedings of the Institution of Civil Engineers-Engineering Sustainability* Vol. 167, No. 6, pp. 241-248. Thomas Telford Ltd.

Chernyshova O., & Tokmylenko, T. 2020. "Summer School: a non-formal way to tackle education challenges" *Education Dimension,* 3, 267-287.

Craps, S., Pinxten, M., Saunders, G., Leandro Cruz, M., Gaughan, K., & Langie, G. Professional roles and employability of future engineers. 2017. In *Proceedings of the 45th SEFI Annual Conference 2017-Education Excellence for Sustainability, SEFI 2017* (pp. 499-507). European Society for Engineering Education SEFI.

De Haan, G. 2010. "The development of ESD-related competencies in supportive institutional frameworks" *International Review of Education*, 56,2, 315–328.

Kolmos, A., Hadgraft, R. G., & Holgaard, J. E. 2016. "Response strategies for curriculum change in engineering". *International Journal of Technology and Design Education*, 26,3, 391-411.

Kolmos, A., & J. E. Holgaard. "Employability in Engineering Education: Are Engineering Students Ready for Work"? 2019. In S. H. Christensen, B. Delahousse, C. Didier, M. Meganck, & M. Murphy (Eds.), *The Engineering-Business Nexus: Symbiosis, Tension and Co-Evolution*. Philosophy of Engineering and Technology, vol. 32, pp. 499–520. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-99636-3_22

Larsen, P.G., Fernandes, J.M., Habel, J., Lehrskov, H., Richard, V., Wallington, O., & Zidek, J. 2009. “A multidisciplinary engineering summer school in an industrial setting” *European Journal of Engineering Education*, 34,6, 511-526.

Novak, K., & Bracken, S. 2019. “Introduction: Universal Design for Learning: a global framework for realizing inclusive practice in higher education”. In *Transforming higher education through Universal Design for Learning*, pp. 1-8. Routledge.

Qosaj, J., Corti, D., Terzi, S. 2023. “Innovation & Entrepreneurship in engineering curricula: evidences from an international summer school” In *IFIP International Conference on Advances in Production Management Systems*, pp. 461-475. Cham: Springer Nature Switzerland.

Rieckmann, M. 2012. “Future-oriented higher education: Which key competencies should be fostered through university teaching and learning?”, *Futures*, *44,*2,127-135.

Thürer, M., Tomašević, I., Stevenson, M., Qu, T., & Huisingh, D. 2018. “A systematic review of the literature on integrating sustainability into engineering curricula”. *Journal of Cleaner Production*, 181, 608-617.

UNESCO. 2017. “Education for Sustainable Development Goals – Learning Objectives”, ISBN 978-92- 3-100209-0.

Wiek, A., Withycombe, L., & Redman, C. L. 2011. “Key competencies in sustainability: a reference framework for academic program development”, *Sustainability Science*, 6,2, 203-218

Yearworth, M. 2016. “Sustainability as a ‘super-wicked’ problem; opportunities and limits for engineering methodology”. *Intelligent Buildings International*, 8,1, 37-47.

PROMETHEUS CHALLENGE: AN ETHICS TRAINING FOR ENGINEERING STUDENTS

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ABSTRACT

Science and technology have the potential to profoundly transform societies. Employed within a logic of innovation, they disrupt the reference points and values needed to judge and act. This raises several ethical risks, notably the inability to know clearly whether a specific process or technical invention will raise moral issues. Because of their involvement in the design of new technologies, engineers of all specialties are the first to be exposed to this disturbing and unpleasant situation. It therefore seems essential to develop ethics training programs for this specific audience. The Prometheus Challenge is one such proposal. Inspired by the methods of active and creative pedagogy, this two-days training aims to develop awareness of ethical issues, reflexivity, and autonomy in judgment. It also fosters the ability to formulate appropriate ethical assessments of science and technology problems through collective debate. It has already been tested with four groups of students from

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several engineering schools in Grenoble (October 2022 and February 2024). The feedback from students and facilitators is mostly positive. They praise the interdisciplinarity made possible by the mix of students from different backgrounds and the presence of various facilitators trained in ethics. They also appreciate the alternation between theoretical content and debate time, that raises awareness about ethical issues and allows them to reflect on their future engineering profession.

1 INTRODUCTION

Ethics is recognized both as a graduate attribute and a professional competence in the ENAEE (European Network for Accreditation of Engineering Education) and IEA (International Engineering Alliance) guidelines, which represent engineers in 35 countries globally. Indeed, teaching engineers about ethics is crucial for several reasons. First, choices relating to sciences, technologies, and public policies must be ethically justified, i.e. by considering socially accepted and defensible values in the context of public debate. Second, the favorable image of positivist rationalism, which has prevailed since the nineteenth century, is now in decline. Trust in science and technology is being challenged due to past industrial disasters and reactions to the current environmental crisis. This public distrust is also reinforced by the fact that engineering is often subject to a logic of productivity and profitability, relegating ethics to the background. Finally, the continuous technological innovation disrupts uses and ethical points of reference that are needed to judge and act. This raises questions about the practical application of ethics by scientists and engineers. Hence, it seems essential to propose ethics training specifically adapted to these professions and integrated into their training curriculum. This is the goal of the Prometheus Challenge, a teaching method invented by Prof. Thierry Ménissier (philosophy, Université Grenoble Alpes) (Ménissier 2022).

Based on an active and creative pedagogical approach, the Prometheus Challenge aims to develop awareness of ethical issues, reflection, autonomy of judgement, and the ability to formulate appropriate ethical evaluations for the problems posed by the design and use of technologies through collective debate. It also aims to provide philosophical knowledges adapted to current ethical issues and moral dilemmas encountered in the different fields of science and engineering.

By invoking the name Prometheus, we wish to express that today’s engineering students potentially find themselves in the situation experienced by the titan of Greek mythology. This legend is related by Hesiod in his Theogony: Prometheus gave fire to humans after stealing it from the Olympian gods. This present, fire, the symbol of technical intelligence, turns out to be ambivalent. While it is an effective means of transforming matter, it is also potentially destructive and dangerous if left unchecked. Moreover, the myth tells us that the possession of fire carries the risk of fostering what the ancient Greeks called hubris: a propensity for excess and violence, which can lead to uncontrolled and potentially destructive behavior for the individual and society. The myth of Prometheus therefore seems to contain a warning about the dangers associated with the use of technology and the risks inherent in its advances. The exploitation of technical tools, the acquisition and domination of technical knowledge, as well as the development of technological and scientific power, represent major challenges for humans. Some psychoanalysts even go so far as to speak of a deep and insurmountable guilt, described as "Promethean guilt" (Azar

2015). This myth has resurfaced in popular culture with remarkable force, recurrence and fecundity, whether through novels since Mary Shelley's "Modern Prometheus" (Shelley 1818), or more recently in mainstream films, such as the Prometheus of Ridley Scott in 2012. These numerous revivals reflect the importance of the myth of Prometheus for our time. Today's scientists and engineers are faced with the challenge of mastering powerful science and technology, with effects that are often ambiguous and potentially disturbing for society and nature.

In this article, we wish to present the context and method of this training. Then, we will analyze the sessions organized up to now to reflect on how best to promote ethics training in the scientific and engineering community.

2 BACKGROUND

The Grenoble area is a major center for research and innovation, sometimes referred to as "Europe's Silicon Valley". It boasts numerous cutting-edge infrastructures, including the European Synchrotron Radiation Facility. Grenoble Alpes University is also a major center for technical and scientific training. In particular, it is home to the Grenoble Polytechnic Institute (Grenoble INP), which groups together 7 engineering schools and 1 management school. Including the integrated preparatory cycles, Grenoble INP welcomes over 8,000 students and awards around 1,500 engineering diplomas per year.

In 2022 et 2024, Grenoble INP organized the Kaleidoscope week: an event meant to bring together students from different schools during several educational workshops. Each student had the opportunity to choose from about fifty different activities, including the Prometheus Challenge. This challenge was proposed and supervised by members of the Ethics & AI chair of the MIAI Institute (Multidisciplinary Institute in Artificial Intelligence), one of the 3 French research institutes in artificial intelligence. We also relied on the tools and methods developed by Promising, the pedagogy and creative thinking department of the university.

3 THEORETICAL AND METHODOLOGICAL FRAMEWORK

3.1 Theories at the service of practice

The Prometheus Challenge is scheduled to last 2 days. It is divided into a series of nine modules, listed in Table 1. Its purpose is to make students practice ethics. It is based on an active problem-solving pedagogy where theory is necessarily linked to practice.

The training begins with workshops to raise student’s awareness of the ethical issues associated with engineering professions (modules 1 to 4). During module 5, we present four distinct forms of reasoning used to address moral problems[2] : Kantian deontologism, Bentham’s utilitarianism, Aristotelian virtue ethics and axiology. After a short presentation of these forms of reasoning, students are invited to implement them on a topic of their choice to test their differences and limitations.

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[2] Deontologism, Utilitarianism and Virtue ethics are the normative ethics theories more commonly studied, see (Billier 2014) or (Downs 2012). Axiology (theory of values) was added, since it is particularly well suited to tackling ethical challenges.

The choice of these theoretical currents responds to a methodological concern: since ethics is not an absolute value and ethical judgments may vary, we choose to appeal to different schools to account for the different possibilities of reasoning. The Prometheus Challenge thus demonstrates an assumed eclecticism.

In addition to the four forms of reasoning mentioned, two theoretical elements that are particularly important for ethical reflection are also mentioned: the notion of responsibility and that of value. The notion of responsibility is introduced through the figures of Prometheus, then that of Frankenstein (introduction to the challenge and module 3), to raise the consequences of actions undertaken in the name of technology and science. Indeed, these two literary figures open the door to a reflection on the anticipation of rebound effects and the long-term perspective of the practice. Then, the work on values (modules 6 and 7) allows us to return to the foundations of philosophical reflection on morality and its norms. Values, which are strongly rooted in culture, are intuitively mobilized to address morally problematic situations. A work of reflection on values, justification, and hierarchy allows us to take a step back from this intuitive level, to register on a critical level (according to Richard Hare's distinction (Hare 2017)) and thus refine the ability to make ethical judgments.

Table 1. Modules' descriptions

Modules	**Description of the activities carried out by the students**	**Duration**
Identify ethical situations and make recommendations		
1) Ethical risks	Choose a technology that raises risks. Identify those that fall under ethics. Formulate recommendations to mitigate these risks.	30 min
2) Cases of conscience	Imagine an example of an ethical dilemma that an engineer may face. Describe possible solutions.	30 min
3) Frankenstein's responsibility	Identify examples in history or current events of rebound effects that are harmful or dangerous for humanity. Formulate recommendations to frame/regulate these effects.	30 min
Imagining desirable futures		
4) Utopia or dystopia	Using a recent (or future) technology, imagine an ideal society. Represent it graphically.	1h-1h30
Enriching Ethical Reasoning		
5) Ethics beyond utilitarianism	Analyze the dilemmas identified above from the perspective of different forms of ethical reasoning (utilitarianism, deontologism, aretaism, axiologism)	1h30-2h
Reflect on the ethics of your profession		
6) Engineer's values	Identify a list of values that can be claimed by engineers.	45 min
7) Value cards	Depict the most important value(s).	45 min

8) Engineer's oath	Prepare a solemn declaration committing to respect the above values.	1h-2h
9) What's next?	Imagine what actions can be implemented at the end of the training.	30 min

3.2 An active and creative pedagogy

The pedagogical challenge of this training is to transmit knowledge in ethics that can be used to address complex situations. To achieve this, we rely on an active pedagogy based on creativity and emotion. We take into account the three strategies proposed by (Vanpee, Godin, et Lebrun 2008) for implementing active teaching in large group: 1) placing the student in an active situation based on global and complex tasks; 2) splitting up the groups; 3) encouraging the transfer of learning by implementing contextualized teaching. Each theoretical content is followed by group application exercises, based on concrete cases proposed by the facilitators and by the students. The modules on ethical risks and cases of conscience (modules 1 and 2) allow a step back on the social dimension of the engineering profession, particularly concerning technological innovation. Then, the participants are engaged in a reflection on the potential unforeseen rebound effects related to scientific development (module 3), and next to formulate ethical assessment, based on the work on values (modules 6 and 7).

This teaching strategy aims to include the three main factors that encourage student commitment, acording to (Viau 2009). First, a sense of value of the activity is created by contextualising it to the students' future profession. The second factor is controllability, which refers to the potential control that students have over the course of the activities proposed to them. Since the students themselves choose the subjects on which they work, the sense of controllability is very high in the Prometheus Challenge. The final factor is the sense of competence to complete a task, which is facilitated by providing them with the key elements (theoretical content, support) so that they can carry out the activities required.

In this way, students are led to develop reasoned points of view that are subject to a rational, collective and supervised discussion. Here, the role of facilitators is essential. They are responsible for guiding discussions during the group reflection process and then in plenary. This follow-up makes it possible to clarify the theoretical elements covered and to highlight the students' mode of reasoning. Facilitators must then be able to adapt their knowledge of ethics to the problems proposed by the participants during the workshops.

In addition, the Prometheus Challenge calls for creativity, assessment, and emotion to promote ethical sensitivity and the appropriation of theoretical concepts. Creativity and assessment are at the top of Bloom's taxonomy of educational objectives, because they foster learning that lasts (Anderson et Krathwohl 2001). Emotion is also an important variable in the learning process (Puozzo 2013) since there is a "close relationship between the content of an idea and the affective dimension to which it is attached" (*Ibid.*). In the case of the Prometheus Challenge, a real work on emotion is required from all the participants. From the very beginning of the training, the facilitators have to create an atmosphere that makes students willing to work collectively, to listen and to be open to each other. Since the participants don't know each other, each half-day starts with a few minutes of warm-up and ice-breaker activities. The body is engaged by vocal exercises or by movements where the awareness of others is important (for example: walk in a defined area and follow changes of pace).

Regarding the content, the modules are introduced with mythical narratives, literary and historical references with strong symbolism, to question the engineering profession, its potentials, and its risks. Group exercises seek to deepen this emotional work, engaging the creativity of the students. It is also an opportunity for them to engage in activities that are rarely present in their usual curriculum, such as drawing or theatrical performance. In particular, the modules on utopia (module 4), values (module 6-7) and engineer's oath (module 8) lead students to imagine the potential of their profession, as well as the possible contributions they can make, by giving free rein to their imagination. Examples of their creations are showed in Figure 1.

Fig. 1 Examples of student creative productions.
On the left, module 4 (utopia). On the right, module 7 (value cards).

4 RESULTS

For its first edition at Kaleidoscope Week (October 2022), the Prometheus Challenge took place over two sessions, with a total of 175 participants. In February 2024, the second edition took place, with 53 participants also spread over two sessions[3]. We collected the participants' feedback over the two years through an online survey filled at the end of the training (module 9). The first part of the survey contains several closed-ended questions regarding the session of the challenge, school of the student and overall assessment. The second part of the survey consists of three open-ended questions: strengths of the training, weaknesses, and suggestions for improvement.

We received 107 responses in 2022 and 46 responses in 2024. There are no substantial differences between the first and second editions, nor according to the schools from which the participants come from.

The overall assessment of the activity is positive, with an average of 4.4/6, on a scale where 4 corresponds to "satisfactory" and 5 corresponds to "very satisfactory"

[3] This year we see a lower number of students, partly because in 2022 several schools have asked their students to choose an activity on ethics. This year it was no longer the case.

(see Figure 2). Among the strengths identified by the respondents in both parts of the survey, we can mention the plurality of the discussions (favorized by the instruction to create groups between students from different backgrounds), as well as the balance between theory and practical work.

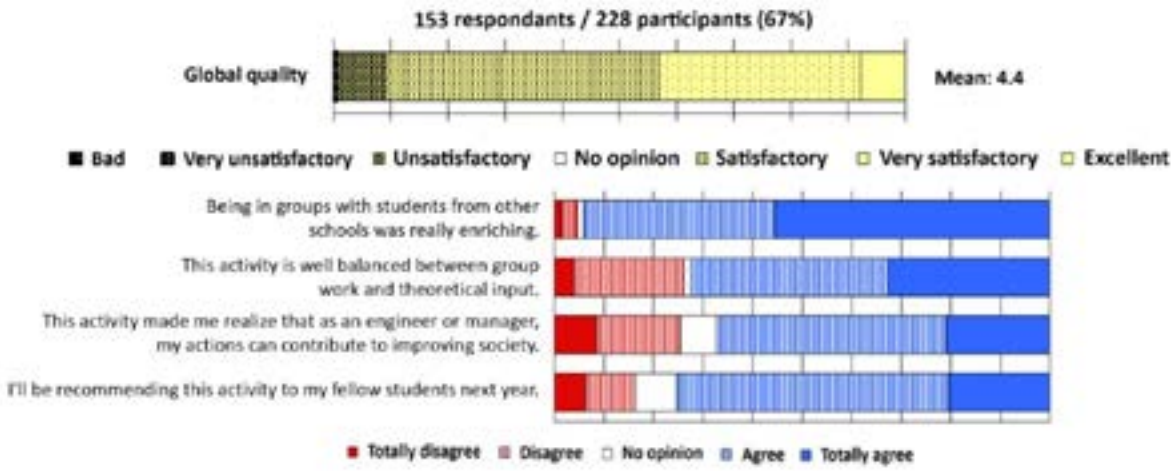

Fig 2. Student survey results (2022 and 2024)

While answering the open-ended questions, the students mentioned four other positive aspects: the theoretical contributions in philosophy (9 mentions for the year 2024, out of 46 responses); the role played by the facilitators (7 mentions in 2024), whose relevance of their interventions and varied backgrounds are appreciated ("supervisors who get out of the habit", "Interventions by philosophy professors"), as well as reflexivity on the engineering profession ("open-mindedness and reflection on our future actions") and the pedagogical approach integrating collective debates.

These elements seem significant, since they are then found in the participants' proposals. For the 2024 session, 7 people expressed that they would have appreciated more theoretical or philosophical elements. In addition, the role of the speakers is also mentioned 7 times in 2024, but this time concerning their support for the groups and their feedback on the activities carried out, as a point to improve or a weak point ("Make more visits to the groups"). These remarks seem to us to underline the involvement of the students in the exercises. In 2024, 4 students proposed to increase debate times.

Overall, the pedagogical objectives seem to have been achieved. We interpret the requests of some participants for more philosophical content and time for debates as a proof of success in raising awareness of ethical issues. Exchanges within each group and plenary discussions allowed us to see an appropriation of the theoretical content. Among the points for improvement, we recognize the importance of strengthening exchanges between student groups, an important moment for clarifying the ethical concepts.

5 CONCLUSION

Active pedagogy is the key to success for the Prometheus Challenge. By alternating the transmission of theoretical knowledge with practical collective work, in a creative and welcoming atmosphere, it allows an open-mindedness that is conducive to ethical reflexivity. The challenge is experienced by the participants as an enrichment and a valuable opportunity to reflect on their future engineering practices. The post-challenge survey analysis shows their engagement and satisfaction. It must be underlined that the role of facilitators is crucial. While transmitting philosophical theories, they must continuously adapt to the participants by clarifying the concepts to their understanding and integrating their topics of concerns, thus strengthening their involvement and interest in the challenge.

The Prometheus Challenge places animation at the heart of its innovative pedagogy by offering a continuous and complete training process to participants. After completing the training, each participant has the possibility to become a facilitator. To obtain the facilitator certification, a candidate needs to participate in a 6-hour preparation seminar and to accompany a complete cycle of the challenge as a co-facilitator. They can then join the team of facilitators, a think tank that contributes to improve the challenge, exchange best practices, and develop their skills in ethics. This ongoing training process ensures respect for the values of democratic inclusion defended by the first creator of the challenge. It also promotes the renewal of the team of facilitators, whose expansion and diversification allow to reach an increasingly wider public.

Although originally proposed for engineers, the Prometheus Challenge has been designed to be easily adapted to other audiences. A double transformation can be carried out: the modification of the initial myth and the choice of suitable examples, without upsetting the order of the modules. A version for management students could be based on the myth of Midas, which describes the curse that befalls the ruler of Phrygia, punished by Dionysus for wanting to accumulate too much money. A version oriented towards environmental ethics has been tested and named by the students from the myth of Persephone, which evokes the regular return of the seasons. In these modifications, the initial myth plays the same role as that of Prometheus: to provide an imaginative and emotional basis that engages the participants in ethical reflection.

REFERENCES

Anderson, Lorin W., and David R. Krathwohl. *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives: complete edition*. Addison Wesley Longman, Inc, 2001.

Azar, Amine. 2015. "Trois sources de la culpabilité : surmoïque, œdipienne et prométhéenne". *Ashtaroût, bulletin volant n° 2015·0303*, mars. https://www.academia.edu/11295107/Trois_sources_de_la_culpabilit%C3%A9_surmo%C3%AFque_%C5%93dipienne_and_prom%C3%A9th%C3%A9enne_version_remani%C3%A9e_.

Billier, Jean-Cassien. *Introduction à l'éthique*. Paris : Presses Universitaires de France, 2014. https://www.cairn.info/introduction-a-l-ethique--9782130632610.htm.

Downs, Jennifer. "A Brief History of Ethics". *Ethics in Forensic Science*, 2012, 1-25. Oxford: Elsevier.

Hare, Richard M. "Methods of bioethics: Some defective proposals". *Ethics and Medical Decision-Making*, 2017, 393-406. Routledge.

Ménissier, Thierry. *Challenge Prométhée. Une formation pratique à l'éthique pour les scientifiques et les ingénieur.es*. TheBookEdition, 2022.

Puozzo, Isabelle. "Pédagogie de la créativité : de l'émotion à l'apprentissage." *Éducation et socialisation*, n° 33 (juin 2013). https://doi.org/10.4000/edso.174.

Ridley, Scott. *Prometheus*. 2012.

Shelley, Mary Wollstonecraft. *Frankenstein; or, The Modern Prometheus*. 1818. https://gutenberg.org/ebooks/42324.

Vanpee, Dominique, Véronique Godin, and Marcel Lebrun. "Améliorer l'enseignement en grands groupes à la lumière de quelques principes de pédagogie active." *Pédagogie médicale,* 2008, 32-41.

Viau, Rolland. *La motivation en contexte scolaire (6e édition)*. De Boeck Supérieur, 2009.

TESTING IS LEARNING: USING RANDOMIZED, PARAMETRIZED, AND DIVERSIFIED WEEKLY ONLINE QUIZZES WITH ANSWER-DEPENDENT FEEDBACK IN MULTIVARIABLE CALCULUS

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ABSTRACT

In this paper, we present the development and evaluation of an online quiz system designed to enhance learning outcomes in multivariable calculus (MC) for engineering students. MC is crucial for understanding various engineering disciplines but often poses challenges due to its abstract nature. The quizzing system integrates formative and summative assessments, drawing on cognitive psychology research, and aligns with educational principles emphasizing active learning. Results indicate a positive correlation between engagement in practice quizzes and graded quizzes scores, supporting the system's effectiveness in improving student performance. However, student feedback suggests areas for improvement, particularly in quiz randomization and feedback adaptiveness. The study underscores the importance of integrating technology-enhanced learning tools into mathematics education, offering insights for future refinement and implementation in engineering curricula.

1 INTRODUCTION

Multivariable calculus (MC) is a core course in the mathematical curriculum of engineering programs, offering a crucial mathematical framework for the analysis and resolution of complex problems across a spectrum of engineering disciplines. This course builds upon the foundational knowledge acquired in introductory Calculus, extending mathematical concepts to multiple variables and enabling engineering students to model problems more accurately. MC is essential for the mastery of fundamental subjects such as thermodynamics, kinematics, and fluid mechanics, which are integral to the engineering discipline.

However, despite its critical importance, MC poses significant challenges to engineering students as concepts are built up sequentially, requiring sufficient proficiency at each step. MC is frequently experienced by students as a challenging and abstract course, which can lead to frustration and disengagement. In response to these challenges, we developed a structured online quizzing system, incorporating both formative and summative elements, based on research insights from cognitive psychology and in alignment with the institution’s vision on education and assessment. The aim of the study presented in this paper was to evaluate the impact of the Quiz System on student performance and their subjective learning experience.

1.1 Theoretical and Practical Underpinning for the Quiz System

The act of (repeatedly) recalling previously learned information from memory has been proven as a robust effect to enhance learning and long-term retention (Agarwal et al., 2021; Rowland, 2014). This phenomenon is also referred to as the *testing effect* or *test-enhanced learning* (Roediger & Karpicke, 2006). Studies exploring this effect in the classroom showed that weekly quizzes improve end-of-course test performance (e.g. McDaniel et al., 2007). In the context of calculus courses specifically, research suggests that practice testing benefits within-semester retention (Lyle et al., 2020; 2022). Researchers attribute the impact of this phenomenon to the fact that (repetitive) practice testing requires active, recurring engagement with the material and promotes deeper processing (Dunlosky et al., 2013). Though, studies so far often take place in a laboratory or controlled setting. Therefore, it has been stressed that further investigation is required on how to establish the power of practice testing in authentic educational settings (Dunlosky et al., 2013).

Corresponding with these research insights, the education institution's vision on education focuses on a student-centred teaching method that promotes active learning, emphasizing four learning principles: constructive, contextual, collaborative, and self-directed learning (CCCS). Within this framework, the quiz system plays a crucial role in fostering self-directed learning. It encourages students to plan, monitor, and evaluate their own learning process by engaging with the practice questions (PQs), possibly improving student learning (Gaspar Martins, 2018). Regarding assessment, the institution highlights a balance between assessment for formative evaluation and summative decisions.

In this line of reasoning, the PQs allow students to check their understanding of the subject matter at any time and as many times as they want. Moreover, the answer-dependent feedback is necessary and timely, allowing students to update their learning trajectory. The final question of each quiz asks the student to estimate how many questions they got right, providing a reflective moment in each quiz. In addition, the weekly graded quizzes (GQs) spread out the summative decision over multiple and frequent insights into student learning, obtained in a low-stakes environment. All in all, the quiz system as investigated in this study is built on a robust framework from both a theoretical as well as a practical perspective on student learning.

1.2 Research Context: Multivariate Calculus

Multivariable Calculus is an intermediate-level mathematics course of 5 ECTS in the BSc Circular Engineering at the institution where the research was conducted. The course had 59 students and was taught in period 5 (April-May) of the first bachelor year, alongside Thermodynamics, building on the prerequisite courses Calculus and Linear Algebra, which are taught in Period 1 and 2, respectively. The course was divided in seven modules focusing on: 1) vectors and the geometry of space, 2) infinite sequences and series, 3) partial derivatives, 4) vector-valued functions and motion in space, 5) optimization, 6) multiple integrals, and 7) integrals and vector fields. Each module featured one lecture and one or two tutorials, in which 12-15 students come together for interactive group sessions. While tutorial attendance was mandatory, lectures were not. Pre-lecture and pre-tutorial tasks helped the students to prepare for the content of the lectures and tutorials.

The course featured assessment components for formative evaluation and summative decisions. The assessment for formative evaluation included two voluntary ungraded components: a prerequisite quiz at the start of the period and PQs, which were aligned with the GQs. The assessment for summative decisions includes three mandatory graded components: a closed-book written exam (70%), a team assignment (15%), and weekly GQs (15%). The components were weighted into a numerical grade on a scale from 1 to 10, with 10 being the highest possible score and 1 the lowest. A bonus point could be earned by making the pre-requisite quiz and the pre-lecture and pre-tutorial tasks. The course is developed and hosted on the Learning Management System CANVAS.

2 METHODOLOGY

2.1 Mixing Formative and Summative Assessment: Repeated Practice and Graded Quizzes

For each module, we introduced topic-aligned PQs and GQs where students had the flexibility to attempt the PQs multiple times and receive fast automatic grading and instant feedback, in line with existing systems (Greenhow, 2015; Lowe, 2015; Marjoram 2013). The feedback mechanism is tailored based on the accuracy of the response: incorrect or partially correct answers prompt the delivery of hints or partial solutions to guide the student, while correct answers are met with a "validation" response, providing a detailed, worked-out solution. Questions can also feature neutral information that is provided regardless. Our strategy aims to enhance the formative and feedback-driven aspect of the PQs. Similarly, the GQs follow this feedback-centric approach, with the key distinction that they can only be attempted a single time. Students decide themselves when to move on from PQ to GQ, in line with self-directed learning principles, see Fig 1.

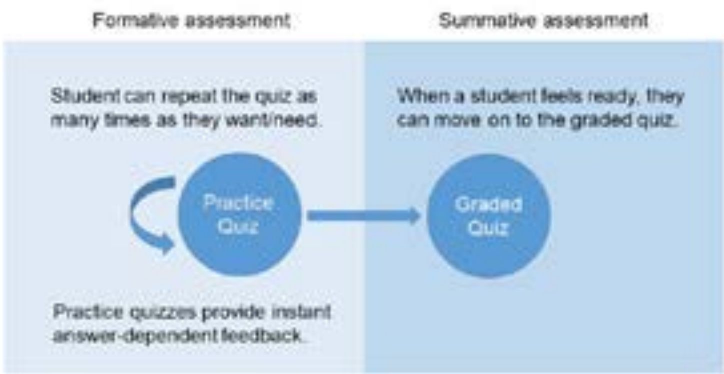

Fig. 1. Successive, topic-aligned practice and graded online quizzes fit the UM vision on assessment, combining formative and summative components, and encouraging students to take ownership of their learning by letting them decide on when they feel ready.

This PQ-GQ combination is repeated weekly for the whole period, creating multiple “low”-stake assessments that feature both a formative and summative component. This approach aims to nudge the students to “stay on track,” see Fig 2.

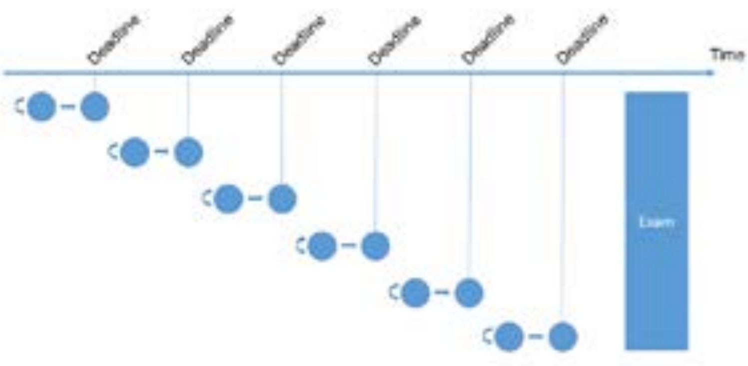

Fig. 2. Multiple, frequent, “low”-stakes practice quizzes and “mid”-stakes graded quizzes with instant answer-dependent feedback build up to the final exam in this course. Multiple, clearly communicated deadlines nudge students to stay on track throughout the period.

2.2 Meaningful Retries: Randomization, Parametrization, and Diversification

PQs with unlimited retries requires each retry (or at least the first few retries) to be meaningful for the learning experience. If the quiz is static, i.e., it remains the same after every retry, then students will not be incentivized to retry multiple times. If the quiz, on the other hand, is *dynamic*, i.e., it changes after every retry (in a reasonable way), then students are nudged towards multiple retries, which can positively affect their learning experience. In order to make multiple retries meaningful, we use three guiding principles: 1) randomization, 2) parametrization, and 3) diversification.

2.2.1 Randomization

The teacher constructs a quiz in Canvas by choosing questions from item banks. Questions banks are tied to a specific Intended Learning Outcome (ILO) allowing teachers to choose which ILOs can be assessed in a particular quiz, see Fig 3. Instead of choosing a particular question in an item bank, we randomly pull a question from each item bank, making each quiz unique. It is crucial to have sufficient questions per item bank to make the quizzes sufficiently randomized. Given time constraints, we aimed to implement five questions per item bank. (The number of questions in an item bank can range between 1 and 10, but, *on average*, we have about five questions per item bank.) As an example, a quiz consisting of ten questions, drawing from item banks with five questions each, would have 5^{10} (i.e., about 10 million) possibilities.

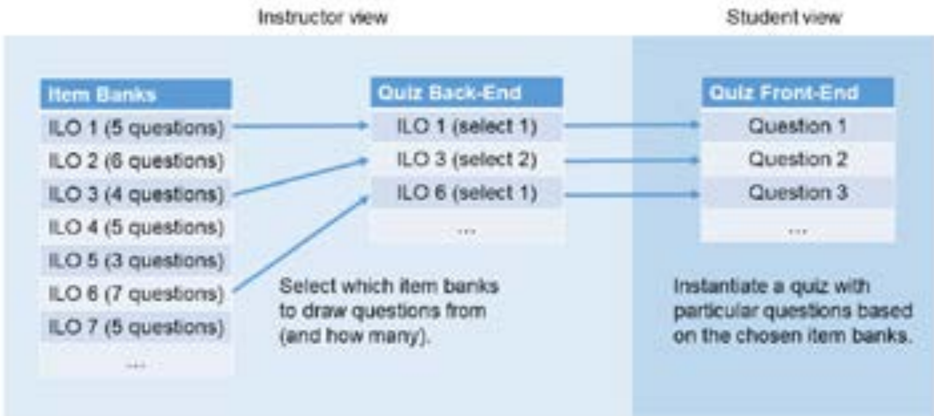

Fig. 3. Randomizing the quiz questions makes the quizzes more meaningful for the students. This is possible by using the item bank system in Canvas, drawing random questions in the back-end and generating unique instantiations for the student.

Randomization can make multiple retries more meaningful. In addition, PQs and GQs are constructed in the same way, hence, students are rewarded for attempting the PQs multiple times because it will allow them to maximize their score on the GQ. This of course has the downside that students can retry many times, pushing the limits of the system, to obtain more answers, thus the importance of parametrization.

2.2.2 Parametrization

Parametrization allows the construction of apparently unique quizzes. We achieve this by using the Canvas-supported formula question, which is a numeric-answer question that involves one or more parameters. One can set bounds on each of the parameters and number of decimals used. Based on these settings, a desired number of possible problems and corresponding solutions (with a margin of error) can be generated. In our question repository 110 out of 510 questions are parametrized, i.e., 21.6% of the repository. For example, consider the integral:

$$I = \int_a^b \int_0^{\sqrt{x}} \frac{y}{cx}\, dy\, dx \tag{1}$$

Where a, b, c are integers and bounded as $1 \le a \le 4$, $5 \le b \le 10$, and $1 \le c \le 10$. The solution of the integral is given by $I = \frac{b-a}{2c}$.

2.2.3 Diversification

We used a variety of Canvas question types to vary the experience of each quiz. Table 1 shows the question types used and their distribution. Multiple choice, multiple answers, formula, and numerical answer questions were mainly used because they are the most straightforward for mathematics-related topics.

Table 1. Distribution of question types in our item banks.

Question Type	**Amount**	**Percentage**
Multiple choice	210	41.2
Formula	110	21.6
Numerical answer	60	11.8
Fill-in-the-blank	41	8.0
True/False	31	6.1
Multiple answers	23	4.5
Matching	17	3.3
Categorization	12	2.3
Hotspot	5	1.0
Ordering	1	0.2
Total	**510**	**100**

2.3 Implementation

The quiz system consists of 510 quiz questions across 109 item banks with one to ten questions per item bank and on average five questions per item bank, where 110 out 510 are parametrized. The quiz system is implemented a separate course in the Canvas LMS system using item banks and quizzes. The course features information on the system so that other teachers can easily join, update, change, and expand the item banks and quizzes as they see fit.

We created item banks aligned with specific ILOs using a simple naming convention: topic – subtopic – concept, where the latter is optional, with a list of tags for ease of sorting. Sub-concepts are used to differentiate further if necessary. The topics correspond to the seven modules mentioned above. For example, the multiple integral module was structured in three topics: double, triple, and multiple integrals, and further refined as illustrated in Table 2.

Table 2. Example of the naming convention used for organizing the item banks in Canvas.

Double integrals	Rectangular coordinates	Computation
		Construction
		Order of integration
		Splitting
	Polar coordinates	Computation
		Construction
		Order of integration
	Substitution	
	Transform	Rectangular to/from polar

2.4 Data Collection

We collected course grades, a pre- and post- survey, and the default end-of-period course evaluations. The grades consist of multiple components: weekly quizzes, assignments, exam, and resit, and anonymized by the course coordinator. We also extracted metadata such as number of attempts, difficulty indices, etc. The pre- and post- survey took place in a tutorial at the start/end of the period, resp., but before the final exam. The surveys were administered anonymously via Qualtrics. The end-of-period course evaluations are also anonymous.

All students in the course (N = 59) were considered possible participants in the study. They were informed at the start of the course about the data collection. The assessment is an integral part of the course. Participation in the pre-survey (N = 46), post-survey (N = 45), and course evaluations (N = 11) are voluntary. No remuneration was provided. We received ethical approval by the institution’s ethical review committee to conduct the research. We omit the course evaluations because the number of submissions were very low.

3 RESULTS

3.1 Grade Analysis

Grade analysis indicates that students that engage more in the PQs tend to have higher GQ scores, see Fig. 4 (left). This makes sense as the PQs and GQs draw from the same item banks. The effect on the final exam score is less clear, see Fig. 4 (right), which can be due to the (closed-book) exam having different question styles.

Rounded mean number of attempts on practice quizzes

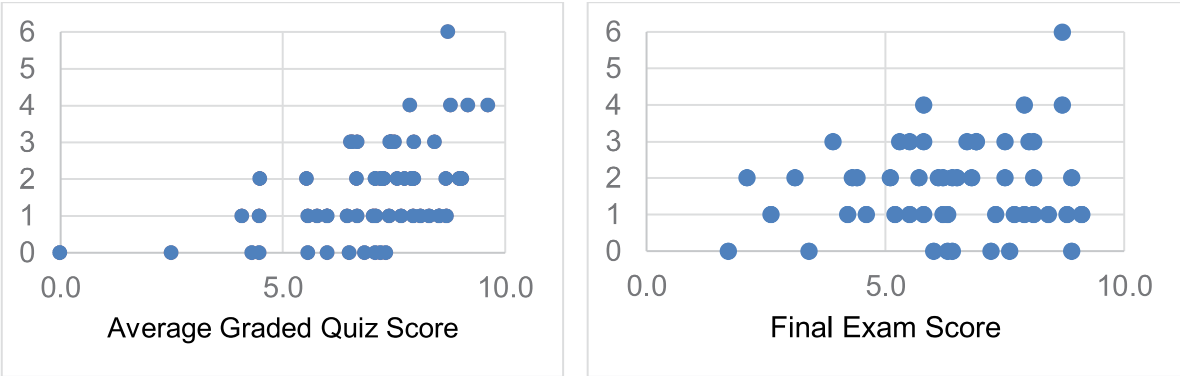

Fig. 4. Students that engage more in the practice quizzes tend to have higher average quiz scores, while the effect on the exam score less pronounced.

3.2 Survey Analysis

3.2.1 Practice Quizzes

The survey seems to support that students reported positively about the weekly PQs as a learning experience, Fig. 5, especially as a preparation for the GQs.

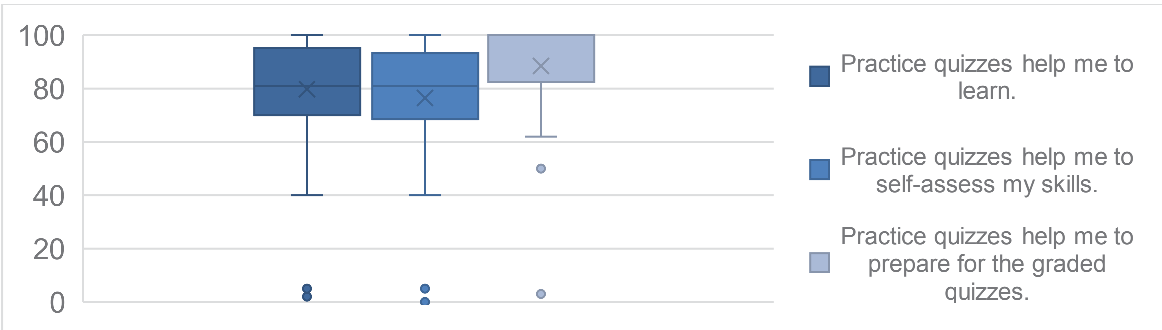

Fig. 5. Students experienced the graded quizzes as a helpful learning experience overall, especially as a preparation for the graded quizzes. Students indicated how much they agree with the statements on a scale of 0 (no agreement) to 100 (full agreement).

The responses to the open-ended question "*Why do you think the practice quizzes helped you to prepare (or not) for the weekly graded quizzes?*" indicated two main advantages of PQs. First, students reported that PQs can give a good impression of what to expect for the GQs: "They give us ideas on the types of questions that will be there and provide us with technique about how to approach the questions." Some students indicated that this could also have a perverse negative effect "…because most of the time they're very similar and so I do the practice quizzes so often until I understand them and then the graded ones are pretty easy." On the other hand, this can also be seen as a positive because at least they engaged a lot with the PQs. Second, students indicated that the PQs are a great revision tool: "I think the practice quizzes enable me to see what topics I need to review to take the graded quiz, and overall which topics I need to review for the exam." Another student mentioned: "It trains you on the kind of problems you need to prepare for in the graded quiz, it particularly helps with time management and acts as a reality check for acquired knowledge. It also incentivises you to revise questions that took longer to answer." Finally, students suggested possible improvements to the PQs: "It might be nice to have a randomized question (or two) from a previous section to help with interleaved learning. I would not necessarily suggest this for the graded quizzes though."

3.2.2 Graded Quizzes

The survey seems to support that students reported positively about the weekly GQs as a learning experience, see Fig. 6, but less so as a preparation for the final exam.

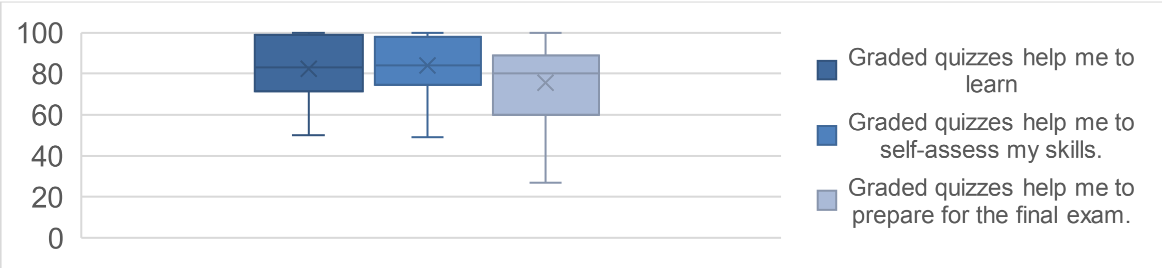

Fig. 6. Students experienced the graded quizzes as a helpful learning experience, but less so for the final exam. Students indicated how much they agree with the statements on a scale of 0 (no agreement) to 100 (full agreement).

The responses to the open-ended question "*Why do you think the graded quizzes helped you to prepare (or not) for the final (exam)?*" were mixed. On the positive side, students indicated that GQs helped them to stay on track ("They allow me to assess my progress throughout the period rather than having only the exam at the end as a final assessment. This means that throughout the period I can see how well I am doing and if there are any gaps in my knowledge.") and that they lowered the stakes of the exam ("They were helpful and since they count for credit they also take a little bit of pressure off."). On the other hand, students reported their concern about a possible difficulty gap between the GQs and the final exam: "I think the graded quizzes allow me to see where I am at in understanding the material, and where I need to review. I am concerned the exam will be a lot more difficult than the graded quizzes, as I imagine the questions will cover multiple topics." and "I feel like only some questions from graded quizzes can reach exam level difficulty. However, they are good to get a decent base on the subject to be able to tackle difficult questions."

3.2.3 Randomization and Parametrization

The survey indicates that randomization and parametrization can be improved, see Fig 7. Students' responses to the question "*Were the quizzes sufficiently randomized and parametrized?*" were mixed. While some students found the quizzes sufficiently randomized, others argued the contrary: "They weren't very randomized, you had to do the quiz more than five times to get the full range of questions, doing it twice often just gave you the same questions. Also, the answer dependent feedback was not very helpful. It would be better just to explain the correct worked out solution." This is because item banks have between 1 and 10 questions; some banks need more questions to improve the randomization. Interestingly, students were also critical about the *need* for randomization in the GQs: "I don't believe they should be randomised because I think it is unfair that all students are given a different quiz that contributes to their final grade, when some questions could be 'easier' to different students and that means that it doesn't feel good."

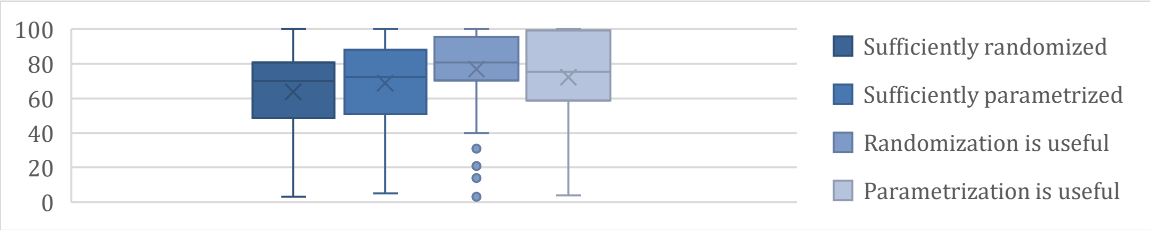

Fig. 7. Students' experience regarding randomization and parametrization was mixed. Students indicated how much they agree with the statements on a scale of 0 (no agreement) to 100 (full agreement).

3.2.4 Answer-Dependent Feedback

The survey indicated some dissatisfaction with the strategy for answer-dependent feedback, e.g., "Please give the worked out solutions to the questions regardless of if we get the answer right or not." Some students seemed frustrated when they got the answer wrong, and the feedback only gave a hint on how to continue instead of a fully worked-out solution: "I would prefer if the practice quizzes on the answers you got wrong give you more details for what you got wrong." Indeed, feedback should be more adaptive and personalized, but we are limited by the LMS' functionality.

4 SUMMARY AND ACKNOWLEDGEMENTS

The aim of this project was to develop a repository of questions that are aligned with ILOs of MC. Our approach featured weekly PQs and GQs with answer-dependent feedback. Randomization, parametrization, and diversification creates a unique student experience per quiz attempt. The quiz system is constructed so that it can easily be used and expanded by other teaching staff. Weekly GQs provide multiple "low"-stakes tests with instant-answer dependent feedback, nudging students to stay on track (Dunlosky et al., 2013). The PQs lowers the stakes of the GQs, providing additional scaffolding and increasing self-directedness. The approach is aligned with the institution's vision on assessment, providing multiple, frequent, and "low" stakes formative and summative assessments. Future work involves further randomization and diversification, the introduction of interleaving and improved feedback.

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REFERENCES

Agarwal, P. K., Nunes, L. D., & Blunt, J. R. (2021). Retrieval practice consistently benefits student learning: A systematic review of applied research in schools and classrooms. *Educational Psychology Review*, 33(4), 1409-1453. https://doi.org/10.1007/s10648-021-09595-9.

Dunlosky, J., K. A., Rawson, E. J. Marsh, M. J. Nathan, and D. T. Willingham. "Improving Students' Learning With Effective Learning Techniques: Promising Direction From Cognitive and Educational Psychology." *Psychological Science in the Public Interest*, 14, no. 1 (January 2013): 4-58. https://doi.org/10.1177/1529100612453266.

Gaspar Martins, S. "Weekly homework quizzes as formative assessment for Engineering students are a fair and effective strategy to increase learning?" In *Proceedings of INDRUM 2018, Kristiansand, Norway, April, 2018,* 105-114.

Greenhow, M. “Effective computer-aided assessment of mathematics; principles, practice and results.” *Teaching Mathematics and its Applications* 34, 3 (Septemer 2015): 117-137. https://doi.org/10.1093/teamat/hrv012

Lowe, T. W. “Online quizzes for distance learning of mathematics.” *Teaching Mathematics and its Applications* 34, 3 (September 2015): 138-148. https://doi.org/10.1093/teamat/hrv009

Lyle, K. B., C.R., Bego, R.F. Hopkins, J.L. Hieb, and P.A. Ralston. “How the amount and spacing of retrieval practice affect the short-and long-term retention of mathematics knowledge.” *Educational Psychology Review*, 32 (2020): 277-295. https://doi.org/10.1007/s10648-019-09489-x.

Lyle, K. B., C.R., Bego, P.A. Ralston, and J.C. Immekus. “Spaced retrieval practice imposes desirable difficulty in calculus learning.” *Educational Psychology Review*, 34, no. 3 (2022): 1799-1812. https://doi.org/10.1007/s10648-022-09677-2.

Marjoram, M., P. Robinson, C. O’Sullivan, and M. Carr. “Improving the key skills of engineering students in Mathematics.” In *Proceedings of the 41st SEFI Conference*, Leuven, Belgium, September 2013.

McDaniel, M. A., J.L. Anderson, M.H. Derbish, and N. Morrisette. “Testing the testing effect in the classroom.” *European Journal of Cognitive Psychology*, 19, (2007): 494-513. https://doi.org/10.1080/09541440701326154.

Roediger III, H. L., and J.D. Karpicke. „The power of testing memory: Basic research and implications for educational practice.” *Perspectives on Psychological Science*, 1, no. 3 (2006): 181-210.

Rowland, C. A. “The effect of testing versus restudy on retention: A meta-analytic review of the testing effect.” *Psychological bulletin*, 140, vol. 6, (2014): 1432. http://dx.doi.org/10.1037/a0037559.

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An Automatic Grading System for Large Classes

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***Conference Key Areas**: Digital tools and AI in engineering education, Open and online education for engineers*
***Keywords**: Automatic Grading, Infrastructure Management, Engineering Education, Grading at Scale*

ABSTRACT

We present the design, development, and evaluation of an automatic grading system that integrates Moodle with a Kubernetes cluster, aiming to be sufficiently general for use across a variety of courses. Experimentation in two large courses demonstrated the system's capability to support diverse programming assignments, handle substantial concurrent user loads, and enhance the educational experience. Future work will focus on system refinements, exploring additional integrations, and open-sourcing the project to benefit the wider educational community.

1. INTRODUCTION

Automatic testing of programming assignments, recognized for its effectiveness in providing prompt feedback to students and enhancing the scalability of grading processes, is increasingly adopted globally. Within our institution, this trend is reflected across numerous large courses, where we observed similarities in grading processes. We discussed with instructors collectively teaching over fifteen courses across various faculties, each using their own distinct infrastructures, although performing similar functions: students submit their source code for evaluation, feedback is generated on a remote machine and communicated back to them. Developing and maintaining these infrastructures represents a significant investment. Additionally, the presence of multiple systems requires students to adapt to a wide range of user interfaces, workflows, and reporting systems.

This situation highlighted the necessity for a unified system that could be adopted across multiple courses to reduce operational costs and enhance the overall student experience. We identified that an appropriate system would need to be:

- **General:** Not tied to a programming language or assignment format.
- **Simple:** Easy to operate by the students, teachers and system administrators.
- **Automatic:** No human intervention should be necessary for grading.
- **Scalable:** It must be possible to handle thousands of concurrent users, which is crucial to be used during exams and peak submission times.
- **Local:** Students' data must remain within the private network of our institution.

Many existing open-source and commercial solutions (discussed in section 7) do not meet all of these requirements, often being either too specialised, challenging for first-year or non-CS students (e.g., solutions based on Git), or necessitating the outsourcing of data handling.

This inadequacy has prompted us to design and build our own system tailored to these needs, which we present in this practice paper. We evaluated our system over a semester within two significant courses:

- **CS-107: Introduction to Programming (503 students):** The first programming course in the computer science curriculum at our institution. It was important for students to have a simple user interface (UI) since most of them are not yet familiar with tools such as git. Our system was used to automatically grade a self-assessment project and to verify the integrity and proper structure of a larger project.

- **CS-214: Software Construction (383 students):** A second-year course that introduces functional programming, software engineering principles, and formal verification concepts. Here, students completed weekly programming assignments, which were graded using our system. Additionally, our system has also been used to grade its final exam.

In Section 2, we begin by providing a high-level description of the system, followed by details on its implementation in Section 3. We then describe some applications tested in pilot courses in Section 4. The performance and usability of the system are evaluated in Section 5. Finally, future improvements are outlined in Section 6, and we compare our system with alternative solutions in section 7.

2. SYSTEM OVERVIEW

Our system integrates *Moodle* with a *Kubernetes* cluster and our key contribution is establishing a bridge between the two.

Moodle Plugin: Our system extends Moodle through a custom plugin.
Moodle (Dougiamas and Taylor, 2003) is an open-source Learning Management System (LMS) and the officially supported tool for collecting submissions and distributing online material in many universities. It enables educators to create different content types through *Activities*, including static content as well as dynamic content such as quizzes, polls, and assignments. Comparative studies by Kumar, Gankotiya, and Dutta (2011), along with a systematic review by Gamage, Ayres, and Behrend (2022), have underlined Moodle's efficacy and its evolving role in e-learning. Its widespread adoption among faculty and student body and built-in support for useful settings (e.g., the number of allowed attempts and the submission time window) make it a good foundation to build upon.

Kubernetes Cluster: When students submit their work, our Moodle plugin creates a job within a Kubernetes cluster to run a *Docker image* provided by the teacher. Docker (Merkel, Dirk. 2014) is a virtualization technology that has seen widespread adoption over the past decade. Docker allows for the definition of computing environments, known as images, specified in text files. Kubernetes (Hightower, Burns, and Beda 2017) facilitates the creation of clusters where these images can be efficiently deployed and managed. Basing our interface on Docker images gives teachers complete freedom to run arbitrary programs or workflows for grading student submissions, allowing for a diverse range of assessments possibly beyond programming assignments.

Web Service: The Moodle plugin communicates with the Kubernetes cluster through a small web service. This additional component enables more fine-grained access policies than a direct connection between Moodle and Kubernetes would allow, and also enhances system modularity.

3. IMPLEMENTATION

We extend Moodle's capabilities; and specifically the *Assignments* activity, with a plugin. This plugin allows us to hook into certain events such as submissions by students and assignments creation or deletion by teachers. In particular, the plugin performs an HTTP request to our web service, notifying it of a new submission ❶. In addition to defining webhooks, our plugin extends the Moodle API by providing an additional HTTP endpoints that allows downloading the submission ❺ and uploading grades and feedback to submissions being graded ❾. This endpoint is secured using Moodle's *web services authentication* mechanism.

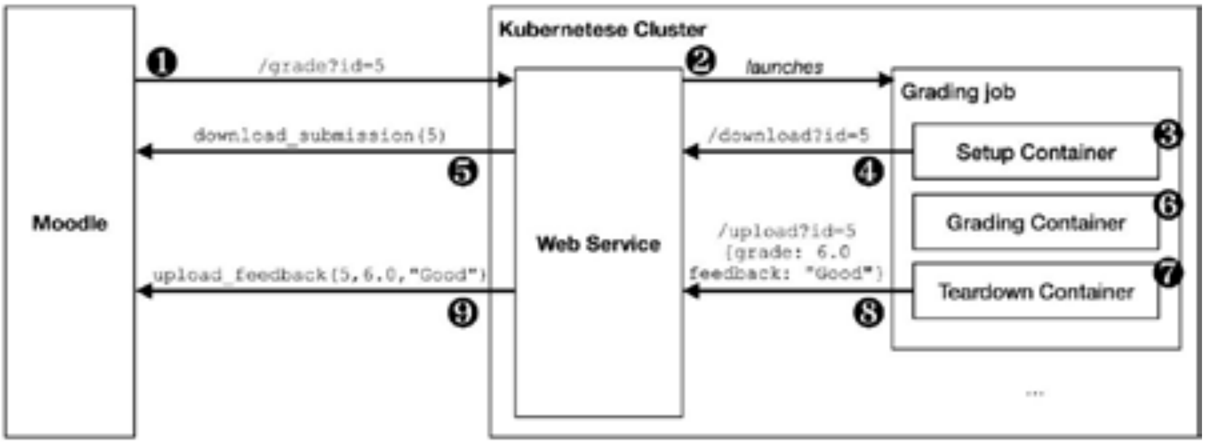

Figure 1: Step-by-step workflow: from the submission to the feedback

As the receiving end of the requests, our service defines a minimal API. On grading requests ❶, the service proceeds by creating a Kubernetes Job ❷; a scheduled task, that will safely download the submission ❹, execute the grading environment ❻ and upload the feedback to Moodle ❽. To enable the possibility to replicate the service, our system avoids storing the state. As such, we currently do not use any database. Authentication is performed by comparing the provided token by a token initialised during the startup of the service. To provide *high-availability* and increase the throughput, the webservice is replicated over multiple nodes of the cluster. On the Kubernetes side, the scheduled job is an aggregate of three *containers* running sequentially. While each container is isolated from the others, they are linked by a shared folder mounted into their file systems, allowing them to share data. The first container ❸ is responsible for downloading the submission ❹ and preparing the grading by putting the files in a dedicated folder in the shared space. The second container ❻; an instance of the provided Docker image, is responsible for running and generating the feedback. It is under the full control of teachers, and it can execute arbitrary code. We require from this executed image to store the feedback in a specific folder of the shared resource. This small contract, with the ability to fully define the grading environment, makes this system *general*. The last container ❼ will upload the feedback and grade to Moodle by calling a specific endpoint of the webservice ❽.

To secure the system, we make sure that all the endpoints of the webservice are protected. As such, we require for each request an authentication token to be stored in the header. Alongside it, and for internally used endpoints ❹❽ –which are not meant to be used by users– an additional parameter consisting of a digest of both the context and an internal secret is required. Requests to internal endpoints are generated by the service itself when building the job; specifically in the definition of the setup ❸ and teardown ❼ containers.

4. APPLICATIONS

Our system is agnostic on the format of submissions—files submitted via Moodle are directly forwarded to the grading jobs, which can perform arbitrary operations before generating feedback. This approach opens the room to a variety of applications. In this section, we outline a few of them that were tried during the test phase of our system.

Both CS-107 and CS-214 make extensive use of unit testing. For these cases, we employ a wrapper script on top of the testing framework—JGrade[1] for CS-107 and MUnit for CS-214—to count points and extract feedback. For first-year students in CS-107, we enhance the feedback by displaying test results in an HTML document, which makes navigation easier. In contrast, second-year students in CS-214 are presented with direct text outputs.

Feedback solely based on input-output tests has limitations, especially for solutions that are unusual, whether in a good or in a bad way. For instance, different implementations of the greatest common divisor function for two natural numbers, despite having identical input-output behaviours, might embody distinct algorithmic approaches (e.g., subtraction-based vs. modulo-based Euclid's algorithm). Milovancevic et al. (2024) conducted a trial in the CS-214 course to address this problem, employing our system with a custom image that integrates formal verification of students' code. Specifically, they extended the Stainless verifier (Hamza, Voirol, and Kunčak 2019) to compute equivalences between student submissions and reference solutions. This system not only verifies the correctness of solutions but also analyses and clusters submissions.

In CS-214, students learn the concept of equational reasoning with programs. This primarily consists in transforming simple code expressions using a given set of axioms, emphasising the mathematical foundations of programming. Checking these proofs is also an opportunity for automatic grading. To do so, the teaching staff developed a small surface syntax on top of the LISA interactive theorem prover

[1] JGrade is an in-house library built for grading on top of JUnit 5. Authors are planning to make it open-source in the future.

(Guilloud, Gambhir, and Kunčak 2023), enabling students to write their proofs similarly as they do in traditional paper exercises.

Beyond grading code, another application example is the teaching of *git*. CS-214 teaches students to generate and manipulate *git* patches—text files containing the differences between two project versions. Adapting the grading image for this course to automatically test and apply these patches was straightforward.

5. EVALUATION

Our system allowed course teams to focus on developing the grading logic rather than on infrastructure management. Moodle instance and the Kubernetes cluster were maintained by system administrators, and the maintenance required for the plugin and web service after this initial development phase was low. Early feedback from the teaching teams suggests that routine maintenance tasks, such as updating tokens or adjusting to Moodle updates, should require roughly one to two days of work per semester for a student.

We estimate the development cost of our system at around $16,000[2]. The running costs of the Kubernetes cluster is not known in our case because it was part of the shared resources of our institution, but we estimate that a similar setup running on Amazon EC2 would cost approximately $9,000 per semester[3].

One of the goals of our system is to efficiently manage the load and to be secure enough to be used during exams. We had the opportunity to validate these aspects during the final exam of the CS-214 course. There, we successfully handled 1715 submissions from 383 students across two batches, including about 600 submissions in the final 15 minutes of each batch with no failures and no delays. A potential drawback of our direct use of Kubernetes jobs worth noting is that it does not use first-in-first-out scheduling, but this was not an issue for us as we provisioned enough resources to avoid queuing delays. If needed, there exists systems that implement this on top of Kubernetes[4]. Additional logistics aspects of organising this exam can be found in (Chiplunkar and Pit-Claudel 2024) .

[2] The bulk of the expense was attributed to the development work, which was undertaken by students for a total of 450 hours at a rate of $25 per hour. Additionally, domain specialists installed and configured the Moodle plugin, and created and administered the Kubernetes cluster, amounting to about 20 hours of work at $80 per hour. Project supervision involved around 80 hours from a PhD student at $25 per hour and 20 hours from a staff member at $80 per hour.

[3] Our Kubernetes setup comprised 3 admin nodes, each with 4 cores and 8 GB of RAM, and 5 worker nodes, each with 8 cores and 8GB of RAM, for the semester's duration. For the CS-214 exam, we increased the number of worker nodes to 13 for 20 days. Running on Amazon EC2 instances would incur approximately the following costs for 6 months: 3 c6g.xlarge instances for admin nodes at $1660 and 5 c6g.2xlarge instances at $5540 for six months, assuming a 1-year reservation paid upfront. For the exam period, an additional 8 c6g.2xlarge instances for one month would cost $1600. The total cost per semester would therefore be $8800.

[4] For example, kueue is a Kubernetes queuing system.

While we lack comprehensive quantitative data on student usability, informal feedback indicates that a large majority of students found the tool user-friendly. On a more concrete note, an analysis of the CS-214 final exam data revealed that out of 1367 submissions (counting only the latest attempts), 31 had missing files, 10 were left in draft mode, and 18 were complete yet unsubmitted, indicating that approximately 4% of students encountered difficulties. These challenges, especially under the stress of exam conditions, highlight areas for potential improvements in the interface's simplicity that we plan to address (see Section 6.).

6. FUTURE WORK

In this section, we describe a few directions in which our work can be improved.

We are actively documenting the system; from the development, installation by system administrators to the usage by students and teachers, including the development of grading images. We also plan to test the system in more classes and to open-source for other schools to use.

In addition to the informal feedback we already got, the natural next step will be to collect more qualitative data and conduct surveys among the students and the teaching staff, which we plan to do during the second trial phase of our tool.

We are also implementing new features and usability improvements, both for students and teachers. Notably, we plan to add the possibility to check the current status of a submission—for example whenever it is queued or has timed out—from Moodle's interface. Additionally, we plan to integrate more monitoring and management features for teachers, for example allowing them to access raw logs of the containers. To facilitate this, we might switch to a custom Moodle activity in the future, instead of extending the *Assignments* activity.

As it is, the integration with Moodle only allows us to fully grade the project. One use case would be to allow the system to partially grade the submission; by validating the submitted code and delay the grading process for later; e.g. to be graded manually.

We will also investigate the possibility of extending the frontend to support additional LMS. Advanced classes might also benefit by allowing their students to integrate the system with their workflows. For example, by providing students with specific submission tokens and a dedicated API, they would be able write their own submission script or even define custom workflows using *GitHub Actions* or GitLab's equivalent.

7. ALTERNATIVES AND RELATED WORK

Prior to the widespread adoption of Docker and Kubernetes, Danutama and Liem (2013) developed a system using custom sandboxes for isolation. Peveler, Maicus, and Cutler (2019) analysed Docker-based isolation versus jailed sandboxes for automatic grading, implementing both and concluding that Docker offers stronger isolation guarantees with minimal performance overhead. Calderón, Petersen, and Rodas (2020) introduced SALP, a project aligning with our goals of modularity and generality, albeit as a standalone system rather than integrating with an LMS. Rao (2019) discussed a system similar to ours but tailored for the Canvas LMS. Tafani-Dereeper (2017) designed a system integrating Moodle with RabbitMQ and a set of workers using LTI, which we avoided due to its unsuitability for asynchronous grading and our preference for direct Moodle integration to leverage existing assignment activity features. A+ represents a comprehensive, albeit complex, solution with extensive functionality, including a Moodle plugin last updated in 2021. Unlike these systems, which involve states, databases, separate authentication systems, or UIs, our solution is more minimalistic and has less components to administer and maintain.

For the predecessors of the CS-214 course, we initially adopted GitLab, creating individual repositories for each student and leveraging custom runners for continuous integration. This method, however, presented challenges, particularly during exams, with performance issues leading to outages on both the frontend and Git servers. The recommended GitLab setup for handling 1 push per second with up to 3000 users—a 27-node system—proves both costly and overly complex for our needs. Alternatively, GitHub Classrooms, a system designed to streamline the use of GitHub for educational purposes, was considered. It simplifies repository management and student submissions but lacks the capacity for detailed points allocation. While direct usage of GitHub Actions could potentially address some of these limitations, using it requires additional effort and lacks the user-friendly interface advantages. Tu et al. (2022) highlighted similar constraints.

Commercial platforms like Ed Lessons and Gradescope offer web-based interfaces for coding, and manual or automated grading of programming assignments, with Gradescope additionally featuring a GitHub plugin and plagiarism detection capabilities. However, these are separate systems that educators must familiarise themselves with, and they raise concerns regarding sensitive data ownership.

8. CONCLUSION

We described the architecture of an automatic grading system in Sections 2 and 3. By leveraging standard tools such as Moodle and Kubernetes, we developed the system with minimal effort. We evaluated its effectiveness through pilot tests in two courses totalling about a thousand students, including one where it was used for the final exam. The system demonstrated its versatility by supporting several programming languages and assignment types, as evidenced in Section 4. Furthermore, we confirmed its scalability and practical usability in real-world scenarios in Section 5. Looking ahead, we aim to refine our system based on user feedback, pursue further integrations, and make our solution open-source, as discussed in Section 6.

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REFERENCES

Calderón, Diego, Erick Petersen, and Oscar Rodas. 2020. 'SALP: A Scalable Autograder System for Learning Programming - A Work in Progress'. In 2020 IEEE Integrated STEM Education Conference (ISEC), 1–4. https://doi.org/10.1109/ISEC49744.2020.9280574.

Chiplunkar, Shardul, and Clément Pit-Claudel. 2024. 'Lessons Learned from the First Edition of a Second-Year Course in Software Construction'. European Society for Engineering Education (SEFI).

Danutama, Karol, and Inggriani Liem. 2013. 'Scalable Autograder and LMS Integration'. Procedia Technology, 4th International Conference on Electrical Engineering and Informatics, ICEEI 2013, 11 (January): 388–95. https://doi.org/10.1016/j.protcy.2013.12.207.

Dougiamas, Martin, and Peter Taylor. 2003. 'Moodle: Using Learning Communities to Create an Open Source Course Management System'. 171–78. Chesapeake, VA, USA. https://research.moodle.org/33/.

Gamage, Sithara H. P. W., Jennifer R. Ayres, and Monica B. Behrend. 2022. 'A Systematic Review on Trends in Using Moodle for Teaching and Learning'. International Journal of STEM Education 9 (1): 9. https://doi.org/10.1186/s40594-021-00323-x.

Gordon, Chelsea L., Roman Lysecky, and Frank Vahid. 2021. 'The Rise of Program Auto-Grading in Introductory CS Courses: A Case Study of zyLabs'. https://peer.asee.org/the-rise-of-program-auto-grading-in-introductory-cs-courses-a-case-study-of-zylabs.

Guilloud, Simon, Sankalp Gambhir, and Viktor Kunčak. 2023. 'LISA - A Modern Proof System'. In DROPS-IDN/v2/Document/10.4230/LIPIcs.ITP.2023.17. Schloss Dagstuhl – Leibniz-Zentrum für Informatik. https://doi.org/10.4230/LIPIcs.ITP.2023.17.

Hagerer, Gerhard, Laura Lahesoo, Miriam Anschütz, Stephan Krusche, and Georg Groh. 2021. 'An Analysis of Programming Course Evaluations Before and After the Introduction of an Autograder'. In 2021 19th International Conference on Information Technology Based Higher Education and Training (ITHET), 01–09. https://doi.org/10.1109/ITHET50392.2021.9759809.

Hamza, Jad, Nicolas Voirol, and Viktor Kunčak. 2019. 'System FR: Formalized Foundations for the Stainless Verifier'. Proceedings of the ACM on Programming Languages 3 (OOPSLA): 166:1-166:30. https://doi.org/10.1145/3360592

Kumar, Sheo, Anil Kumar Gankotiya, and Kamlesh Dutta. 2011. 'A Comparative Study of Moodle with Other E-Learning Systems'. In 2011 3rd International Conference on Electronics Computer Technology, 5:414–18. https://doi.org/10.1109/ICECTECH.2011.5942032.

Lee, Haden Hooyeon. 2021. 'Effectiveness of Real-Time Feedback and Instructive Hints in Graduate CS Courses via Automated Grading System'. In Proceedings of the 52nd ACM Technical Symposium on Computer Science Education, 101–7. SIGCSE '21. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3408877.3432463.

Milovancevic, Dragana, Mario Bucev, Marcin Wojnarowski, Samuel Chassot, and Viktor Kuncak. 2024. 'Formal Autograding in a Classroom (Experience Report)'. https://infoscience.epfl.ch/record/309386

Peveler, Matthew, Evan Maicus, and Barbara Cutler. 2019. 'Comparing Jailed Sandboxes vs Containers Within an Autograding System'. In Proceedings of the 50th ACM Technical Symposium on Computer Science Education, 139–45. SIGCSE '19. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3287324.3287507

Rao, Dhananjai M. 2019. 'Experiences With Auto-Grading in a Systems Course'. In 2019 IEEE Frontiers in Education Conference (FIE), 1–8. https://doi.org/10.1109/FIE43999.2019.9028450

LARGE GROUP AR LAB EXPERIMENT SIMULATION TO INCREASE STUDENT PARTICIPATION

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ABSTRACT

This paper presents the design and implementation of a novel Augmented Reality (AR) experience for teaching engineering students the principles of elastic beam theory. Traditionally, this concept has been conveyed through physical laboratory experiments. However, at Sheffield University's Department of Multidisciplinary Engineering Education, such setups require extensive preparation by technical staff

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to accommodate large student cohorts. This translates to lengthy turnaround times between activities and hinders efficient laboratory scheduling.

Furthermore, the existing equipment similarity with previous sessions earlier in the semester contributes to lower student engagement and participation compared to other experiments utilizing different sets of apparatus. The proposed AR solution addresses these shortcomings by eliminating the need for a complex physical setup within the lab. Students only require an AR headset and a designated 2x2 meter flat space. Initial data suggests a significant increase in student participation and satisfaction with this AR approach.

Beyond its logistical advantages, the AR simulation holds immense potential for enriching learning experiences. It allows for the rapid manipulation of material properties, beam cross-sections, and data overlays in innovative ways, exceeding the capabilities of traditional equipment. This enhanced flexibility paves the way for a more dynamic and engaging learning environment for engineering students.

1 INTRODUCTION

The landscape of Higher Education (HE) is undergoing a transformation fueled by the burgeoning adoption of Extended Reality (XR) technologies. Encompassing a spectrum of immersive experiences, XR incorporates Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). VR creates interactive, computer-generated environments, while AR overlays digital information onto the physical world. MR, meanwhile, seamlessly blends elements of both. Recent advancements and investments in hardware and software have propelled XR technology into a period of significant resurgence, with its applications extending far beyond commercial and domestic use. Meta reviews have indicated a year-on-year increase in published papers on this topic within the field of education, often with a large focus on teaching practical-procedural skills in engineering (Radianti et al. 2020) and this trend has continued up to the year of writing (Lin et al. 2024).

Meta-reviews of recent studies of XR technologies in HE have shown encouraging patterns, with VR increasing student engagement across a number of measures (Lin et al. 2024) with one meta-review focusing on Engineering showing impact on student satisfaction in 96% of cases (Vicente dos Anjos et al 2022)

In previous work, the authors have highlighted many of the perceived benefits and pitfalls of XR technology in the field of engineering pedagogy and explored the effects of fidelity, cost and interactivity on student learning outcomes and virtual laboratory engagement (Bangert et al. 2023) in a flipped learning context. This practice paper aims to highlight ongoing work within the institution to enable better student engagement and efficient use of timetabled resources, whilst maintaining standards of learning attainment. The scope of this work has been based on the total replacement of a physical laboratory activity; the “Deflection of a Beam” lab. This activity is taught to over 150 undergraduate students from the Department of Civil, and General Engineering at the university. The 2020 meta-review previously mentioned (Radianti et al. 2020) suggested there was a lack of publications showing XR activities based on existing experiments, as is offered here.

1.1 Activity and Learning Objectives

The lab activity is based on the elastic beam theory. Students conduct a load test on a flexible elastic beam by hanging weights to it and record the maximum upward and downward deflections at each load increment. At peak load, students also record the cartesian coordinates of seven points along the beam. These data are used to plot the load-deflection curves and the deformed shape of the tested elastic beam. The data processing is assisted with the use of a spreadsheet template that is available to the students on the Blackboard VLE (Virtual Learning Environment).

The students are challenged to create their loading procedure design based on the setup limitations of the experiment, to experimentally interpret the concept of curvature and to justify any discrepancy with the theory.

Students are also expected to gain some laboratory skills, in this case, taking readings from various types of distance measuring devices and dealing with the associated errors and precision. For the students at this point in their studies, it could be the first time they have had to use any form of analogue dial gauge for displacement (see Fig 2).

1.2 The Physical Lab Apparatus

Fig 1 shows the experimental apparatus consisting of a simply supported steel beam, with a cantilever portion where the load is applied. Dial gauges 1 and 2 are used to measure the maximum deflection both within the supported span and in the cantilevered portion of the beam. Dial gauge 1 offers readings between 0-20 mm while dial gauge 2 is between 0-50 mm, both with graduations of 0.01 mm. A caliper and a micrometer are also made available to measure the specimen dimensions and a ruler to estimate the deflected shape of the beam at peak load.

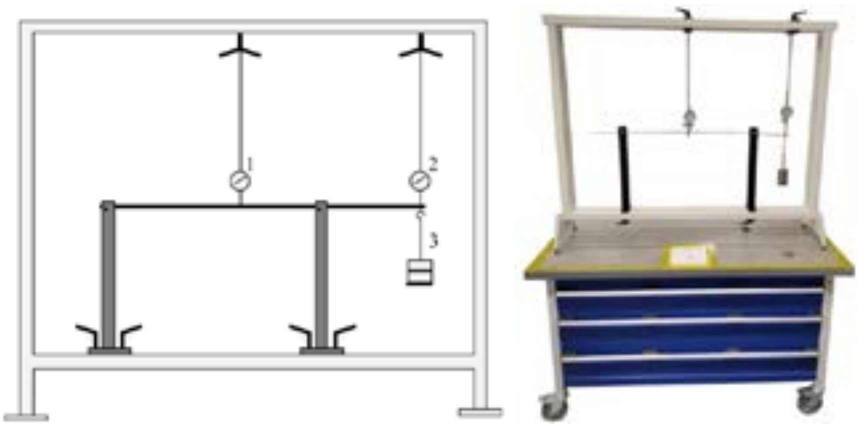

Fig. 1. Diagrammatic representation of experimental apparatus (Left) Photo (right).

1.3 Room for innovation

The existing format and structure of lab sessions have remained largely unchanged for the past decade, with only minor adjustments made over time. However, when compared to similar structural experiments conducted in the same laboratory, this particular session has consistently struggled with low student engagement and attendance rates. There's been speculation that this lack of enthusiasm may stem from student fatigue due to the repetitive nature of the experiments. Despite each experiment having different learning objectives, they all follow a familiar pattern of load-testing, data collection, and analysis, using similar equipment.

Recognizing this challenge, the authors opted to revamp the delivery of the activity while preserving its intended learning outcomes. This involved transitioning from the traditional lab format to a new approach with two distinct stages: 1) Substituting the original activity with a high-fidelity augmented reality/virtual reality (AR/VR) simulation. 2) Directly simulating real-world engineering examples related to the concept, rather than replicating the old experiment. This approach allows for the inclusion of virtual content that may not be feasible, safe, or cost-effective to implement on a large scale in a physical laboratory setting. The following outlines the initial phase (1) of this initiative and its impact on undergraduate engineering students.

2 METHODOLOGY

To realize a bespoke AR learning environment, a game engine was determined to be the optimal platform. This engine would offer the necessary functionalities: immersive visualizations, interactive features, and realistic physics simulations. Following a rigorous evaluation process, the free educational version of Unity 3D (version 2021.3.31f1) was chosen due to its extensive development tools and established compatibility with the selected hardware platform.

The chosen hardware platform consisted of Meta's Quest 3 headsets. These headsets offered a compelling cost-performance trade-off compared to alternative commercial VR systems. Furthermore, their integrated pass-through cameras and depth sensors were critical for facilitating the creation of realistic AR 3D overlays onto the user's physical environment. This technology is crucial for seamlessly blending virtual elements with the real world, a core requirement for an effective AR experience.

The simulation's geometric foundation mirrored the physical equipment's dimensions. These dimensions were meticulously captured and recreated within Solidworks, a 3D parametric CAD software. The resulting high-fidelity model was then exported for further processing in Blender, an open-source 3D modeling program. Within Blender, the 3D mesh underwent a process of optimization. This optimization aimed to minimize the file size while preserving the original geometric details of the model. This balancing act is essential for ensuring smooth performance within the AR experience. To achieve high-resolution measuring scales on the virtual gauges and rulers, a combination of procedural texture mapping and custom UV texture mapping techniques were employed. Procedural mapping allows for the efficient generation of textures based on mathematical algorithms, while custom UV mapping enables precise control over texture placement on the 3D model. Following this meticulous texturing process, the "texture-baked" 3D models were exported as glTF (Graphics Library Transmission Format) files (see Fig 2, right). This format facilitated seamless integration within the Unity game engine, paving the way for the development of the interactive AR learning environment.

Fig. 2. Photo of actual dial gauges (Left), Texture mapped glTF 3D model (Right).

The final component involved the utilization of several plugins within the Unity engine. These plugins, glTFast (4.8.3), Oculus XR Plugin (3.3.0), and XR Plugin Management (4.3.3), played a crucial role in managing file handling and facilitating interactions with the VR hardware. This integration ensured the proper communication between the software and hardware components, enabling the creation of a responsive and immersive AR learning experience.

Custom C# scripts were written to present an accurate deflection of the beam. The differential equations describing beam deflection were solved to give two equations for vertical deflection as a function of horizontal position on the beam for a given applied force: one valid in the region between the supports and one for the region of overhang. The mesh for the beam is divided into 100 sections. The vertices at each section are moved up or down according to the relevant equation, producing the impression of a smooth curve. Specific values at the locations of the dial gauges are similarly calculated for display with rotating hands (with values outside the measurement range of each dial gauge being clamped).

Parameters for beam dimensions and material constants are set within the unity editor (with the mesh automatically reflecting the given dimensions). The parameter for spacing between the pillars is inferred at runtime from the geometry of the scene, and the force parameter is updated as weights are added or removed by the user. A magnifying glass was implemented using a second camera attached to one eye of the XR rig with a narrower field of view than the default. This camera was rendered to the texture of a magnifying glass lens. This allowed a region of the scene to be viewed at a larger size and higher resolution than the natural scale and resolution of the headset without expensive ray tracing (Fig 3).

Fig. 3. In headset image of the magnifying glass effect on a gauge (Left) and ruler (Right).

The user experience of the simulation is as follows; once the program is loaded the user is presented with a scale-correct simplified version of the flexible beam and mounting frame apparatus in the location where the activity is taking place (See Fig 4). Using the Oculus controllers or their hands, users can pick up any of the available weights (1, 5, 10 N) and place them on the weight hanger at the end of the beam to be tested. The users can also pick up the magnifying glass to help them see the measuring scales on the apparatus more clearly. Note, that the weights have physical interactions with the surroundings (gravity and collisions), whilst the magnifying glass interacts without collisions or gravity so that it can be placed in space without being held by the user.

The other interactive elements are the vertical measurement ruler, which can be moved on the x-axis along the length of the horizontal ruler, the rightmost support pillar for the beam, which can also be moved along the x-axis across the frame, and the hangers holding both measuring gauges, which can be similarly moved along the beam. Each of these axis-locked interactions has a restricted range of motion that matches those of the physical equipment itself. The interactive elements in this simulation are considered to be crucial not just for functionally mirroring the physical experiment, but also for increasing the rates of students' knowledge and skill acquisition in a virtual environment (Kyaw et al. 2019).

Fig. 4. 3D Unity scene view with the model of the experimental apparatus (left), In AR headset view of apparatus in the lab (center) and the real unit in the same lab (right).

2.1 Simulation Costings & Setup Estimates

As the physical activity has been run within the department for multiple years it was possible to get accurate figures on the amount of staff time required for setting up the teaching and therefore the costs. In addition, it was also possible to do the same for the development of the AR software and the setup of the VR hardware to facilitate the replacement lab activity. Table 2 shows this data with data based on staff time at ~£25/hr. Figures assume one continuous run of teaching, with classes of 40 students working in pairs. Total equipment cost scales in proportion to class size. Setup time scales in proportion to the number of runs of continuous teaching.

Table 2. Cost data for producing/running each form of the activity

Activity	Preparation of Materials (one-off)	Equipment cost per unit (GBP)	Setup and takedown time	Total
Physical Lab	N/A	Frame with beam deflection kits £3324 (x10 units required)	3.5 hours £87.5	£33,328
XR Lab	CAD/3D modeling: 20 hours. Unity development: 40 hours £1500	Quest 3 Headset with strap and gasket £580 (x20 units required)	4 hours £100	£13,200

2.2 Methods of assessment

Data on student engagement with the activity was recorded using a bespoke piece of attendance software designed and built with the department (Funnell 2020). The "Smiley Faces" application presents the students with a series of faces showing a range of 5 emotions from happy to sad on a touchscreen tablet, approximating a 5-point Likert scale. The students click on one of the faces when exiting the lab session to provide quantitative feedback on their experience. These data are aggregated numerically to produce a "satisfaction rating score", see Table 3. In addition, the attendance rate of students was captured, see Table 4.

Table 3. Student Satisfaction Data

Session	Mean Rating (1-5)	Rating Std Dev	Respondents
Physical Lab 1 (2023)	3.9	1.36	8
Physical Lab 2 (2023)	5	0.00	4
XR Lab 1 (2024)	4.8	0.37	19

XR Lab 2 (2024)	4.9	0.34	23

Table 4. Student Attendance Data

Session	Students Expected	Students Attended	Attendance
Physical Lab 1 (2023)	31	23	74%
Physical Lab 2 (2023)	31	13	42%
XR Lab 1 (2024)	36	30	84%
XR Lab 2 (2024)	32	37	83%

2.3 Analysis of findings

The student satisfaction data (summarized in table 3) was combined into two cohorts: with and without XR. The null hypothesis was no increase in student satisfaction. Applying a Mann-Whitney U Test to the two groups , a z-score of -2.213 was produced. With one tail, this gave a p-value of 0.0134, which is greater than the 0.05 threshold to discard the null hypothesis. Thus we demonstrate a statistically significant increase in student satisfaction when presented with an XR lab experience. To what degree this is due to the quality of their learning experience versus the novelty value of using a VR headset is not known.

The attendance for the XR experience was much higher than in previous runs and is high compared to the average lab attendance (76%) and in particular the average attendance of 2024 CIV1000 students (67%), which was the cohort involved. The two 2023 physical labs, taken by GEE208 students, have an average attendance of 58%, which matches exactly the average lab attendance across the year for that cohort in 2023. To generate test statistics the cohorts were again grouped by presence of XR, and a two-sample proportion z-test was applied. The null hypothesis was no increase in attendance in the XR labs. A z-score of -2.93 was obtained, producing a p-value of 0.0034. This is smaller than the 0.05 threshold to discard the null hypothesis. Thus we show a statistically significant increase in attendance in the XR labs. Students were likely drawn to the lab because they knew it would involve a VR component, further suggesting this method of delivery is exciting to students.

The work by (Huang 2020) has shown that in other iVR studies, the “novelty effect” can be powerful in a science/engineering context. The students' motivation and engagement are initially higher, attenuating after multiple sessions. Novelty was not found to have a consistent impact on learning outcomes. As XR becomes more ubiquitous, it will be interesting to see to what extent our observed increase in engagement holds.

3 SUMMARY

This paper explores Augmented Reality (AR) as a way to revitalize a traditional engineering laboratory focused on elastic beam theory. The original lab suffered from low student engagement due to its repetitive nature. To address this, a high-fidelity AR simulation was developed, mirroring the physical apparatus and offering an immersive learning environment. Initial results show increased student satisfaction and attendance, suggesting AR's potential to enhance engineering education. While the long-term impact on learning outcomes needs further study, AR can prepare students for future careers using these technologies. Notably, for this specific lab setup, AR also presented a more cost-effective solution, although initial development required in-house expertise to create the model. Future work will focus on simulating real-world engineering examples in VR to further enhance learning and introduce scenarios impractical in a physical lab.

REFERENCES

Radianti, J., Majchrzak, T.A., Fromm, J. and Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education, [online] 147(0360-1315), p.103778. doi:https://doi.org/10.1016/j.compedu.2019.103778.

Xiao Ping Lin, Bin Bin Li, Zhen Ning Yao, Yang, Z. and Zhang, M. (2024). The impact of virtual reality on student engagement in the classroom–a critical review of the literature. Frontiers in psychology, 15. doi:https://doi.org/10.3389/fpsyg.2024.1360574.

Vicente dos Anjos, F.E., Rocha, L.A.O., Oliveira da Silva, D., Pacheco, R. and Pinheiro, D.M.B. (2022). Impacts of the Application of Virtual and Augmented Reality on Teaching-Learning Processes in Engineering Courses. International Journal of Virtual and Personal Learning Environments, 12(1), pp.1–19. doi:https://doi.org/10.4018/ijvple.291541.

Bangert, Krys, Edward Browncross, Matteo Di Benedetti, Harry Day, and Andrew Garrard. 2023. "Comparing XR And Digital Flipped Methods To Meet Learning Objectives." European Society for Engineering Education (SEFI), Dublin.https://doi.org/10.21427/VJVG-V478 https://arrow.tudublin.ie/sefi2023_respap/131/ .

Funnell, A. 2020. "Using instant student satisfaction ratings to investigate large scale practical laboratory teaching." 2020 IEEE Frontiers in Education Conference 10.1109/FIE44824.2020.9274191 (FIE), 21-24 Oct. 2020.

Huang, Wen. 2020. "Investigating the Novelty Effect in Virtual Reality on STEM Learning." PhD, Arizone State University. https://hdl.handle.net/2286/R.I.57391 .

Kyaw, Bhone Myint, Nakul Saxena, Pawel Posadzki, Jitka Vseteckova, Charoula Konstantia Nikolaou, Pradeep Paul George, Ushashree Divakar, Italo Masiello, Andrzej A Kononowicz, Nabil Zary, and Lorainne Tudor Car. 2019. "Virtual Reality for Health Professions Education: Systematic Review and Meta-Analysis by the Digital Health Education Collaboration." *J Med Internet Res* 21 (1): e12959. https://doi.org/10.2196/12959 . http://www.jmir.org/2019/1/e12959/ https://doi.org/10.2196/12959 http://www.ncbi.nlm.nih.gov/pubmed/30668519 .

Appraising a 2.5th Space: Learnings from the Teaching and Learning Laboratory in Engineering and IT at University of Melbourne

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ABSTRACT

In this Practice Paper we explore the scope of engineering education academic development and support activities being undertaken by the Teaching and Learning Laboratory in Engineering and IT at University of Melbourne, and the context the Laboratory represents. Activities of the Laboratory include educational design support, inductions to teaching coordination, small-class teacher development, peer review of teaching, scholarship of teaching and learning capability development, and many more. We conclude with the specific challenge of establishing the impact and value of these activities, and how best to communicate this to decision-making individuals and groups within our institution. The literature suggests an approach of proxy rather than direct, establishing the circumstances and processes necessary for engineering education excellence, and involving external experts to conduct and validate assessments against these desirable circumstances and processes. Our recommendation from the literature and our own experience is to create and leverage a network for expert review and we seek to invite potential members to collaborate in developing such a network.

1 INTRODUCTION

Higher education is becoming increasingly professionalised. Educators in universities are expected to hold skills, qualification, and recognition in higher education. Engineering education is an established research field well-supported by associations such as SEFI, and their associated journals and doctoral research programs. To support quality higher education, many universities have central academic development and higher education research units. Similar units have been emerging to support quality engineering education and engineering education research.

In this paper we present the scope of work undertaken by one such engineering education and engineering education research unit, namely the Teaching and Learning Laboratory, Faculty of Engineering and IT, University of Melbourne (TLL), progressing from establishing the Laboratory, and seeking to identify and reflect on impact, value, and refinement. We provide a reference for the types of activities such a unit might engage in, and make a case for an expert review network between multiple such units.

1.1 Engineering Education Units

Engineering education units have developed alongside the emergence of engineering education research and practice as an independent specialisation of higher education research and practice (Borrego and Bernhard 2011). These units vary in nature from schools, such as Purdue’s School of Engineering Education, centres such as University College of London’s Centre for Engineering Education, to substantial research clusters such as KU Leuven’s Research in Engineering Education group.

The different structures of these units generally reflect both focus and scale of the units, with some focused on fundamental research and graduate research training, and others focused on local impacts to engineering education practice in their institutions, and wildly different scales in terms of headcount and funding. A characteristic of many engineering education research and development units is a majority of staff being academic, rather than professional. This is important when considering the nature of these units and how their members interact with wider contexts.

A common lens when examining units with non-traditional tasks in university settings is the ‘3rd space’ (Whitchurch 2012), those university employees “who do not fit conventional binary descriptors such as those enshrined in ‘academic’ or ‘non-academic’ employment categories” (Whitchurch 2015). However, this lens does not capture the nature of an engineering education unit made up of academic staff that conducts activities mostly within academic boundaries. This distinction is the basis for the ‘2.5th space’ description we use in this paper and the perceived need for a fresh look at the contexts of such a unit.

1.2 Glossary

For the purposes of this paper, we use terms as follows:

- **Subject:** A semester long unit of teaching which is atomic/indivisible for the purposes of student enrolment, for which students are given a single holistic grade known elsewhere as unit, course, paper, etc.
- **Faculty:** The highest level of division between disciplinary units of the university
- **School:** The next level of division inside the faculty.
- **Department:** The final relevant level of division inside schools
- **Unit:** A group, team, or other organisational entity, which is tasked with a specific purpose, e.g. an educational development unit.

2 THE TEACHING AND LEARNING LABORATORY

2.1 History, Establishment, and Structure

The TLL was established in 2022 to revitalise the pursuit of quality and innovation in teaching and learning in the Faculty of Engineering and IT. The TLL comprises a core team of the director leading three academics (including the authors) engaged in research in engineering education, and academic development activities. The Faculty has more than 470 academics. We have established relationships with several TLL Affiliates - academics with primary roles in schools and departments within the Faculty, who contribute to TLL research and development initiatives.

The TLL is a research-driven unit with a remit to support enhancements to teaching and learning in engineering and information technology through capability development of and support for academics, celebration of teaching and learning, research, and evaluation. The TLL is a unit at the Faculty-level. In the organizational chart, the Director reports to the Deputy Dean Academic, as does the Associate Dean Academic. The TLL is staff-facing rather than student-facing, influencing students indirectly through academics who teach and through curriculum initiatives.

The University of Melbourne is research-intensive. Academics within the TLL undertake various balances of research, education, and leadership & service. We undertake research in engineering and computing education, and engineering and computing practice. We provide capability development and support activities with peers rather than with students. Our research and the education we provide are intentionally integrated and therefore the demarcation between research and education is complex. For example, the development of innovative teaching is both an education activity and a research activity.

2.2 TLL Activities and Initiatives

The staff in the TLL deliver programs and events to upskill academics, improve the quality of education in the Faculty, promote a culture of teaching excellence, reward and recognise excellence, and conduct education evaluation and research. Below we provide an overview of the breadth of TLL activities, excluding general service and leadership within the institution.

Subject Design Workshops

Subject Design Workshops are one of the more common activities of the TLL, with approximately 20-30 workshops conducted each year. The purpose of the workshops is to improve the quality of teaching and learning within the faculty, and to raise the profile of teaching and learning from an administrative task to a design-oriented task.

The format of each SDW is unique. However typically they are initiated with a series of scoping discussions between the academic and the director of the TLL followed by a workshop of duration within the range 2 hours to several days. The focuses of the workshops range from a single component of a subject to a full subject design or revision. They are motivated by a range of possible triggers from the academic seeking to innovate, to a recommendation by an academic head.

The TLL's primary role in the SDWs is to inform and guide the academics with research-informed approaches and questions, and not to dictate practice. The subject coordinators and subject teams develop material such as lectures, assessments, and tutorial material, with our guidance.

Academic Induction and Support

The TLL facilitates a 2-day induction to teaching and subject coordination, for academics new to teaching in the Faculty. This induction incorporates guest sessions by relevant service providers within the University and with academics from the Faculty. As well as introducing relevant teaching policies and responsibilities, the induction also provides a brief taster of subject design, evaluation, and pedagogic theory. Thirty to fifty academics attend each year. The inductions are heavily interactive, with most sessions modelling experiential learning where participants might for example consider their subject's intended learning outcomes within Bloom's Taxonomy, or conduct live observations of people to learn about classroom observation evaluations. We link the inductions to follow-up support, either through formal programs described below, or through ad hoc relationship building and discussions around teaching and learning practice between the new academic and the TLL.

Small-class Teacher Development

The TLL provides an extensive development program for small-class teachers. To date, these teachers are employed on a largely casual basis. They deliver classes such as tutorials, laboratories, and workshops. The program comprises a mandatory full-day induction workshop, a mandatory inclusive education workshop, and optional workshops on strategies for engaging students and giving effective feedback. Every workshop is offered each semester. Each year more than four hundred new teachers attend the compulsory workshops.

The induction at the beginning of each semester includes some similar mechanical elements to the academic induction, with guest speakers from Human Resources, and from Health, Safety, and Wellbeing, and a tour of relevant policies and procedures. We introduce the small-class teachers, many of whom are new to teaching, to methods for effective teaching, and to management of unexpected situations.

The strategies to engage students and giving effective feedback workshops were developed to expand on topics introduced in the mandatory induction. These additional workshops are later in the semester for two reasons: first, to allow for more time to cover the material in detail and include active participation and feedback, and second, so that new teachers have had an initial experience with teaching to appreciate challenges and identify gaps in their knowledge.

The inclusive education workshops are designed to improve inclusivity in teaching, in response to well-known systemic barriers in engineering and computing education and practice for people with marginalised or non-traditional attributes. These attributes include gender, socio-economic status, and many others. The workshops focus on unconscious biases that small-class educators and/or their students might bring into the classroom, and strategies to recognise these and mitigate their impact.

Communities of Practice

The TLL promotes and supports the development of education-based communities of practice within the Faculty. These communities may be led by any academic from within the Faculty, including TLL staff. There are currently two active communities, the Generative AI in Teaching Community, and the Indigenous Engineering Community, with additional communities emerging on topics including immersive teaching technology, sustainability, and project-based learning.

The Generative AI in Teaching Community of Practice, which has seen explosive growth since its inception in mid-2023, brings together academics and professional staff who are interested in exploring topics including academic integrity, teaching innovations, ethics of AI, use within the profession and many more. The TLL takes a direct hand in leading and facilitating this Community, delivering seminars, discussion groups, and workshops, and managing the online community. The Community has over 400 members and has developed from a Faculty community into a University Community of Practice. By contrast, the Indigenous Engineering Community of Practice has 47 members interested in integrating Indigenous values in curricula. These members engage meaningfully and intensely sometimes over multiples days, aligning with emergent opportunities.

HDR Research Training

The TLL has multiple PhD candidates supervised by TLL academics and affiliate supervisors. Topics under research include sustainability in engineering education and practice, integration of Indigenous values in engineering education, reproductive equity among engineers, Indigenous equity in engineering outcomes, learning analytics, and feedback in computing education. The candidates, academics, and affiliate supervisors form the TLL Research Group, with regular research seminars, invited speaker presentations, and discussions around topics such as methodologies, research design, and research support technologies, and shared project updates.

Innovative Teaching Spaces and Methods

Staff in the TLL collaborate with architects, consultants, and facilities staff to design and pilot new physical spaces for teaching and learning, and work with academics to pilot new and innovative teaching methods and designs in these new spaces. This work accompanies multiple building construction projects and refurbishments underway at significant scale and pace. New teaching methods being piloted focus on breaking down barriers between ‘delivery’ style lectures and tutorials, and ‘experience’ style workshops and laboratories, to promote seamless and integrated flat-floor teaching where appropriate for the intended learning outcomes.

Peer Review of Teaching

The TLL staff designed, developed, and lead a peer review of teaching pilot. The program is a peer-to-peer focused initiative with no oversight from supervisors or managers. Academics have full control over what they have reviewed, who conducts the review, and when the review occurs. The review can take place on any desired aspect of teaching or curricula. To participate in the program, academics complete a workshop facilitated by a TLL lecturer to manage expectations and develop skills in reflection and constructive feedback. Emphasis is on actions academics take following reviews.

Seminars and Workshops

The TLL leads regular professional development and awareness seminars and workshops for academics in the Faculty, around topics such as curriculum innovation, accessibility, education policies and others. The TLL also holds a series for academics to share innovative teaching practices, and shorter bespoke series on a given topic, the first of these being a 3-part series on assessment. These seminars and other TLL activities are informed by a Working Group of academics from across the Faculty, to ensure relevance and support impact.

Industry Practice and Engagement

The TLL actively engages with industry along bi-directional lines: first, the influence of industry on education in the form of accreditation bodies and the promotion of authentic practices in the design of curricula and assessment that the TLL supports, and second the influence of engineering and computing education and practice research on shaping current and future practice in industry. We value our strong connections with peak bodies including Engineers Australia with whom we will host an Engineering Practice Research Summit in 2024.

Scholarship of Teaching and Learning Support: I.D.E.A.S.

The TLL is pioneering a dedicated scholarship of teaching and learning (SoTL) group named IDEAS: Impact from, Development in, Evaluation as, and Application of SoTL. This group is a hybrid of masterclass series, community of practice, and project collaboration space for academics in the Faculty to develop their skills in SoTL as distinct from their existing discipline skills, and to promote the active incorporation of SoTL activities in day-to-day teaching practice in the faculty. This group defines SoTL to be the incorporation of educational research to inform teaching practice in local contexts, and the active evaluation and dissemination of beneficial teaching practice in those contexts.

Broad Engineering Education Research

In addition to the specific activities above which often involve the creation of engineering education research outputs either inherently or indirectly, academics within the TLL and TLL Affiliates are leading engineering education research. Areas of active interest include engineering practice, authentic education and assessment, inclusivity, learning analytics, generative AI in education, Indigenous engineering, and evaluation techniques.

3 THE CHALLENGE

3.1 Evaluation of Impact

A significant challenge (and opportunity) facing the TLL team is how to identify, understand, and communicate the TLL's impact and the value it provides within the Faculty. Good practice for continuous improvement requires meaningful and timely evaluation including lagging and leading indicators of success. There is a need to understand the impact and value of activities, to improve and refine their delivery, identify areas of priority, and align with wider Faculty strategies.

Additionally, while there is currently a significant level of goodwill and space to experiment afforded to the TLL, any well-governed organisation will monitor the value of initiatives. In order to reaffirm resources and ensure we continue to deliver quality and innovation in teaching, the TLL staff must seek and communicate this evidence.

Exploring Existing Evaluation Models

Through review of the literature, the only readily available evaluation model for units with related scope and remit was identified by Kneale et al (2016) and several cited works related to that framework (e.g. by Chalmers and Gardiner (2015)). Although examples exist of evaluations of individual activities, assessing adoption and impact, and identifying findings, outside the above framework, no holistic approach to evaluation and communication of impact was identified.

The key limitation of individual approaches is the lack of a holistic view on impact and value for a given unit, and the way that unit is structured to deliver an overall suite of initiatives both formal and informal. This is critical in an environment where the impact that arises from an integrated teaching and learning unit such as the TLL is anticipated to come not from initiatives in isolation, but rather from widespread cultural and capability change that emerges progressively out of many initiatives, as well as informal collegial interactions between peers. This is a limitation shared by Kneale et al (2016), who provide guidance on the evaluation and communication of individual activities rather than holistically – albeit with consistency between evaluations of different activities that would support aggregation.

Current Evaluation Practices in the TLL

There remains a need to evaluate individual aspects as the necessary components of any wider communication of impact and so these inputs are valuable in determining the best way for the TLL team to evaluate our activities and communicate the Lab's impact and value. However, the consequences of the above limitation mean applying these existing methods on a per-activity basis has shown limited effectiveness.

Evaluation is time-intensive, and good evaluation is more time-intensive. Seeking the maximum value out of the available time and effort for evaluation can only be achieved by considering values across different activities. Academics are already overburdened in terms of workload and available time, and over-surveyed wherever professional development activities occur. This is already an issue we observe for participation in development initiatives in the first instance, but further inhibits the effective gathering of quality data which typically requires more invasive and participant-time-intensive methods.

Evaluation has multiple target audiences, and the communication of value must be in the language of those who are responsible for reacting to and supporting that value. For many audiences, concise stand-alone communication is necessary, such as a single slide in a strategy meeting or executive summary.

One of the active investigations of the TLL is therefore to develop an approach to holistic evaluation and communication of value, an outcome of which is described below.

4 FUTURE DIRECTIONS: IMPACT AND EVALUATION INTER-UNIT REVIEW

4.1 Evaluation by Proxy

In investigating parallel challenges experienced within the higher education sector, in conjunction with the framework presented by Kneale et al (2016), following up on work by Chalmers and Gardiner (2015), our most significant conclusion was that educational quality, and programs to improve the same, were evaluated on a basis of proxy. While it is perhaps a managerial imperative to seek measures that will describe performance, as a discipline we have yet to develop a way of establishing teaching excellence in the form of a number, or at least a number which is valid, useful, and free from blatant inequity (Heffernan 2022).

Two promising methods of proxy were identified: proxy by circumstance and/or process, and proxy by authority. Proxy by circumstance and/or process is the evaluation of teaching excellence via observing that there is fertile ground from which that excellence might spring. In the context of this paper this would require identifying likely contributors to success and using those as a measure.

Proxy by authority is the act of decision-making individuals or bodies deferring to the opinion of acknowledged experts. This is routinely used in higher education for the purposes of audit and review, as well as accreditation (Duarte and Vardasca 2023; King 2012). In this case this proxy would also be necessary to identify and validate the selection of desirable circumstances and processes to measure against.

4.2 Operationalising Reviews

We conclude that the ideal solution for the TLL lies in establishing a culture of external review by experts in the field of engineering education practice, development, and research. This will serve both to provide valuable insight and direction for the TLL internally, and the credible communication of successes, opportunities, and contextual inhibitors to decision-makers. Rather than a complex document showing the multi-faceted interacting elements in any educational context, these can be abstracted away behind a simple but powerful statement, e.g. "the review by entity XYZ has drawn conclusions 1, 2, and 3, and made recommendations 4, 5, and 6". This is already a language these decision-makers are fluent in through audit, review, and accreditation processes.

Willing, relevant experts would be critical, to identify the desirable circumstances and processes, conduct a review against those, and present findings in the necessary forms for internal and external use. We anticipate a review network across engineering education units, expert engineering education practitioners, and researchers. Members of the network would establish common expectations about the desirable circumstances and processes which underpin such reviews. Work is ongoing in the TLL to establish such a network, and we invite interested groups and individuals to connect with us to join in its development.

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REFERENCES

Borrego, Maura, and Jonte Bernhard. 2011. "The Emergence of Engineering Education Research as an Internationally Connected Field of Inquiry." *Journal of Engineering Education* 100 (1): 14–47. https://doi.org/10.1002/j.2168-9830.2011.tb00003.x.

Chalmers, Denise, and Di Gardiner. 2015. "An Evaluation Framework for Identifying the Effectiveness and Impact of Academic Teacher Development Programmes." *Studies in Educational Evaluation* 46 (September): 81–91. https://doi.org/10.1016/j.stueduc.2015.02.002.

Duarte, Nelson, and Ricardo Vardasca. 2023. "Literature Review of Accreditation Systems in Higher Education." *Education Sciences* 13 (6): 582. https://doi.org/10.3390/educsci13060582.

Heffernan, Troy. 2022. "Sexism, Racism, Prejudice, and Bias: A Literature Review and Synthesis of Research Surrounding Student Evaluations of Courses and Teaching." *Assessment & Evaluation in Higher Education* 47 (1): 144–54. https://doi.org/10.1080/02602938.2021.1888075.

King, R W. 2012. "National Processes to Support Continuous Improvement in Engineering Education in Australia." In *Proceedings of the 40th SEFI Annual Conference 2012 - Engineering Education 2020: Meet the Future*. http://www.scopus.com/inward/record.url?eid=2-s2.0-84939491763&partnerID=40&md5=026bc73ff06e4ae484e755e603b5b183.

Kneale, Pauline, Jennie Winter, Rebecca Turner, Lucy Spowart, Jane Hughes, Colleen McKEnna, and Reema Muneer. 2016. “Evaluating Teaching Development in Higher Education.” https://www.advance-he.ac.uk/knowledge-hub/evaluating-teaching-development-higher-education.

Whitchurch, Celia. 2012. *Reconstructing Identities in Higher Education*. *Reconstructing Identities in Higher Education: The Rise of Third Space Professionals*. Routledge. https://doi.org/10.4324/9780203098301.

Whitchurch, Celia. 2015. “The Rise of Third Space Professionals: Paradoxes and Dilemmas.” In *Forming, Recruiting and Managing the Academic Profession*, 79–99. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-16080-1_5.

TAKING THE INITIATIVE FOR INNOVATION IN ENGINEERING EDUCATION – LAUNCHING THE IDEE MODEL

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ABSTRACT

The Initiative for Innovation in Engineering Education, IDEE, is a university-wide activity at Delft University of Technology (TU Delft), aiming to strengthen the capacity for evidence-based innovation in engineering education. The goal is to create a more systematic and evidence-informed approach to educational innovation at TU Delft, and to ensure that the knowledge gained is documented and shared with the wider education community. This paper describes the first steps in establishing the structures for the initiative, identifying the educational themes to be addressed, mobilising teams of faculty members and recruiting junior researchers, creating support for these teams, and building a productive community. Through this setup, IDEE has high ambitions for creating both educational innovation and associated

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scientific gains. It is also intended to create role models for novel kinds of academic careers with an emphasis on teaching.

1 INTRODUCTION

1.1 Engineering Education Innovation and Research as Strategic Goals

Delft University of Technology (TU Delft) is committed to innovation and research in engineering education, as evident in its Strategic Framework (TU Delft Strategic Framework, 2020-2024; Strategic Agenda 2024-2030). The strategic goals are to further strengthen the connection between research and education by supporting research into education and learning, and fostering a culture of evidence-based innovation and experimentation in teaching and learning. To reach these goals, the university needs a structured way of driving innovation in education to address challenges in education, in a scientific and timely manner. It is important that the knowledge gained can be preserved and implemented by the wider education community, in the education at TU Delft as well as globally.

For this purpose, the university has launched the *Initiative on Innovation in Delft Engineering Education*, IDEE. The term innovation is consciously chosen as it does not just refer to producing novel ideas per se, but to making a meaningful impact through the implementation of new practices in education. Within this initiative, scientific staff members from across the faculties work in teams, with each team addressing an educational challenge, called a *theme*. Themes should represent issues of broad relevance to the university and to engineering education in general.

1.2 Comparable initiative as inspiration

Comparable initiatives can be found at EPFL in Switzerland and Utrecht University in the Netherlands. At EPFL, the Center for Learning Sciences, LEARN, is a collaboration between researchers, practitioners and policy-makers in the field of education. It aims to continuously improve education by designing solutions informed by the state-of-the-art, and empirically evaluating the impact of their implementation (EPFL, n.d.). The 'Senior Fellow Programme' at Utrecht University (Utrecht University, n.d.) aims to strengthen educational leadership within the university and to increase the number of professors with a special focus on education. The programme contributes to the visible appreciation for education and teaching and demonstrates that also a full professor career in education is possible. The programme also aims to promote innovation in teaching and learning and to increase the overall quality of education. Senior Fellows are intended to play a key role in improvements of the education at the university and be an inspiration to their colleagues (Crone et al., 2023).

When creating IDEE, these role models were adapted for the context of TU Delft. This concerned the way the educational challenges were prioritised by many stakeholders, operating in teams to tackle the challenges (as opposed to single scientists innovating or addressing research questions from a specific course), the expectations of the career path (enabling advancement in careers on all levels rather than a specific track to full professorship), adding junior researchers to the teams, and focusing on Engineering Education Research and Innovation for TU Delft and the wider community.

1.3 Combining research and innovation to create institutional change

The design of IDEE was guided by some principles to ensure that the teams can create impact. Firstly, the teams should work on a coherent set of university-wide educational challenges, or themes. This is based on the recognition that in a complex environment like higher education an organization requires simultaneous and sustained interventions to gain momentum for changing practices (see for instance Luisiani & Langley, 2019, cited by Schophuizen et al., 2022). By choosing coherent challenges that are widely supported by both upper management and the education community at TU Delft, IDEE ensures a collective sense of responsibility to create educational change on an institutional level.

Secondly, the challenges are tackled by teams. When individual educators innovate in their courses and programs, impact is often limited to a single faculty, or even department. The IDEE teams are interdisciplinary in nature as they consist of scientific members from different faculties, mostly with an engineering background. To strengthen the capacity for educational innovation, each team hires a PhD and two postdocs, with stronger educational background. To include student perspectives, the teams will also involve students in different ways, for instance via surveys, student councils, freelance student project employees, and teaching assistants. This is underpinned by the idea that co-creation between students and faculty staff not only leads to greater value for output, but may also result in greater value to the individuals who are participating (Dollinger & Lodge, 2019).

Thirdly, research shows that when educators make changes in their teaching practices, they can’t always identify if the changes are made based on scientifically sound principles (Kottmann, Schildkamp & van der Meulen, 2023). Therefore, IDEE intends to build bridges between ongoing innovative practices and research, making the underlying scientific principles considered and explicit. A close relationship between educators’ practice and educational research offers opportunities to understand the complex process of educational innovation and consider educators’ and students’ needs. The ideal is to combine the innovations and research in an iterative process. Within the IDEE themes, challenges are discovered, and possible solutions are identified within existing practices or designed based on literature. This process then continues with testing, evaluating, and re-developing. Research shows that a design-based research approach has the potential to promote and facilitate context-sensitive interventions that address issues recognized as relevant by the participants (Tinoca et al., 2022).

Finally, IDEE creates a space for educators to showcase their innovative practices, finding interesting practices of peers and sharing their lessons learned. By bringing their practices into the research being done within IDEE, it creates evidence of faculty teaching competence while also offering a way to strengthen it further.

1.4 Recognition and Rewards in the Dutch Context

IDEE should also be understood in the light of an important shift on the national level, as the Netherlands is currently going through a renegotiation of the academic career system. In the new system for recognition and rewards, less emphasis is given to quantitative measures of research output, such as number of publications and h-index. To enable more diversity in academic career paths, people can have profiles with different balance between education, research, valorisation and leadership (Recognition and Rewards, 2019).

This new career system is already in place, but it is early days and there is still a need to fully make sense of the implications. In this context, IDEE should be seen as a way for TU Delft to manifest the recognition and appreciation of quality of education. Through their engagement in IDEE, numerous people will have the opportunity to strengthen their educational expertise and build up a merit portfolio of scholarly educational innovation. Especially, because IDEE is funded by the strategic funds of TU Delft, it offers educators a first stepping stone into the field even if they do not have a prior record in educational research. Accordingly, IDEE aims to be a productive breeding ground for role models with an emphasis on education, exemplifying new kinds of legitimate and fully recognised and respected career profiles (Crone et al., 2023; Graham, 2018).

2 THE BASIC SETUP OF IDEE

2.1 Teams and Themes

IDEE is designed to offer opportunities for teams of scientific staff members to work on educational challenges. Each team consists of several educators, with a PhD student, two post-docs (one after the other) and an educational developer. While faculty members stay embedded in their respective departments, the teams will also partially work together to inspire each other and share experiences and knowledge. The aim is to have up to five teams working each on a different educational theme at any given time, with each team having five years to research, experiment, evaluate, implement and disseminate their educational innovations.

The themes to be addressed in IDEE are chosen to be relevant and highly interesting for engineering educators, not only strategically important across the faculties of TU Delft but also generally in the engineering education community. To prioritise between potential themes, the following five principles were applied:

I. The theme addresses an educational challenge.
II. The theme relates to TU Delft degree programmes.
III. The theme concerns TU Delft as a whole and is, or is expected to become, relevant to most faculties.
IV. The goal is to improve engineering education at TU Delft.
V. Developed innovations must be applicable to the TU Delft campus and preferably beyond.

The first three themes were formulated in consultation with a group of stakeholders consisting of program directors, representatives of 4TU[*], policymakers, managers within the Department of Education and Student Affairs, and the vice-president of Education. The resulting themes were *Students taking responsibility for their own learning process*; *Retention of knowledge and skills*; and *Future engineering skills*. They are each described in more detail in Section 4 below.

2.2 Mobilising Teams Around the First Themes

During spring 2023, the three themes were announced in an open call to attract educators across the university. The open call ensures an intrinsic motivation of the educator joining the initiative, which is a strong determinant of teachers' commitment

[*] 4TU is the federation of the four technical universities in the Netherlands, see: www.4tu.nl

to education innovation (Kottmann, Schildkamp & van der Meulen, 2023). In total about 60 educators submitted letters of interest, indicating their chosen theme, and elaborating on the roles that they were willing to take. The participation was not limited and the result was three large groups of faculty members mobilising as teams to formulate a project proposal for the work.

The three teams received a go-ahead in September 2023 and started recruiting the PhD candidate and their first post-doc. This required them to identify who, out of their numerous faculty members, would be the supervisors and promotors, and they also had to select a place in the organisation that the student and postdoc would formally belong to. The first three vacancies were advertised in December 2023 and attracted in total 190 applications. At the time of writing, the first few PhD candidates and postdocs have accepted their offers of employment and candidates for additional positions are being interviewed.

2.3 The Next Round of Themes

IDEE is designed to have up to five teams working at any given time. During 2024, two additional themes are being formulated, and new teams will be created around them. The process starts again with formulating themes that are currently relevant in the field, and specifically at TU Delft, involving the same stakeholders as in the previous consultation session. After the open call, the project managers will organize a number of sessions in which the teams collaboratively work towards a project proposal. In the first round in 2023, this part of the process was left unstructured and up to each team to organise themselves. This was difficult for them especially because the teams were very large and the challenge new. This time, therefore, a somewhat more structured approach will be adopted to provide the teams with more guidance. The sessions will support the teams in getting to know each other as teammates, connecting to IDEE as a program, exploring the theme with educators, students, educational experts and policy makers, identifying problems and opportunities within it, choosing a focus for the project, and defining the mode of collaboration as a team.

3 ORGANISATION AND PROCESSES

3.1 Funding and Support Organisation

IDEE is one of the activities of the Teaching Academy (TA), a network for and by educators of TU Delft with the mission to collaboratively enhance engineering education and drive education innovations across the faculties of the university. Through the TA, each IDEE team is funded for five years, covering the cost for a PhD student, two consecutive postdoc positions (of two years each), and a learning designer (on 20%). In addition, the faculty members are expected to spend 20% of their time, as part of their regular research time.

IDEE is also supported by two project managers (one is the third author), in total 1,4 full-time equivalent. The project managers support the teams by overseeing the overall processes, connecting different stakeholders, facilitating collaboration among the teams, organising events and supporting day-to-day activities of the teams. The project managers collaborate with the Academic Director of the TA (the first author), specifically in positioning IDEE within the university context, and with the Scientific Expert to create a supportive work environment for the PhD’s and Postdocs and guide the teams in the educational research field.

A Scientific Expert in Engineering Education (the second author) was recruited in a part-time (20%) position as Professor in Engineering Education Innovation from 2024. The role is to support the IDEE community in their work, with an eye to furthering the quality and impact of the educational innovations, the quality and impact of the scholarly contributions, and the development of all the people involved – not least the PhD students and post-docs.

The IDEE Board is responsible for strategic management. It consists of the Vice President for Education, the Strategic Policy Advisor for Education, the Academic Director of the TA, and the Scientific Expert of IDEE.

3.2 Enhancing Competence

Team members are offered a program to develop themselves in the area of innovation and change. The aim is to strengthen their capacity for combining innovation and research activities that impact engineering education university-wide. The topics addressed are, for example, transdisciplinary team work, engineering education scientific methods, peer consultation, innovation methods, co-creation sessions and valorisation strategies (Crone et al., 2023; Kottmann, Schildkamp & van der Meulen, 2023).

3.3 Forming a Community

IDEE will organize events where the broader TU Delft education community comes together to learn about the projects, new developments, experiments, innovations, to seek inspiration for addressing their own educational challenges. The objective is to work together and find synergy with other educational innovation and research activities at the university, as well as collaborations on the national level such as the 4TU.Center for Engineering Education (4TU.CEE, n.d.). IDEE also aims to become an attractive environment for scholarly exchanges with international partners. International networks such as SEFI is a natural place to find interesting and interested friends, allies, and partners.

To support the community building, IDEE and its teams have a virtual presence. One part of the Teaching Academy’s portfolio is also the Teaching Lab, which is a physical space on campus suitable for hosting large and small meetings, events, and incoming visits. Such activities are intended to strengthen the relationships across the community. Some would be led by internal participants and focus on the work in the teams. Others will feature external experts to discuss subjects of joint interest to the themes. Some events will be more widely open, to enhance the visibility of IDEE, internally, nationally and internationally.

The PhD candidates and post-docs are a key group within IDEE. In addition to the wider aiming workshops and seminars mentioned above, there will be an ongoing seminar to directly support the junior researchers as a group, also with activities such as study trips and joint conference participation.

4 Introducing The First Three Themes

Based on the proposals as written by each team, the first three themes are here introduced, starting with a brief description, some possible questions to be addressed and mentioning some of the planned output. For full descriptions, see the website where each theme has a section (IDEE, n.d.).

4.1 Theme: "Students taking responsibility for their own learning process"

"Taking responsibility and acting autonomously are key competencies for professional engineers and their future contribution to society. They also play an important role in stimulating intrinsic motivation. In this theme, the main question is how to create the conditions to have students take the responsibility for their own learning process. These conditions apply to students, lecturers, the curriculum as well as the learning environment in which they operate."

- What do students need to be able to take responsibility?
- How to design a curriculum which allows students to take responsibility?
- What should lecturers do to stimulate and enable students to take responsibility?"

Some of the outputs that are expected in this theme is a *Glossary of Common Ground* that includes the shared approaches, concepts, and mindsets on the theme, and resources for addressing the issues through a *Pedagogical Pattern Language* (Laurillard, 2012) for pedagogies that foster student responsibility.

4.2 Theme: "Engineering students' progression and retention of knowledge and skills"

"The design and implementation of a seamless continuum of education should take place at all levels: as a learning activity in a single course, as a connection between multiple courses in a single program, with teachers and learners being part of a local teaching and learning culture."

- How to design a consistent curriculum to stimulate progression, retention and transfer of knowledge and skills?
- How to teach new concepts to foster students' understandings of this knowledge with a view on progression ("forward teaching")?
- How to support students in transfer of their knowledge and skills to new settings and applications?

This theme will be addressed through design-based research. Some of the expected result will be principles for curriculum and course design to promote progression, retention and transfer.

4.3 Theme: "Future engineering skills"

"Courses on engineering skills are part of many engineering education programmes. In a rapidly developing society, required engineering skills change quickly. One of the challenges is to better anticipate engineering skills needed in the future and to stay updated on the state-of-the-art engineering skills needed in society."

- How to design agile degree programmes in which future engineering skills are effectively acquired and seamlessly integrated?
- How to make sure that the skills addressed in the programmes are in line with the skills needed?
- How to stimulate critical reflection among students on the application of new engineering skills in professional practice and society?

Some output that is expected in this theme is an *Inventory of transdisciplinary teaching and learning* that is already practised at the university, a *List of desirable skills* with a *Stakeholder analysis*. Later stages, the team formulates and pilots *Design principles for future course development and for program development*.

5 DISCUSSION

5.1 Combining Innovation and Research

The aim of IDEE is to further meaningful *combinations* of innovation and research. The intention is to support a scholarly approach to innovation, meaning systematic rather than ad hoc interventions. The experiences of educational experimentation are intended to contribute to the engineering education research field. In other words, the work should be evidence-informed as well as evidence-producing. One potential research approach is to use a design-based cycle to test, evaluate, redesign and adapt solutions. Documentation and scholarly communication of the experiences plays an important role not only for spreading the innovations within the university, where the work should be made tangible and visible, but also beyond in the wider community of engineering educators. Submitting work to conferences and journals makes it subject for qualified international peer review, while it also provides forms of archiving and dissemination. Together with establishing local recognition and legitimacy for the educational innovation at TU Delft, such traditional research outputs also serve as recognised merits in an academic career. This is of particular importance since the Dutch academic career system is currently open for reconsideration, and there is a need for role models with regards to careers in which education is emphasised.

Combining innovation and research is not trivial, however. For those who base their scholarship on educational innovation, as the IDEE educators are expected to do, the challenge is to make direct impact within their own environment, *and* to design and publish their work in a way that is both scholarly and useful to others.

5.2 Worthy Ambitions

IDEE sets the ambitions high, but the aims are worth striving for and the conditions have arguably never been better.

The legitimacy of IDEE will rest on its ability to create positive impacts on education, to enable addressing the challenges in education and driving innovation. Therefore, the work needs to be locally embedded in contexts where the real, practical problems exist, and where experimentation can take place under realistic conditions involving students and staff. This is where the ideas must prove their usefulness. Impact is likely to be created through the process (rather than just by the research output on its own), especially through collaboration with colleagues and students in the different educational contexts.

Research output plays a key role for creating a strong presence and recognition in the research community. This is important for IDEE as a whole, and for the involved individuals. Since the themes that will be addressed in IDEE have emerged as strategically important within TU Delft, they are likely to be relevant and timely also for others in the research field.

A key legacy of IDEE is the involved people. This initiative should strengthen a significant number of long-term strong supporters of educational innovation and research. The people involved should develop attractive expertise, capacity to handle educational challenges, and ability to lead future endeavours. Their long-term career is a showcase for the model and an important indicator of success; it will also be seen as an indicator for the importance of education at TU Delft.

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REFERENCES

4TU.CEE, 4TU.Centre for Engineering Education. Website. Accessed June 13, 2024. www.4tu.nl/cee/

Crone, V., F. Prins, C. Lutz, I. Meijerman, V. Schutjens, M. van der Smagt, L. Wijngaards-de Meij, N. Bovenschen, and M. Kluijtmans. ”Strengthening educational leadership through a professional development programme in conjunction with a teaching-focused full professor career track: reflections of participants.” *International Journal for Academic Development* (2023): 1–13. https://doi.org/10.1080/1360144X.2023.2207309

Dollinger, M. and J. Lodge. “Student-staff co-creation in higher education: an evidence-informed model to support future design and implementation.” *Journal of Higher Education Policy and Management* 42, 5 (2020): 532–546. https://doi.org/10.1080/1360080X.2019.1663681.

EPFL LEARN. Website. Accessed June 13, 2024. http://learn.epfl.ch/

Graham, R. *The Career Framework for University Teaching: background and overview.* London: Royal Academy of Engineering, 2018.

IDEE, TU Delft. Website. Accessed June 13, 2024. www.tudelft.nl/teachingacademy/themes/initiative-on-innovation-in-delft-engineering-education-idee

Kottmann, A., K. Schildkamp, and B. van der Meulen. “Determinants of the Innovation Behaviour of Teachers in Higher Education.” *Innovation in Higher Education* 49 (2024): 397–418. https://doi.org/10.1007/s10755-023-09689-y.

Laurillard, D. *Teaching as a design science: Building pedagogical patterns for learning and technology.* New York: Routledge, 2013.

Lusiani, M., and A. Langley. “The social construction of strategic coherence: Practices of enabling leadership.” *Long Range Planning* 52, 5 (2019): 101840. https://doi.org/10.1016/j.lrp.2018.05.006

Recognition and Reward, 2019. “*Room for everyone's talent: towards a new balance in the recognition and rewards of academics. Position paper.”* Accessed June 13, 2024. http://recognitionrewards.nl/

Schophuizen, M., A. Kelly, C. Utama, M. Specht, and M. Kalz. “Enabling educational innovations through complexity leadership? Perspectives from four Dutch universities.” *Tertiary Education and Management* 29, 4 (2022): 471–490. https://doi.org/10.1007/s11233-022-09105-8.

Tinoca, L., J. Piedade, S. Santos, A. Pedro, and S. Gomes. "Design-Based Research in the Educational Field: A Systematic Literature Review." *Education Sciences* 12, 6 (2022): 410. https://doi.org/10.3390/educsci12060410.

TU Delft. *Strategic Framework 2018-2024.* Accessed June 13, 2024. [Link]

TU Delft. *Strategic Agenda 2024-2030.* Accessed June 13, 2024. [Link]

Utrecht University Senior Fellow Programme. Website. Accessed June 13, 2024. www.uu.nl/en/education/centre-for-academic-teaching-and-learning/about-us/community/senior-and-principal-fellows/senior-fellow-programme

COLLABORATIVE CO-DESIGN AND IMPLEMENTATION OF A PRACTICAL MANUFACTURING MODULE FOR LARGE CLASSES

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ABSTRACT

To enable engineering students to design effectively for manufacturing, hands-on practical experience is of paramount importance. Although students who are planning to progress into professional engineering careers do not necessarily need hands-on proficiency in all techniques, a basic understanding of the capabilities and limitations of different manufacturing processes is required. Students should be aware of how issues can arise by considering key aspects of manufacturing processes. Providing access to this, however, is a complex undertaking. Large engineering cohorts and limited resources and teaching spaces mean it can be difficult to provide every student with these opportunities. This paper reports on the redevelopment of an undergraduate manufacturing module for second year engineering students. The course was developed based on input from several stakeholders (lecturer, student co-design and workshop personnel) with feedback gathered at regular points before, during and after module implementation.

The new module allows students to produce an artefact which requires CNC machining, drilling, turning, metal folding, 3D printing and laser cutting. Student surveys, attendance analysis and detailed interviews were used to ascertain the effectiveness of the module. Analysis has shown that average attendance has increased by 6% and feedback from students was very positive, with 96% rating the practical elements as either good or very good.

The benefits of developing the module with stakeholder involvement has ensured that students are introduced to processes by experienced technicians, that logistically the workshop schedules have run efficiently and that the Student Voice has been considered throughout, resulting in a high-quality experience for the students.

1 INTRODUCTION

1.1 Background

According to (Graham 2018), the style of educating engineers is rapidly changing, increasing the amount of project/problem-based content within modules and moving away from the traditional lecture-based approach. Additionally, accrediting bodies require that students are given these experiences to meet mandatory learning outcomes, such as the UK Engineering Council's AHEP4 standards ("The Accreditation of Higher Education Programmes (AHEP) Fourth Edition" 2020). However, in parallel, Mechanical Engineering undergraduate programmes have increasingly large class sizes, particularly in Stages 1 and 2, which presents the risk that, as the student numbers rise, engagement will fall (Kinsella, Mahon, and Ullis 2017).

A significant body of pedagogical literature has focussed on the challenges of large class sizes and student engagement (Cole and Spence 2012; Shekhar and Borrego 2018). Finn et al. (Finn, Pannozzo, and Achilles 2003) reviewed the existing literature on class size effects and concluded that; "students in small classes are more engaged in learning behaviours," and that, "teachers' interpersonal styles benefit from class-size reduction." Svinicki and McKeachie (McKeachie and Svinicki 2011) also noted that, "students in a large class are usually more anonymous and feel less personal responsibility, reducing motivation for learning."

It has been reported that the most effective teaching involves active student participation and meaningful activities for learners (Freeman et al. 2014). Increased educational engineering practice including project/problem-based activities is a resource intensive endeavour, particularly, with increasing class sizes (McCartan et al. 2008; Servant-Miklos and Kolmos 2022). However, it can be an effective method to reduce the staff-student ratio and can allow students to learn from experienced technical staff beyond the traditional 'teaching by telling' methods and help link theory and practice (Prince 2004; Kamp 2023; Alhawiti 2023).

It is unrealistic to expect a single lecturer or delivery technique to facilitate all types of learning for a large class in a practical environment. Therefore, to enable engineering practice in education, a number of stakeholders are typically required.

1.2 Stakeholder involvement in curriculum development

Stakeholder involvement in course development has been widely studied (Lu, Nguyen, and Ersin 2015; Ringler 2022). The biggest stakeholders are the students, since they have the largest stake in the final outcome (Mulay, Tandon Khanna, and Somaiya 2017). Lu et al. (Lu, Nguyen, and Ersin 2015) note that, "having students take part in curriculum development cultivates a sense of shared responsibility among faculty members and students." Indeed, Kay et al. (Kay 2010) suggest students should be considered as, "evaluators, participants, partners, cocreators, experts and as change agents." However, other key stakeholders such as technicians and postgraduate demonstrators are important in the development and delivery of a course, particularly with practical elements.

Student input is normally incorporated based on feedback from the previous academic year. End of term evaluations (module and teaching evaluation questionaries (MEQ/TEQ)) are a standard part of course evaluations (Ringler 2022). However, the virtue of relying on end of term surveys has been questioned. Literature has shown that, "factors other than teaching quality, including the size of the class, course grade distributions, and whether it was being taken as an elective or a requirement can influence students' responses on such evaluations" (Villanueva et al. 2017).

1.3 Module Case-Study – Manufacturing Technology

This paper will focus on Manufacturing Technology (MEE2034), a second-year undergraduate module for all students from Mechanical, Aerospace and Product Design Engineering pathways within the School of Mechanical and Aerospace Engineering (SMAE) at Queen's University Belfast ("School of Mechanical and Aerospace Engineering | Queen's University Belfast," n.d.).The purpose of the module is to instil fundamental understanding of different manufacturing technologies and facilitate some workshop practice. In accordance with Engineering Council requirements, students must utilise practical skills in laboratory and workshop environments and experience solving "broadly-defined problems" ("The Accreditation of Higher Education Programmes (AHEP) Fourth Edition" 2020). Additionally, the module is vitally important to the CDIO (Conceive, Design, Implement and Operate) educational framework implementation in SMAE, as it directly links to CDIO standards 4 (introduction to engineering), 5 (design-implement experiences) and 7 (integrated learning experiences) and is also relevant to standards 6 (engineering learning workspaces) & 8 (active learning) (Berggren et al. 2003).

For over 20 years the workshop elements of this module were delivered at a local technical college, experienced in training technicians and operators via skilled workshop staff and multiple machines, external to the university. Due to external factors, in March 2023, the module could no longer be facilitated externally and would be brought to SMAE. This necessitated the rapid development of a new module to ensure that students were still provided with a good hands-on workshop experience, starting in September 2023. The rest of the paper will focus on the collaborative work to complete the module redesign.

1.4 Rationale

The aim of this study is to document the process of incorporating stakeholder input, specifically lecturer, technician, and student voice into the development of a new manufacturing module for engineering students. In this exercise a number of requirements needed to be met; the module should be able to cater for a large cohort (150+ students) but also react to variation in student numbers year on year and it should include dependence-based tasks to replicate real-world manufacturing processes. The research question was answered through a series of stakeholder engagement and feedback exercises before, during and after module implementation. Various levels of feedback, surveys and interviews, were used to ascertain the effectiveness of the module (i.e. both practical and lecture components).

2 METHODOLOGY

2.1 Module Design

There are a wide range of manufacturing processes and technologies used both in industry and within the School Workshops. The SMAE technical team encompasses workshop and technician staff, who are highly experienced, time served machinists, toolmakers or fabricators, with a combined 286 years of experience in both industry and academia. The SMAE boasts a wide variety of capabilities, such as: Laser Cutting, Hot Wire Foam Cutting, 3D Printing, CNC machining, a robot platform and various Polymer & Composite Processes. Clearly, there are too many to be covered in one twelve-week module. Therefore, the approach here was to focus lectures on the underlying theory of different manufacturing methods while facilitating some workshop-based practice on the available equipment and resources. These sessions would consolidate fundamental principles rather than teaching students how to use the latest piece of manufacturing equipment (Smith et al. 1995).

Stakeholder input was key to the module development, particularly since the practical aspects would be delivered by the technical team, rather than the lecturer. The primary development challenge was creating a structure encompassing a variety of manufacturing processes and scheduling the sessions. There were 172 students enrolled in Manufacturing Technology in 2023/24 (110 Mechanical, 62 Aerospace and 10 Product Design) and students were divided into 29 groups (five or six students per group) to allow for scheduling at each session.

Module design centred around the manufacture of an artefact, and associated programme of workshop practice, shown in Figure 1, to expose the students to different manufacturing technologies around the school. Five technician-led workshops and demonstrations, shown in Figure 2, including CNC milling, lathe turning, water jet and laser cutting and 3D printing were devised. In addition, three sessions of hand tool-based tasks, including sheet metal work, measuring, drilling, tapping and final assembly were included. Complimentary lecture material to supplement the learning from hands-on experience, along with both formative and summative assessments, were also created.

Fig. 1. Artefact

Fig. 2. Students taking part in practical tasks

Practical sessions would promote specific skills, demonstrate fundamental principles, and support manufacturing theory presented in the lectures. The practical tasks could also be linked to the different learning stages in Bloom's Taxonomy. Table 1 compares the tasks with the learning stages and shows that the practical programme can cover four of the six levels of the revised Bloom's Taxonomy (Krathwohl 2002).

Table 1 - Link between workshop tasks and Bloom's Taxonomy

Workshop Topic	Workshop Task(s)	Bloom's Taxonomy Level
3D Printing (including assignment)	Design a new component, Observe and learn about concepts, Operate the 3D printer and relevant software.	Create, Remember, Apply
Laser cutting (including assignment)	Design a new component, Observe and learn about concepts.	Create, Remember
CNC Machining/Waterjet	Observe and learn about concepts.	Remember
Sheet Metal Work / Drilling and Tapping	Operate workshop equipment, Interpret engineering drawings.	Analyse, Create, Apply
Final Assembly	Assemble various components according to engineering drawings	Analyse, Create, Apply

A period of iterative module design was completed where the learning was standardised across practical classes ensuring all students receive identical teaching and hands-on experiences. The member of the technical team with a particular specialism reviewed and commented on the proposed lecture content for that part of the module. Similarly, the module coordinator reviewed the scope of each practical. This ensured a synergy between lecture and practical content. Some students would complete practical sessions before the lecture or vice-versa.

The assessment structure for the module remained unchanged from 2022/23 with 70% coursework and 30% class test. However, the contributing elements of coursework were different. 40% was associated with workshop participation, two small SolidWorks design and make tasks, and final assembly of the artefact. A further 30% came from a group assignment, beyond the scope of this paper.

2.2 Learning environment

The workshop and practical sessions were facilitated by the SMAE Technical Team. Sessions were delivered across four primary locations; The Engineering Workshop (Figure 3), two student groupwork rooms and the Student Design Centre (Figure 4).

Fig. 3. Ashby Engineering Workshop

Fig. 4. Ashby Student Design Centre

2.3 Student Co-Design

Once a baseline lecture and practical programme had been designed a period of student co-design and evaluation was completed. Four third-year students were recruited, who had completed the previous version of the module. These students were asked to complete a dry-run of the practical sessions, review the assignment documents and other information before providing feedback from a student perspective. This student feedback was collected through a review meeting and incorporated into the module design.

2.4 Surveys and Data Collection

The effectiveness of the new module in encouraging active engagement with subject content (Taylor 2016), was evaluated using both quantitative data (attendance, student surveys and assessment marks) and qualitative data (student interviews).

Two short Vevox surveys were taken during the week two and week eight lectures to get both an early indication of student perceptions when modifications could still be made, and an overview of student satisfaction when the course content was complete. One-to-one interviews with students were completed in weeks 11 and 12 of the semester. Students were selected from the class list, both male and female, both BEng/MEng and from the three degree pathways. All students were asked the same questions from a predefined list (Krueger and Casey 2009).

3 RESULTS

3.1 Survey Data

During the development of the module, a focus group of students who had completed the module in the original format at the external college was gathered, and the practical elements of the module in its new form were delivered to them. Feedback on the content, clarity and timing was collected. The feedback received on the new format was very positive, with students commenting on how interesting the sessions were, particularly with equipment they have never seen before. Some comments were made surrounding timing, a lack of hands-on experience and about the content of the sessions. Before the module was delivered to students, changes to the timing of each session and to some of the content were made in line with these comments. During the semester, a total of 112 (65%) and 67 (40%) students, respectively, completed the two Vevox surveys, with 93% and 96% rating the practical classes as good or very good. In week eight, 95% of respondents rated the support provided by technicians, demonstrators or lecturers at the practical sessions as good or very good (Figure 5).

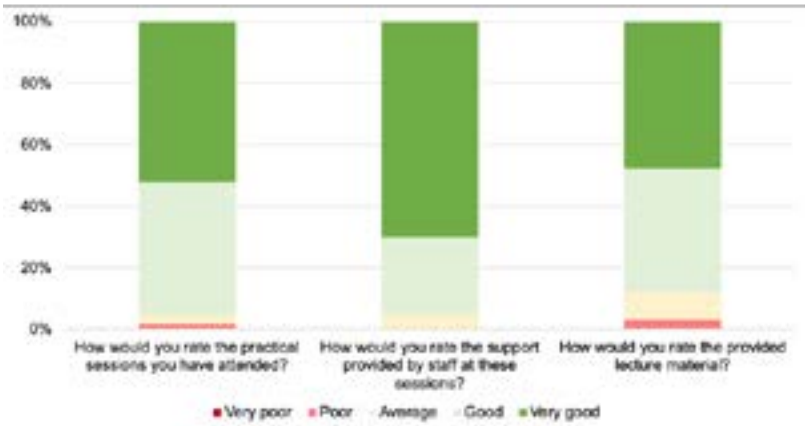

Fig. 5. Selected student survey responses from week eight lecture.

3.2 Student Comments

Table 2 presents selected comments on module content and perception from interviewed students. All students stated they felt they were learning when completing the practical classes. The collaborative effort to create synergy between the lecture and practical content was appreciated and reflected in student feedback, as there were, “good links between the lecture content and the practical classes.”

Table 2: Selected comments on module content and perception

How did you find the practical classes?	*“[It was] good to see all practical elements in person. The CNC practical was a lot of standing - too much information for the time spent. Technician support throughout was great.”* *“I very much enjoyed the practical sessions – I did Technology and Design at school and missed the practical side in first year Aerospace. Seeing the workshop was great.”*
How did you find the lecture material?	*“Very good lecture content with good links to our Design and Manufacturing module. Despite a couple of repeated lectures, I took different things from each.”* *“[The] lecture content was interesting – clear layout and diagrams,* *One mechanical and one aero example would have been good.”*
Did you feel you were learning when	*“Yes – more so when actually doing and when practicals complimented each other”*

completing the practical classes?	*"Yes – in some more than others. I don't feel I learned as much when only observing."*
How did you find the module overall?	*"Manufacturing Technology has been my favourite subject this year. I really enjoyed making the artefact and enjoyed [the] lectures. I appreciated how the subject could be applied to industry."* *"Happy overall with module - a good break from the theory heavy modules. I really like having the artefact on my desk and play with it when working."*

3.3 Comparison with previous module implementation

Weekly student engagement was high at practical sessions, always above 78%, however, lecture attendance was more variable, plateauing between 40% and 60% from week three. Lecture attendance generally decreased throughout the course of the semester. Student feedback indicated that some felt the lecture was less engaging if they had already attended the corresponding practical session. This could be an example of students' strategic approach to assessment and attendance (Gibbs and Simpson 2004), however, interest in the subject matter also plays a key role in promoting attendance. Further analysis of each practical at the end of the semester showed that only single digit numbers of students missed both opportunities to attend individual practical elements. While the content of the practical sessions was not identical across years, there was an increase in attendance for all sessions. This could be due to the summative assessment strategy allocated to each, however, an additional session outside of this strategy still had overall attendance of 93%.

3.4 Overview of outcomes

The end of module results were compared with previous, non-Covid academic years. The grade average has been rising steadily for the last number of years, 68% in 22/23 and rose again to 76% in 2023/24 (Table 3).

Marks were available for participating in the workshop elements (15% split over five sessions). Assignment 1 (20% of the module) involved the submission of two sets of Computer-Aided Design (CAD) files and the manufacture of laser cut and 3D printed elements with simple marking rubrics. While feedback indicted that students enjoyed these tasks, and the intended goal of promoting student engagement with the workshops was achieved, marks were high on an absolute scale of attainment. The average for the group assignment was 63% and the class test average was 68.9%. The number of fails in 23/24 dropped despite a larger class size.

Table 3: Overview of student outcomes for previous (non-Covid) academic years

Academic Year	No. of students	No. of fails (1st attempt) (%)	Overall average (%)	Std Dev	MEQ Score
2023-24	172	2.33	76.18	9.61	4.3
2022-23	162	6.79	68.46	8.92	4.4
2021-22	155	5.16	65.73	11.33	4.2
2018-19	187	2.67	60.2	9.56	3.9

4 SUMMARY AND ACKNOWLEDGEMENTS

This paper has described the redesign of a manufacturing module for undergraduate engineering students. The course was developed based on input from a number of stakeholders; lecturers, student co-design and workshop personnel. Different forms of quantitative data (attendance figures, student survey data and assessment marks) and qualitative data (interviews with students) were used to gather feedback at regular points before, during and after module implementation.

Technician-led workshops and demonstrations, and hand tool-based tasks were devised which exposed students to different manufacturing technologies including CNC milling, lathe turning, water jet and laser cutting, 3D printing, sheet metal work, measuring, drilling, tapping and assembly. The new module achieved good student feedback and educational outcomes. Analysis has shown that the average attendance has increased by 6% with at least 78% participation in each session, and feedback from students was very positive, with 96% rating the practical elements as four stars or above. Despite it being quite technically and logistically challenging to bring the module into the University in a very a short timescale, the experience for students appears to have been of high quality. Achieving such efficient and effective running of the practical elements of the programme was possible only by working collaboratively with the academic staff, technical staff, including student co-design, and listening to the Student Voice throughout the process. This co-design and collaborative approach will be invaluable to future development of hands-on modules within SMAE but could also be utilised by other institutions.

While engagement with practical classes was high, attendance was comparatively low at lectures. Interaction at lectures has been identified as a key area of focus as has the further development and refinement of the assignments. New Computer Aided Manufacturing (CAM) tasks are planned for 2024/25 which will compliment Computer-Aided Design (CAD), which the same students' study in Stage 1 and 2. The work described herein has been recognised with a teaching award, "Excellence in Teaching or Learning Support by a Team" and by the institutional Continuous Action for Programme Enhancement (CAPE) steering group in their "Institutional Actions for Embedding of Good Practice" report. This demonstrated the impact of the work in influencing the process for curriculum development across an institution, and how this could be adapted to other institutions or settings. This programme will continue to evolve as the School invests in new equipment and infrastructure to further extend onsite manufacturing capacity.

The authors would like to acknowledge the dedication and conscientiousness of the SMAE Technical Team in the support and delivery of this module through the 2023/24 academic year.

REFERENCES

Alhawiti, Naif M. 2023. "The Influence of Active Learning on the Development of Learner Capabilities in the College of Applied Medical Sciences: Mixed-Methods Study." *Advances in Medical Education and Practice* 14 (February):87–99. https://doi.org/10.2147/AMEP.S392875.

Berggren, Karl-Frederik, Doris Brodeur, Edward F. Crawley, Ingemar Ingemarsson, William T.G. Litant, Johan Malmqvist, and Sören Östlund. 2003. "CDIO: An

International Initiative for Reforming Engineering Education.” *World Transactions on Engineering and Technology Education* 2 (1): 49–52.

Cole, Jonathan S., and Stephen W.T. Spence. 2012. “Using Continuous Assessment to Promote Student Engagement in a Large Class.” *European Journal of Engineering Education* 37 (5): 508–25. https://doi.org/10.1080/03043797.2012.719002.

Finn, Jeremy D, Gina M Pannozzo, and Charles M Achilles. 2003. “The ‘Why’s’ of Class Size: Student Behavior in Small Classes.” *Review of Educational Research* 73 (3): 321–68.

Freeman, Scott, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. 2014. “Active Learning Increases Student Performance in Science, Engineering, and Mathematics.” *Proceedings of the National Academy of Sciences of the United States of America* 111 (23): 8410–15. https://doi.org/10.1073/pnas.1319030111.

Gibbs, Graham, and Claire Simpson. 2004. “Conditions under Which Assessment Supports Students’ Learning.” *Learning and Teaching in Higher Education* 1:3–31.

Graham, Ruth. 2018. “The Global State of the Art in Engineering Education.”

Kamp, Aldert. 2023. *Engineering Education in the Rapidly Changing World*. TU Delft OPEN Publishing. https://doi.org/10.59490/mg.71.

Kay, Janice. 2010. “Rethinking the Values of Higher Education - Students as Change Agents?” www.qaa.ac.uk/students/studentengagement/undergraduate.pdf.

Kinsella, Gemma K, Catherine Mahon, and Seamus Ullis. 2017. “Facilitating Active Engagement of the University Student in a Large-Group Setting Using Group Work Activities.” *Journal of College Science Teaching* 46 (6): 34–43. https://www.jstor.org/stable/44579943.

Krathwohl, David R. 2002. “A Revision of Bloom’s Taxonomy: An Overview.” *Theory into Practice* 41 (4): 212–18. https://doi.org/10.1207/S15430421TIP4104_2.

Krueger, Richard A., and Mary Anne Casey. 2009. *Focus Groups: A Practical Guide for Applied Research*. 4th ed. Thousand Oaks, CA: SAGE.

Lu, Chu Ying, Quyen Nguyen, and Ozlem H. Ersin. 2015. “Active Student Engagement in Curriculum Development.” *American Journal of Pharmaceutical Education* 79 (2). https://doi.org/10.5688/ajpe79230.

McCartan, Charles D., Geoff Cunningham, Fraser J. Buchanan, and Marion McAfee. 2008. “Application of a Generic Curriculum Change Management Process to Motivate and Excite Students.” *EE 2008 - International Conference on Innovation, Good Practice and Research in Engineering Education* 3 (2): 37–44. https://doi.org/10.11120/ENED.2008.03020037.

McKeachie, Wilbert, and Marilla Svinicki. 2011. *McKeachie’s Teaching Tips: Strategies, Research and Theory for College and University Teachers.* . 12th ed. Florence, KY: Houghton Mifflen.

Mulay, Rahul, Vandana Tandon Khanna, and J Somaiya. 2017. “A Study on the Relationship between the Voice of Customer with the Cost of Quality in Processes of Professional Higher Education Institutions.” In *South Asian Journal of Management*, 24:55–72.

Prince, Michael. 2004. “Does Active Learning Work? A Review of the Research.” *Journal of Engineering Education* 93 (3): 223–31.

Ringler, Ilene. 2022. “Stakeholder Input in Course Development.” In *International Conference for Media in Education*.

“School of Mechanical and Aerospace Engineering | Queen’s University Belfast.” n.d. Accessed February 27, 2024. https://www.qub.ac.uk/schools/SchoolofMechanicalandAerospaceEngineering/.

Servant-Miklos, Virginie F.C., and Anette Kolmos. 2022. “Student Conceptions of Problem and Project Based Learning in Engineering Education: A Phenomenographic Investigation.” *Journal of Engineering Education* 111 (4): 792–812. https://doi.org/10.1002/jee.20478.

Shekhar, Prateek, and Maura Borrego. 2018. “‘Not Hard to Sway’: A Case Study of Student Engagement in Two Large Engineering Classes.” *European Journal of Engineering Education* 43 (4): 585–96. https://doi.org/10.1080/03043797.2016.1209463.

Smith, Christopher A, Richard W Attwell, Maureen M Dawson, John J Gaffney, Ian Graham, and John Willcox. 1995. “Laboratory Practical Class Provision in a First-Year Undergraduate Modular Programme.” *Biochemical Education* 23 (2): 69–71.

Taylor, Megan Westwood. 2016. “From Effective Curricula Toward Effective Curriculum Use.” *Source: Journal for Research in Mathematics Education* 47 (5): 440–53. https://doi.org/10.5951/jresematheduc.47.5.0440.

“The Accreditation of Higher Education Programmes (AHEP) Fourth Edition.” 2020. www.engc.org.uk.

Villanueva, Keisha A, Shane A Brown, Nicole P Pitterson, David S Hurwitz, and Ann Sitomer. 2017. “Teaching Evaluation Practices in Engineering Programs: Current Approaches and Usefulness*.” *International Journal of Engineering Education* 33 (4): 1317–34.

PELTON TURBINE UNDER DIFFERENT OPERATING CONDITIONS:
An Experimental Pedagogical Study

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ABSTRACT

Practical training is crucial in engineering education as it connects theoretical learning with real-world challenges. By providing laboratory experiences, students develop a comprehensive understanding of engineering principles and their practical applications. This approach ensures that students are well-prepared to meet technical demands throughout their careers, equipping them with skills to operate machinery, conduct experiments, and process and analyse data using software. Additionally, practical training fosters teamwork and communication skills through

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group projects and laboratory work, where students learn to share, to collaborate and to communicate their findings.

The present study addresses Pelton Turbine studies in educational institutions; the Pelton turbine testing methodologies used by two different institutions, the Coimbra Institute of Engineering (ISEC), in Portugal, and the Miguel Hernández University of Elche (UMH), in Spain, are compared, as well as the quality and quantity of results that might be obtained. The laboratory practice of engineering education in the field of turbomachinery in both institutions are analysed in terms of how theoretical and real-scale concepts can be applied with the resources available. In the present contribution, special focus will be given to the results obtained at ISEC due to its greater ability to enable and to reproduce different types of tests. When appropriate, reference will be made to the setup and the methodology used at UMH, particularly the challenges in reproducing the same type of tests due to the lack of the ability to control the flow at the turbine inlet, with the injector, limitation that is common in didactic installations.

1 INTRODUCTION

From an educational perspective, conducting turbomachinery experiments, namely with hydraulic turbines, as closely as possible to reality is often challenging, as it is difficult to provide and to sustain the necessary conditions for its operation with the equipment commonly available in educational institutions; this includes all the auxiliary measuring equipment required to perform detailed tests. Thus, the specific conditions available at a given educational institution determine the type of experiments that can be conducted, and consequently, the quality and quantity of data that can be obtained.

In this paper the results obtained at the Laboratory of Hydraulic Machines (LHM) of Department of Mechanical Engineering of ISEC will be discussed. This contribution represents one outcome of the Erasmus+ program that started in April 2023, and since then is being developed and enhanced between UMH and ISEC. The LHM houses a wide range of hydraulic equipment, as well as instrumentation, measurement, and control devices. It serves as a rich laboratory environment for engineering education and practice, unique in Portugal, and perhaps even in Europe, among University and Polytechnique institutions, offering undergraduate and master’s students the chance to test the three most common types of hydraulic turbines, Kaplan, Francis and Pelton, of considerable size for an educational institution.

1.1 Theoretical Background

In real cases, the water is stored in a dam at a given level. However, throughout the year, that level might change significantly. Besides that, the turbine is coupled to an electric generator that must run at synchronous speed, to match grid values. Since load changes from the grid side may occur, the flow rate, Q, must be changed accordingly so that the turbine rotates at constant speed. Therefore, in pedagogical terms, it is important to have a teaching facility capable of simulating those conditions, outside of nominal conditions of the turbine, as frequently occurs in real-life, to understand the associated phenomena and their influence on the performance of the turbine.

At ISEC, the Pelton turbine, main subject of this paper, consists of a horizontal shaft Pelton Spiral Turbine manufactured by B. MAIER, dating back to 1971, with a rotor diameter of 0.3 m and the nominal conditions presented in Table 1.

The turbine is supplied by a pressurized tank through a constant-speed centrifugal pump, model KSB ETA 80-26, manufactured in 1970, with the characteristics presented in Table 2.

Table 1: Nominal conditions of the Pelton turbine at LHM ISEC

Power	Flow rate	Height	Rotation speed
13.97 kW	0.03 m³/s	60 m	1000 rpm
19 CV	108 m³/h	-	104.7 rad/s

Table 2: Nominal conditions of the KSB ETA 80-26 pump at LHM ISEC

Power	Flow rate	Height	Rotation speed
29.4 kW	0.03 m³/s	65 m	2900 rpm
40 CV	110 m³/h	-	303.7 rad/s

This pump is responsible for simulating the gross head, H_g, available in hydroelectric dams, also known as system head, since for experimental reasons it varies with the head losses in the system. The energy balance between the feed tank and the exit of the turbine at ISEC experimental setup leads to (Mendes 2005; Young et al. 2012):

$$H_g = \frac{P_{tank}}{\gamma} + 0.94\ [m.c.water] \quad (1)$$

where P_{tank} corresponds to the feed tank pressure and the value of 0.94 m to the level difference between the pressure measurement level in the feed tank and the turbine outlet. Accordingly, at ISEC, the energy balance between the entrance and the exit of the turbine leads to (Mendes 2005; Young et al. 2012):

$$H_n = \frac{P_{turbine}}{\gamma} + \frac{V^2}{\gamma}\ [m.c.water] \quad (2)$$

where $P_{turbine}$ corresponds to the pressure at the turbine inlet which, for experimental reasons, is kept constant to be in accordance with typical operating conditions of a turbine in a hydroelectric power plant. The shaft power (at ISEC) produced by the turbine can be determined by (Mendes 2005; Young et al. 2012):

$$\dot{W}_{shaft} = T_{shaft} \times w = 0.735 \times \frac{F \times w}{1000} \quad (3)$$

where F corresponds to the force required to brake the turbine at a certain rotational speed. Finally, the efficiency (at ISEC) can be determined by (Mendes 2005; Young et al. 2012):

$$\eta = \frac{\dot{W}_{shaft}}{\rho g H Q} \quad (4)$$

where H can be either H_g or H_n, depending on whether the objective is to calculate the efficiency of the installation or of the turbine, respectively.

1.2 Performance curves

The acquisition and plotting of different performance curves depend on the information to be obtained and the resources available at each educational institution. To understand the influence of a particular parameter on the turbine, the remaining ones must be kept constant while varying the control parameter chosen. If intended to obtain the performance curves as a function of rotational speed, the net head and flow rate must be kept constant while varying the rotational speed. Once the test is conducted for the desired head, it is possible to vary the head (while keeping the flow rate constant) and repeat the test for each selected head, thereby obtaining the same curves as a function of rotational speed for different heads. A simple change in the presentation of the results allows obtaining the performance curves as a function of head, for the different tested rotational speeds, allowing to understand both the influence of head and rotational speed on the power output and efficiency of the turbine. On the other hand, if the aim is to understand the influence of the flow rate on the performance of the turbine, the head and rotational speed must remain constant. For a given head and rotational speed, the position of the nozzle needle is adjusted, thus resulting in a flow rate variation.

A combination of different parameters allows for a wide range of data to be obtained. For a given constant head, different rotational speeds can be tested by spanning all positions of the nozzle needle for each rotational speed. Therefore, for each rotational speed, the process is repeated by re-adjusting the nozzle needle from the beginning. Similarly, the head can also be varied subsequently, further increasing the number of collected data points, since for another head, different rotational speeds can be tested again, which, in turn, enable the testing of different flow rates.

2 METHODOLOGY

2.1 EXPERIMENTAL SETUP

The experimental setup of ISEC is shown in Figure 1, as well as the corresponding flowchart scheme in Figure 2.

Figure 1: Pelton turbine setup at LHM ISEC.

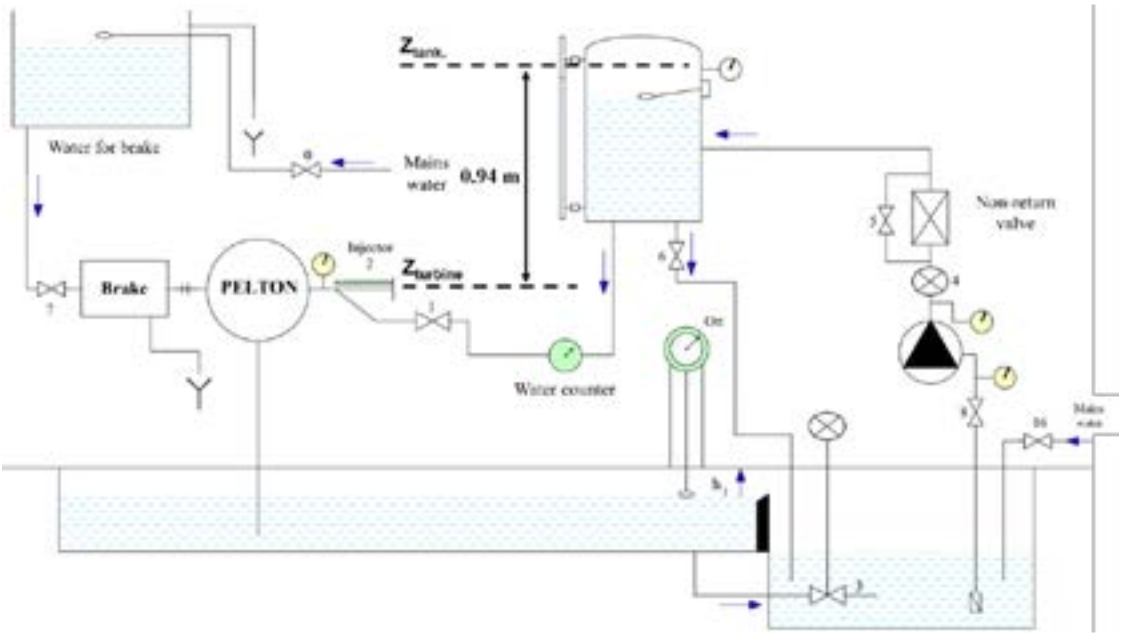

Figure 2: Flowchart scheme of Pelton turbine setup at LHM ISEC.

2.2 Experimental Procedure: Curves as a function of rotational speed or head

To obtain curves as a function of the rotational speed, the net available head and the flow rate must be kept constant throughout each test. The constant flow rate is ensured by maintaining the position of the needle of the nozzle unchanged, while the net head is kept constant by regulating the gate valve (1), shown in Figure 2. The rotational speed is varied by applying a resisting torque on the turbine shaft using a hydraulic brake coupled with a dynamometric balance. The measurement of the rotational speed is accomplished by using different equipment available at LHM such as a tachometer, a stroboscope, or by reading the variation of electrical properties, such as voltage. The braking force applied by the brake is obtained by reading the balance coupled with the brake.

Once the value of head and flow rate is established, the rotational speed is varied within the desired ranges. Upon completed the first test for the specified conditions, the available head measured at point (2) is varied by inducing a pressure drop through valve (1) to the desired head for the subsequent test. However, since this valve simultaneously induces a reduction in the value of the flow rate, the position of the needle valve and valve (1) should be simultaneously adjusted to ensure the desired conditions: the new value of constant head and a constant flow rate, equivalent to the previous test. The results discussed in the following chapter for this type of test were obtained for heads ranging from 40 to 60 meters, a range of rotational speeds from 700 to 1200 rpm, and a constant feed flow rate of 80 m^3/h.

2.3 Experimental Procedure: Curves as a function of the flow rate

To obtain the curves as a function of flow rate, the methodology to follow involves simulating what occurs in a real hydropower plant. For a fixed head, the nozzle opening is varied according to the requirements of the grid, thereby varying the supplied flow rate. After sweeping through all needle positions for a particular rotational speed, the same process can be repeated for another rotational speed. Furthermore, if desired, different heads can also be explored, repeating all the process from the beginning. A sweep of all rotational speeds for all nozzle openings allows demonstrating the influence of the same degree of opening on the value of the useful power for the various rotational speeds. The results discussed in the following chapter for this type of test were obtained for a head of 55 meters, a range of rotational speeds from 700 to 1200 rpm, and a range of injector openings from 20% to 80%.

3 RESULTS

3.1 Energy curves

Figure 3 shows the variation of the system head, the net head and of the velocity head as function of the flow rate, for a net head of 60 m. When the gate valve is fully open, the pressure at the reservoir almost equals the pressure at the injector (since the length of the pipe is small and there are only four components throughout the pipe). Figure 4 shows the variation of the useful (shaft) power, hydraulic power and both the efficiency of the turbine and installation as a function of the flow rate. The test was carried out in order to reproduce the manufacturer's nominal conditions, despite the impossibility of reproducing such high flow rates in the LHM, where the maximum is 80 m^3/h (for the net head of 60 m).

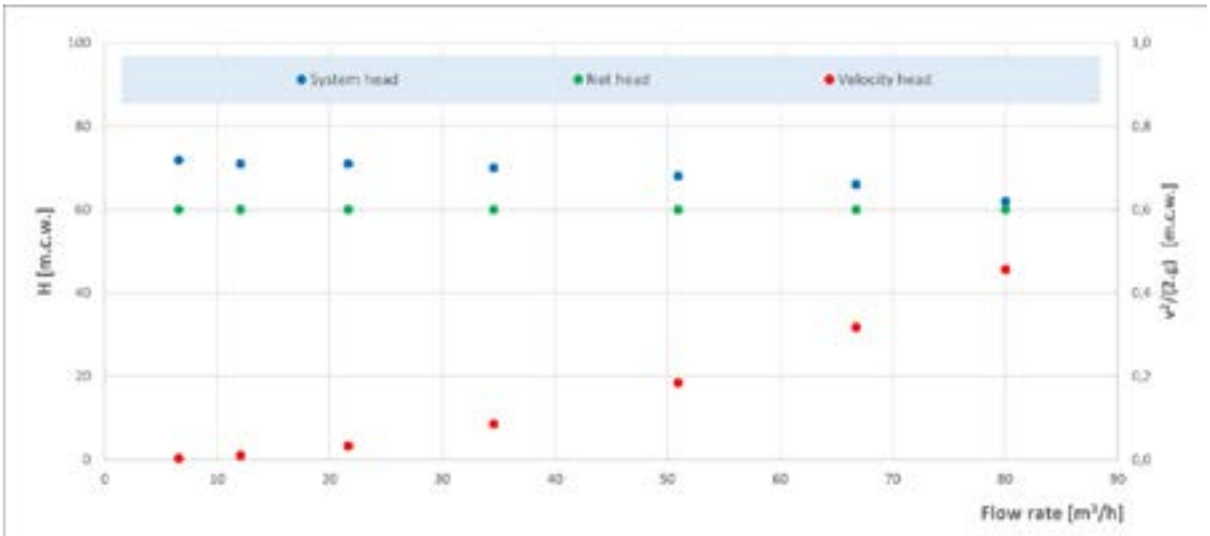

Figure 3: Variation of the system head, the net head and of the velocity head as function of the flow rate, for a net head of 60 m.

Figure 3 and Figure 4, highlight that almost all of the energy available for the turbine is in the form of pressure, with a relative contribution of kinetic energy below 2%, before being fully converted into kinetic energy in the form of a jet in the injector. In this test the maximum values of the useful power and of the efficiency of the turbine were 10.9 kW and 85%, respectively.

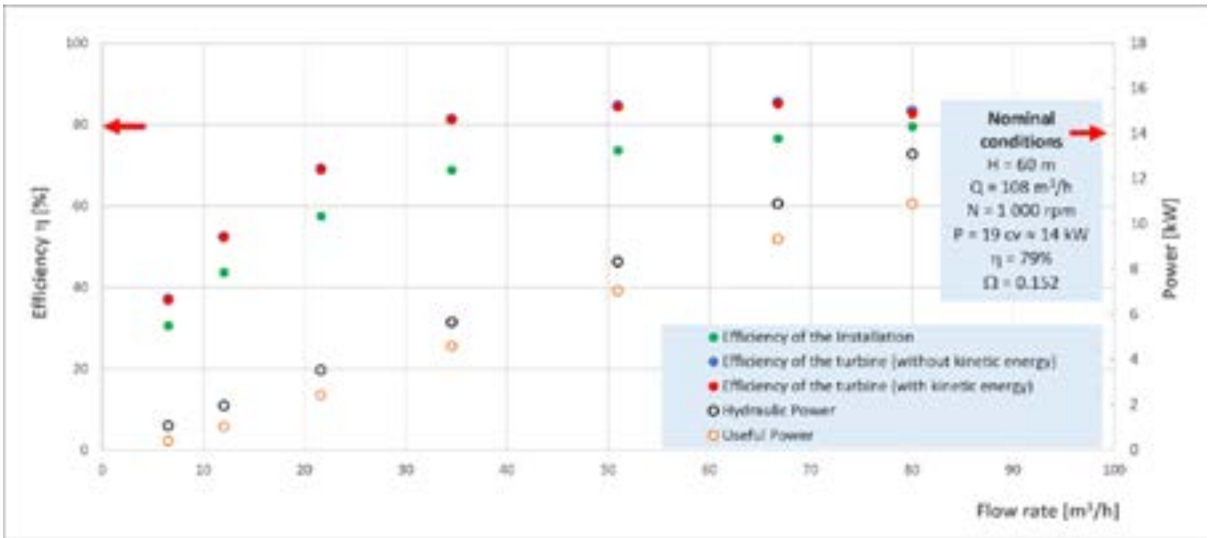

Figure 4: Variation of the useful (shaft) power, hydraulic power and both the efficiency of the turbine and installation as a function of the flow rate.

3.2 Curves as a function of rotational speed or head

Figure 5 and Figure 6 show the variation of useful power and of the turbine efficiency, respectively, as a function of rotational speed for different heads, with a constant feed flow rate of 80 m^3/h. The maximum values of the useful power ranged between 10.9 kW (for a net head of 60 m) and 7.3 kW (for a net head of 40 m) (vd. Figure 5).

Figure 6 shows that, for a net head of 60 m, the efficiency of the turbine ranged between 69.5% and 83.3%.

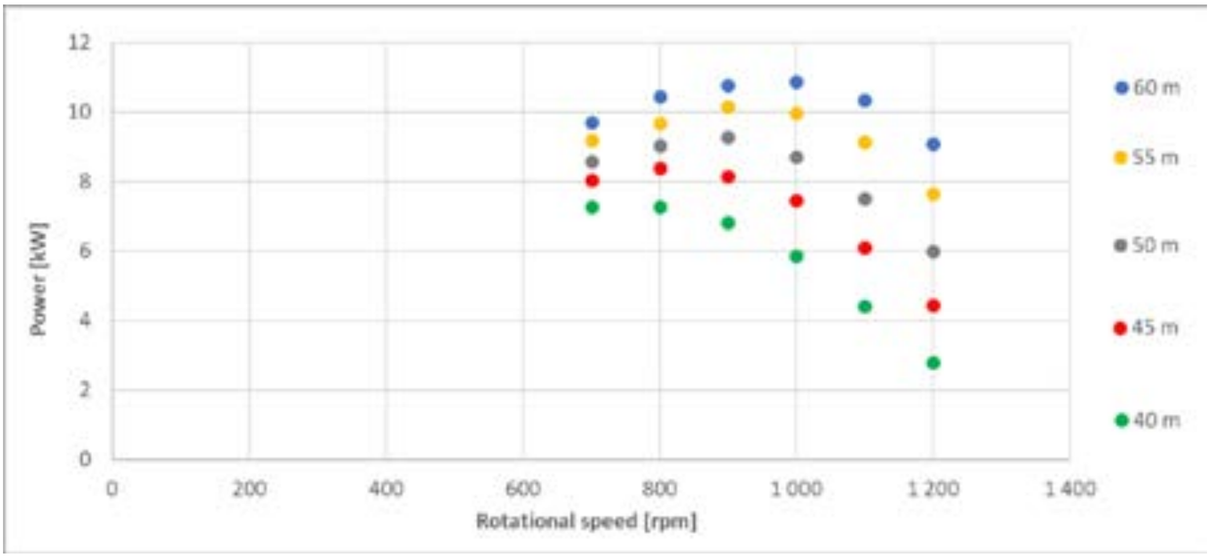

Figure 5: Variation of useful power with rotational speed for different heads, with a constant flow rate of 80 m^3/h

Several didactic facilities, such as UMH, due to the lack of an injector, are unable to fully replicate this type of testing, and while the curves may appear similar, different testing methodologies are used, particularly in maintaining a constant flow between the different curves.

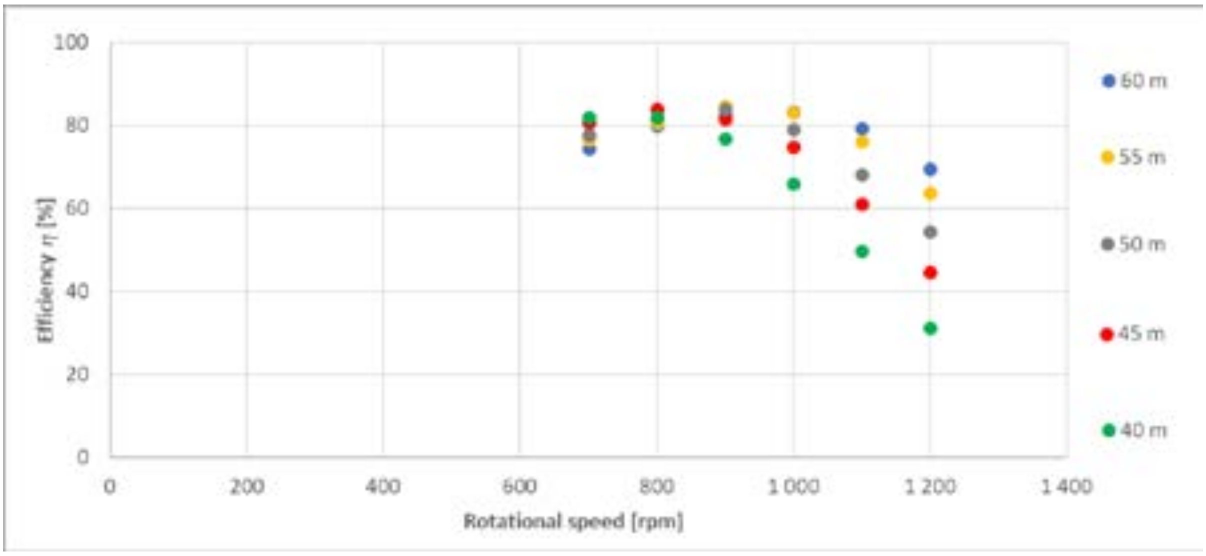

Figure 6: Variation of turbine efficiency with rotational speed for different heads, with a constant flow rate of 80 m^3/h.

3.3 Curves as a function of flow rate

Figure 7 and Figure 8 show the variation of useful power and of the turbine efficiency, respectively, as a function of rotational speed for different nozzle positions, with a constant feed head of 55 m. As previously mentioned, facilities lacking of an injector nozzle are also unable to replicate this type of testing.

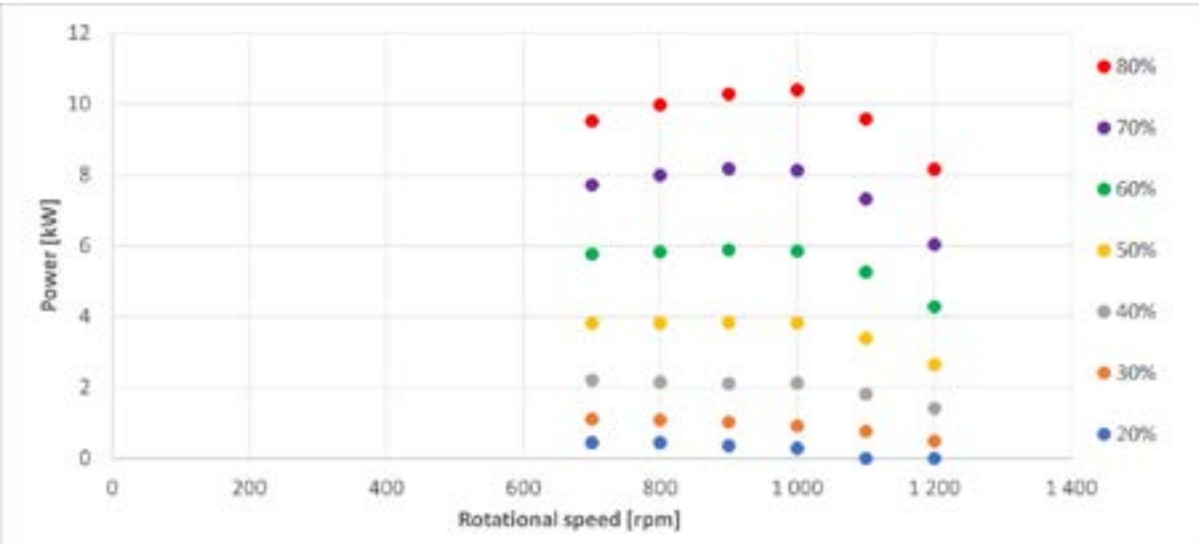

Figure 7: Variation of useful power with rotational speed for different nozzle apertures, for a constant head of 55 m.

Since the head is provided by a pump and the aperture is kept constant between different heads, the flow rate obtained is, barring losses, the maximum flow rate that the pump can provide. In other words, it is always the maximum flow rate available for the reproduced head, not allowing to maintain a fixed head while varying the flow rate. Both figures show that the best performance is achieved at 1000 rpm.

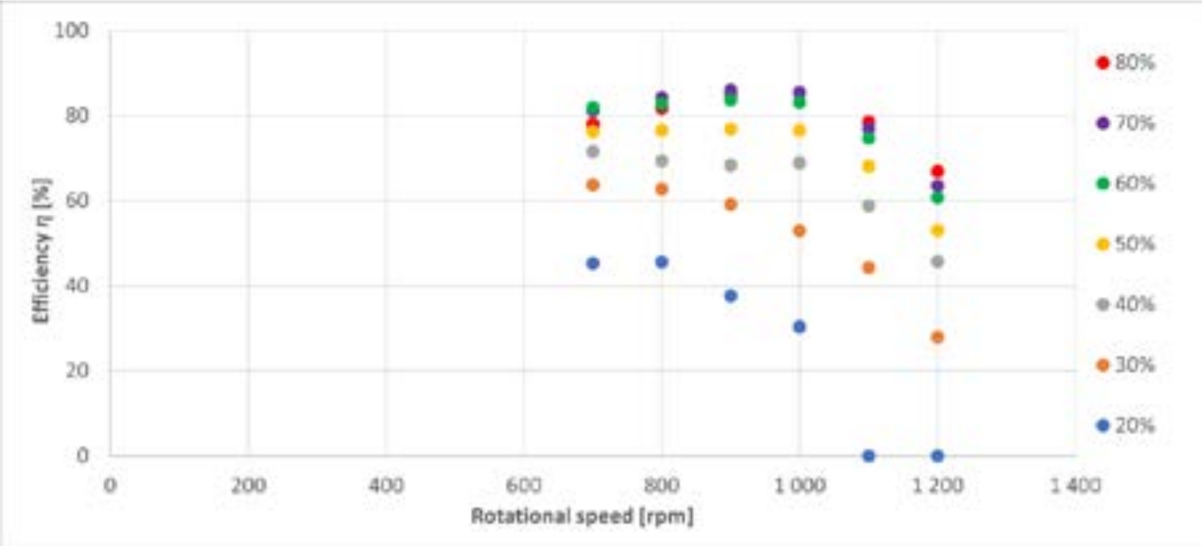

Figure 8: Variation of turbine efficiency with rotational speed for different nozzle apertures, for a constant head of 55 m.

4 SUMMARY AND ACKNOWLEDGEMENTS

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REFERENCES

Mendes, J. C. A. F. (2005). Hydraulic Machines Theoretical Notes. ISEC, Coimbra. (in Portuguese)

Young, Donald; Munson, Bruce; Okiishi, Theodore; Huebsch, Wade, (2012). Introduction to Fluid Mechanics. 5th Edition, Wiley (ISBN: 978-0-470-90215-8).

Experiential Learning for Enhanced Understanding of Disabilities: A Pathway to Inclusive Design through Engaging Students with Accessibility Challenges

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Keywords: *Inclusive Design, Engineering Education, Experiential Learning, Diversity*

ABSTRACT

This paper explores the integration of experiential learning within a curriculum designed to educate students about the importance of accessibility and inclusive design in digital environments. Anchored in Kolb's Experiential Learning Model, the program includes a series of hands-on activities that aim to deepen students' understanding of the difficulties for users with diverse abilities. Initial exercises challenge students to navigate physical spaces in a wheelchair and follow text-based instructions to create an origami cup, simulating the experiences of individuals with physical and cognitive disabilities. These activities are designed to help recognise the challenges inherent in non-inclusive designs and to inspire innovative solutions that enhance accessibility. The course concludes in work placement, where students apply their knowledge in real-world settings. Through this comprehensive approach, the program not only equips students with the skills necessary to create more accessible digital products and services but also instils a lasting appreciation for the principles of inclusive design. This paper discusses the outcomes of these experiential learning

activities, highlighting their effectiveness in students to prioritize accessibility in their work.

1 INTRODUCTION

This practice paper explores the effects of experiential learning activities on User Accessibility students within an Engineering faculty at a University in Ireland, focusing on their comprehension of the challenges faced by individuals with disabilities. Through engaging in these practical exercises, the aim was for students to gain firsthand insight into the obstacles encountered by people with disabilities. The experience also allowed the students to understand the importance of inclusive design and designing for those with diversity in mind. This understanding is anticipated to inspire students to advocate for and contribute to enhancing the accessibility of technical environments.

Accessibility is essential in ensuring an equitable society. According to the World Health Organization (WHO), 15% of the population or 1.3 billion people have some form of a disability (WHO 2023). This includes visual, auditory, physical, speech, cognitive, language, learning, and neurological disabilities. The aging of the global population will further highlight this issue, as it is projected that by 2030, one out of every six people will be 60 years of age or older and common conditions in older age include hearing loss, cataracts and refractive errors, back and neck pain and osteoarthritis (WHO 2022).This increases the need for user accessibility in a range of technological tools and in turn, engineering education needs to respond by providing students with opportunities to learn about accessibility and designing for inclusion. However, impact of accessibility extends beyond individual well-being and touches upon several core pillars of the Sustainable Development Goals (SDGs), underscoring its critical role in engineering education (UN 2015). Accessibility is paramount in advancing SDG 10, which seeks to reduce inequalities within and among countries. It is therefore clear that by removing barriers and creating enabling environments, accessibility ensures that all individuals, including those with disabilities, can fully participate in education, employment, and civic life, thereby contributing to more equitable societies.

There are several design approaches in which accessibility can be incorporated into products and services. These design philosophies include but are not limited to universal design, design for all and inclusive design. While universal design and design for all focus on processes that develop a product or service that can be used by the majority without adaption (Murphy and Goodman 2022, Persson, 2015 #186). Inclusive design is defined as “a methodology that enables and draws on the full range of human diversity. Most importantly, this means including and learning from people with a range of perspectives” (Microsoft n.d.) and so establishes the idea that everyone should be included in the design phase and considers the diversity of the range of human abilities. As Kat Holmes (2018) states in her book mismatch, “it is not designing one product for all people; instead, it’s designing a diversity of ways to participate so that everyone has a sense of belonging”.

In implementing inclusive design, the Inclusive Design Research Centre (IRDC) have developed a guiding framework for designers that consist of the following three dimensions (J. Treviranus 2018a):

1. Recognize, respect, and design with human uniqueness and variability.

2. Use inclusive, open & transparent processes, and co-design with people who have a diversity of perspectives, including people that can't use or have difficulty using the current designs.

3. Realize that you are designing in a complex adaptive system.

The experiential learning activities undertaken by the students in this paper were designed to achieve two primary objectives. These activities aimed to enhance the students' ability to recognize when environments and products do not adhere to inclusive design principles, and to deepen students' appreciation for human uniqueness and variability. This recognition is crucial for identifying opportunities for improvement and innovation in design processes to make them more accessible and accommodating of diverse user needs. ,. By engaging directly with tasks and environments that simulate the experiences of individuals with various disabilities, students were prompted to reflect on the accessibility challenges present in everyday contexts. This hands-on approach not only bolstered their understanding of the theoretical foundations of inclusive design but also equipped them with a practical perspective on how design decisions can impact the usability and accessibility of spaces and products for people with differing abilities. Emphasizing the importance of recognizing, respecting, and designing with human uniqueness in mind, the activities underscored the integral role of inclusive design in creating a more equitable and accessible world, highlighting the need for continued commitment to these principles in future design endeavours.

1.1 Understanding Disabilities

Traditional accessibility content focuses on the details of different disabilities, standards, and policies of ensuring accessibility in technology and suggests that including people with disabilities can give some insights into their needs (LADNER and LUDI). Whereas studies show that the most effective way to impart knowledge about the realities of disabilities is to try to simulate the experience of the disability (Putnam et al. 2016). However, it is important to note, as Jutta Treviranus (Jutta Treviranus 2018b) has pointed out, that simulation exercises do not equate to a genuine understanding of living with a disability. These experiences are unique and deeply personal, beyond the full comprehension of those who do not navigate life with these challenges. Nevertheless, providing students who study accessibility with opportunities to simulate these experiences can significantly increase their awareness. It informs them to the many ways in which poor design can exacerbate the difficulties encountered by individuals with disabilities.

1.2 Experiential Learning

Experiential Learning (B. Kolb 1984) is a learning theory developed on the belief that learning or ideas are not fixed in time but are formed and re-formed through experience. The theory is based on learners been involved in four activities namely Concrete Experience (CE), reflective observation abilities (RO), abstract conceptualisation (AC), and active experimentation (AE).

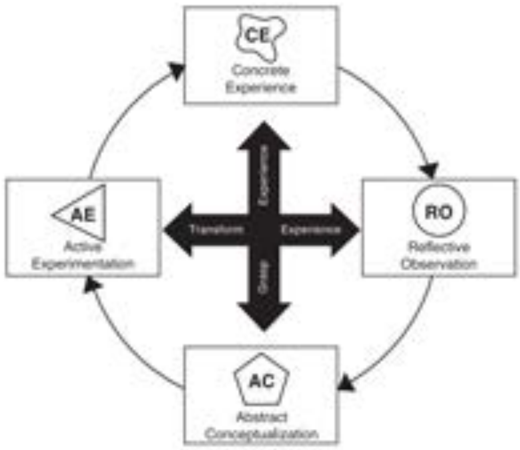


Figure 1: Cycle of experiential learning (A.Y. Kolb and Kolb 2017)

Simulating disabilities through practical experiences stands out as the most impactful method for teaching accessibility concepts (Putnam et al. 2016). As such, experiential learning becomes an essential pedagogical strategy for delivering modules on accessibility. By engaging students in hands-on activities that confront them with the realities of designing for accessibility, experiential learning promotes an understanding of the challenges and opportunities in creating technology that is truly accessible to all.

2 METHODOLOGY

In following the model for experiential learning (Figure 1) as closely as the module allowed the students took part in the activities to simulate disabilities (CE), they then wrote a reflection on their experience (RO), later in the module they developed a report on the accessibility of a website (AC) and then they went on work placement as provided by their course (AE). The qualitative data collected were the reflections and then surveys were distributed after the students returned from placement.

2.1 Concrete Experience

The students took part in two experiences to introduce them to the issues faced by people with disabilities. A wheelchair experience and an experience in which they had to create an origami cup with only written instructions.

2.1.1 Wheelchair Experience

The wheelchair exercise was designed to immerse students in the daily experiences of individuals who navigate university campuses in wheelchairs. Each participant is assigned a realistic task they might encounter in a typical college day. The tasks are varied and specifically chosen to simulate common scenarios a student in a wheelchair might face, such as transitioning between classes located in different rooms or visiting the canteen, A complete list of tasks is included in Appendix 1. Before beginning, students are required to complete a trial run in the wheelchair to ensure familiarity and safety, emphasizing the importance of avoiding reckless behaviour and being prepared for emergencies, with specific instructions to call a designated number if any accidents occur. For example, for tasks involving handling hot beverages in the canteen, students were cautioned to seek assistance if needed, highlighting the challenge of managing such tasks safely while in a wheelchair. Upon completion of their assigned tasks, students are instructed to write a reflective piece. This reflection should cover their experiences, noting any difficulties encountered, tasks they found easier than expected, their emotional response to the experience, and any surprising aspects of navigating the campus in a wheelchair. This exercise is not just about physical navigation; it's an exploration into the accessibility of the campus environment from the perspective of someone using a wheelchair. Through the tasks, students are expected to gain insights into the challenges faced by their peers with physical disabilities and what caused these challenges.

2.1.2 Cognitive Disability Experience

The class were also introduced to an activity in which they created an origami cup using textual instructions (WebAIM 2024).The origami cup activity was designed to highlight the importance of integrating visual content with textual instructions to enhance the user experience, particularly for those with cognitive disabilities. Participants were asked to start with a blank piece of paper, modifying it to a perfect square if necessary. They were then guided through a sequence of precise folding instructions, aimed at transforming the paper into an origami cup. This process involved diagonal folds, aligning corners and edges in specific configurations, and manipulating the paper in a manner that, ideally, resulted in a recognizable cup shape.

2.2 Reflective Observations (RO) - Reflections

After each activity the students were asked to write a reflection on the experience, they were asked a few questions to provoke their own thinking on the challenges of accessibility and the importance of inclusive design, particularly from the perspectives of those with physical and cognitive disabilities.Appendix 1 contains a paragraph of the questions the students were asked to help write their reflection on the wheelchair task and Appendix 2 contains questions on the cognitive disability experience.

2.3 Abstract Conceptualisation (AC) - Accessibility Report

The module's final assignment was to create a report on a website, identifying accessibility issues for users with various abilities and suggest recommendations to improve the accessibility issues. This serves as a key example of the abstract conceptualization phase of the experiential learning cycle. This step moves beyond mere participation in practical activities; it requires the students to critically reflect on their experiences, draw upon the concepts of accessibility and inclusive design, and synthesize this knowledge to identify real-world challenges. By engaging in this comprehensive evaluation, students transition from experiencing and observing accessibility barriers to understanding the underlying principles that guide the creation of more inclusive digital environments. This assignment reinforces the learning gained through direct experience and encourages the development of analytical skills necessary for proposing viable solutions to enhance website accessibility for a broad spectrum of users.

2.4 Active Experiment (AE) - Work placement

The students go on 3 months' work placement in Semester 2, this immerses them in a professional environment where they can actively apply the principles of accessibility and inclusive design they have learned. This stage of the curriculum demonstrates the active experimentation phase of experiential learning by providing students with a platform to test their ideas, strategies, and solutions in authentic settings. A survey was distributed to the students after they finished their work placement to understand if the experiences had helped them in the activities, they took part in on placement.

3 RESULTS

The experiential learning activities undertaken by the students were designed to immerse them in real-world scenarios where the importance of inclusive design becomes evident. Through their reflections and feedback gathered via surveys post-work placement, the impact of these experiences on their understanding and appreciation of diverse users was assessed.

3.1 Reflections on Inclusive Design Principles

The students filled in reflections on their experience based on prompted questions (Appendix 1 and 2).

3.1.1 Wheelchair Navigation Task

Students encountered firsthand the challenges posed by the campus environment to wheelchair users. Their reflections revealed numerous accessibility issues, such as narrow elevators, problematic door designs, and inadequate signage. These observations underscored the necessity for environments and products that adhere to inclusive design principles. For instance, one student noted the difficulty of navigating a standard classroom door, stating, *“Trying to get into the classes was very difficult...the standard classroom door is quite narrow for people in wheelchairs”.* Another reflected on the learning impact due to inaccessible designs: *“It takes a long time to get from class to class, impacting learning.”* These experiences served to enhance the students’ ability to recognize when environments and products do not adhere to inclusive design principles, directly aligning with the first objective of our study.

3.1.2 Origami cup reflections

The origami cup exercise further informed the importance of providing multiple ways to participate and understand instructions, reflecting the second objective of our study: to deepen students' appreciation for human uniqueness and variability. Despite 80% of students successfully completing the task, the exercise revealed critical insights into the necessity of inclusive instruction methods. One student stated, *“I did make a mistake I went the wrong way at the beginning and had to backtrack and read the instructions again”.*Students suggested that pictures or demonstrations could have mitigated their difficulties, highlighting an appreciation for diverse learning needs and approaches.

3.2 Survey Feedback and Increased Awareness

The survey conducted after the students' work placement revealed a significant increase in their awareness of the challenges faced by individuals with disabilities, with the average awareness rating soaring from 2.5 to 8.5 out of 10. This is based on questions 1 and 10 in the survey in Appendix 3. This increase in awareness not only indicates a shift in perspective but also suggests a deeper understanding and respect for human diversity, furthering the second aim of our paper.

As a result of this increased awareness,students expressed a profound change in their approach to design, with one respondent reflecting, “In my future career, I will always consider the challenges faced by all people more closely.” Another noted the impact of these experiences on their design philosophy: “Imagining how differently abled users interact with technology has been a huge consideration in every product or service I have worked on or designed since.”

The activities used in this study are explained in detail within the paper and the attached appendix, making it possible to replicate them. While the survey demonstrated a clear increase in awareness, future research could benefit from a more detailed explanation of the survey methodology and the specific metrics used to measure this awareness. This would provide a clearer assessment of the impact of the experiment and allow for more accurate replication and validation of the findings.

4 CONCLUSIONS AND SUMMARY

This paper has explored the implementation of an experiential learning framework within a module aimed at educating students about accessibility and inclusive design. Through a series of hands-on activities, including a wheelchair navigation task and an origami cup exercise, students were immersed in experiences designed to increase understanding around the difficulties associated with disabilities.

Feedback collected through surveys and reflection pieces provided insights into the students' learning outcomes, highlighting significant growth in their understanding of inclusive design and the importance of accessibility. There was an increased acknowledgement that they had the ability to reduce the challenges for people with disabilities and the students were committed to doing so.

References

Holmes, Kat. 2018. *Mismatch: How inclusion shapes design*. MIT Press.

Kolb. 1984. "Functions of the frontal cortex of the rat: a comparative review." *Brain research reviews* 8 (1): 65-98.

Kolb, Alice Y., and David A. Kolb. 2017. "Experiential learning theory as a guide for experiential educators in higher education." *Experiential Learning & Teaching in Higher Education* 1 (1): 7-44.

Ladner, Richard, and Stephanie Ludi. 2023. "Teaching about Accessibility in Computer Science Education."

Microsoft. n.d. "Inclusive Design." Accessed 8th March. https://www.microsoft.com/design/inclusive/.

Murphy, Eva, and Lizbeth Goodman. 2022. "Unintended Consequences when the Engineering Design Team is Noninclusive: An Exploration of the Literature." 2022 IEEE Global Engineering Education Conference (EDUCON).

Persson, Hans, Henrik Åhman, Alexander Arvei Yngling, and Jan Gulliksen. 2015. "Universal design, inclusive design, accessible design, design for all: different concepts—one goal? On the concept of accessibility—historical, methodological and philosophical aspects." *Universal access in the information society* 14: 505-526.

Putnam, Cynthia, Maria Dahman, Emma Rose, Jinghui Cheng, and Glenn Bradford. 2016. "Best Practices for Teaching Accessibility in University Classrooms: Cultivating Awareness, Understanding, and Appreciation for Diverse Users." *ACM transactions on accessible computing* 8 (4): 1-26. https://doi.org/10.1145/2831424. https://go.exlibris.link/J6DqFP0Z.

Treviranus, J. 2018a. "The Three Dimensions of Inclusive Design: Part Three | Inclusive Learning Design Handbook." https://handbook.floeproject.org/perspectives/the-three-dimensions-of-inclusive-design-part-three/.

Treviranus, J. 2018b. "The Three Dimensions of Inclusive Design: Part Two." https://medium.com/@jutta.trevira/the-three-dimensions-of-inclusive-design-part-two-7cacd12b79f1.

UN. 2015. "Transforming our world: the 2030 Agenda for Sustainable Development." United Nations: New York, NY, USA. https://sdgs.un.org/2030agenda.

WebAIM. 2024. "Cognitive Disabilities Activity." https://webaim.org/articles/cognitive/activity.

WHO. 2022. "Ageing and Health Factsheet." https://www.who.int/news-room/fact-sheets/detail/ageing-and-health#:~:text=By%202030%2C%201%20in%206,will%20double%20(2.1%20billion.

WHO. 2023. "Disability Factsheet." https://www.who.int/news-room/fact-sheets/detail/disability-and-health.

APPENDIX 1: WHEELCHAIR EXPERIENCE

Wheelchair Tasks

This lab will take you through tasks that you will each carry out in a wheelchair on Campus. For health and safety reasons can I ask you to refrain from horseplay. Also, you must complete a trial in the wheelchair before the activity commences. If there are any accidents, we must call 071 9XXXXXX so please keep this number to hand. Also, for the Canteen task please be aware that should you ask for a hot drink and if you cannot handle it with ease you should ask for assistance and reduce the risk of burning yourself.

I will ask at the end of this task that you write a reflective piece about this task.

This reflective piece should discuss how you found the task, what did you find difficult? Were there parts you found easier? How did being in a wheelchair make you feel and was there anything from the experience that surprised you? Overall is there any advice you would offer to either property or timetabling to make the navigation easier following a timetable?

Tasks

1. Its 9am you arrive at registration at 8.50, your first class is in F0014 you must find this class in 10 minutes

2. The lecturer in F0014 lets you finish at 5 to 10, the next class is at 10am in room E0011 time yourself, how long does it take you to get there?

3. You must navigate from F0014 to B1058, we will say that you have 10 minutes to get to the next Class, do you make it?

4.There is an hour break after class in F0014 so you should now make your way to the Canteen and Grab a bottle of water/coffee and navigate to a Table with your item.

5.Make your way from the canteen to room D2037, how much time did you need to get there?

6.After room D2037 you have class in E0011, make your way there and record how long it takes you.

7.From room E0011 you should make your way to D2033 and record how long it takes you.

8.You should make your way from D2033 to A0004 and record how long it takes you.

APPENDIX 2: COGNITIVE DISABILITY EXPERIENCE

The following activity will demonstrate how visual content can supplement text to create a better experience for users, including those with cognitive disabilities.

1. Find a blank piece of paper.
2. If it isn't already perfectly square, cut off one edge of the paper until it is perfectly square.
3. Fold the paper in half diagonally.
4. Lay the paper down in front of you so that the longest edge is facing you.
5. Take the bottom left corner and fold it over the main area of the piece of paper so that the corner touches the opposite edge, and so that the top of the newly folded edge is parallel with the bottom of the piece of paper.
6. Do the same thing to the right corner, folding it across the main area of the piece of paper until it touches the opposite edge. The top edge of this fold should be exactly on top of the top edge of the previous fold.
7. Take the outer layer of the very top corner and fold it down until the corner touches the spot where the bottom of the other two folds meet. You should see a pattern in the shape of an "X."
8. Do the same thing to the other layer, but in the opposite direction.
9. Spread apart the two layers on the top and gently push the sides in.
10. You made an origami cup! (Or did you?)

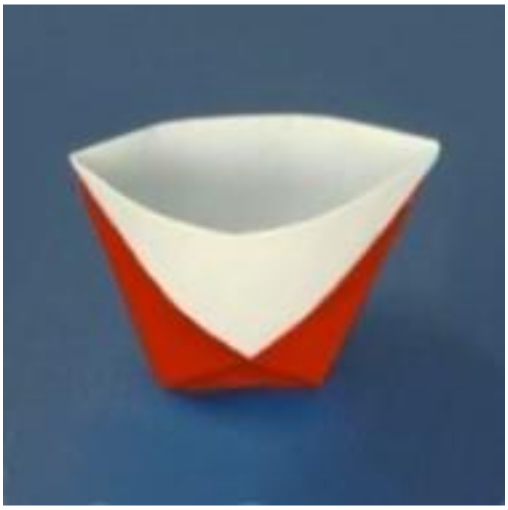
Questions and Discussion – Add answers in red and post to Moodle.

- How successful were you at performing the task?

- Were you able to make anything resembling a cup?

- Are you sure that you performed the task correctly? Perhaps you made a mistake or two, whether you know it or not.

Here's what your origami cup should look like:



How closely does your origami cup match the one pictured above? Is it even close? If not, why not?

Although you may have been able to complete the task by simply reading the instructions, you may have become confused at some point. The instructions may have seemed ambiguous or poorly written. Perhaps you misunderstood an instruction without realizing it.

- Would it have helped to have a picture of the end goal before starting the task?

- Would it have helped to see someone perform the task, or an illustration of how to perform the task?

How This Relates to Cognitive Disabilities

- Visually-oriented readers were at a cognitive disadvantage when trying to fold an origami cup with nothing more than written instructions. Individuals with learning disabilities, reading disorders, or more profound cognitive disabilities often feel similarly disadvantaged when trying to understand concepts that are difficult for them.
- Content needs to be clear and accurate, and sometimes in more than one format, for these individuals to fully understand. In the example of the origami cup, illustrations and animations are particularly useful. With other types of information, audio content may be more appropriate.
- Understanding this principle, making content accessible to people with cognitive disabilities becomes less mysterious, albeit challenging. Designing for people with cognitive disabilities isn't so much an art or a science, but a craft: We are applying creativity to create a tool that widest audience will use to accomplish a task.

APPENDIX 3: SURVEY QUESTIONS

1. On a scale of 1-10, how aware were you of the challenges faced by people with disabilities before participating in these activities?
2. Did you participate in the 'Creating Paper Cup without visual instructions' Activity ? (Please select all that apply)

Questions about the Paper Cup Activity:

3. Describe your initial reaction when you were asked to create a paper cup without visual instructions.
4. How did the absence of images impact your ability to perform the task?
5. In what ways did this activity change your perspective on the importance of visual aids in learning and communication?
6. Did you participate in the 'Navigating Campus in a Wheelchair' Activity ?

Questions about the Wheelchair Navigation Activity:

7. Describe your experience of navigating the campus in a wheelchair. What were the most challenging aspects?
8. How did this activity affect your understanding of the physical barriers faced by people with disabilities on a daily basis?
9. Reflecting on this experience, what changes do you believe could make our campus more accessible?

Impact and Reflection

10. On a scale of 1-10, how aware were you of the challenges faced by people with disabilities after participating in these activities?
11. Has participating in these activities changed your perception of the challenges faced by people with disabilities? Please explain.
12. What is one thing you learned about yourself during these activities?
13. Can you identify any specific moments or tasks that had a particularly strong impact on you? Describe them.
14. In what ways do you think these activities will influence your behaviour or actions towards individuals with disabilities in the future?

Additional Feedback

15. Is there anything else you would like to share about your experience participating in these activities?
16. Do you have any suggestions for how these activities could be improved or expanded in future sessions?

CREATIVE ENGINEERING: APPLYING DESIGN THINKING IN TELECOMMUNICATIONS LABORATORY PRACTICE

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***Conference Key Areas**: Please select two Conference Key Areas*
***Keywords**: D*esign thinking; Project-Based Learning; Engineering; Voluntary; compulsory

ABSTRACT

Engineering students encounter intricate and abstract concepts that can pose challenges for comprehension and practical application. To enhance learning outcomes in this domain, this study proposes the integration of Design Thinking and Project-Based Learning methodologies, fostering creativity and problem-solving skills among students while exploring fundamental concepts in Components and Circuits and Fundamentals of Physics during the first year of the Telecommunication Engineering program. Students engaged in crafting practical projects centered on constructing electronic circuits and applying physical principles through the design and execution of experiments. The proposed methodology guides the entire project lifecycle, from problem identification to the development of final prototypes.

Necessary materials encompassed literature resources, simulation software, electronic components, and measurement tools. Data were collected from voluntary participants in the Fundamentals of Physics I project and compulsory participants in the Components and Circuits project. Evaluation methods included questionnaires and interviews. Results indicate that students acquired practical competencies in electronic circuit construction and experimental design rooted in physical principles. Practical application and experimentation facilitated a deeper understanding of theoretical concepts, leading to enhanced motivation. However, students in compulsory projects reported greater time commitment. This study underscores the efficacy of Design Thinking and Project Based Learning in enhancing complex subject instruction within Engineering programs. Voluntary participation correlated

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with reduced difficulty and heightened satisfaction and interest, affirming the importance of fostering creativity and problem-solving skills to prepare students for success as telecommunications engineers in the professional sphere.

1. INTRODUCTION

Traditionally, engineering education and practice have been characterized by a linear and analytical approach, emphasizing technical proficiency and adherence to predefined standards and specifications. While this approach has led to remarkable technological advancements, it often overlooks the human element and fails to adequately address complex, multifaceted problems. In today's rapidly evolving world, where societal challenges are becoming increasingly interconnected and ambiguous, there is a growing recognition of the need for engineers who can navigate ambiguity, empathize with end-users, and collaborate across disciplines to develop innovative solutions.

Design thinking (DT), characterized as "human-centered," relies on evidence of how consumers interact with a product or service, rather than assumptions made by organizations. It involves observing user behavior and continually refining products or services to enhance user experience—an iterative process aimed at swift prototyping and refinement rather than extensive research [3, 5, 14].

DT, as an iterative process, facilitates our comprehension of users, challenges, and assumptions. It allows us to redefine problems to identify alternative solutions not initially apparent with our initial understanding. DT encourages students to become critical and empathetic thinkers, seeking innovative methods to address real societal needs [6]. Given its ability to reignite creativity, focus efforts, and articulate objectives clearly, DT holds immense significance in business contexts. Engineering programs are increasingly urged to graduate engineers capable of designing effective solutions for societal challenges [15].

On the other hand, Project-Based Learning (PBL) emphasizes active, inquiry-based learning, where students work collaboratively to identify, analyze, and solve complex problems [10]. Projects are designed to be interdisciplinary in nature, drawing on principles from multiple engineering disciplines and incorporating real-world constraints and considerations [16]. By engaging in authentic, open-ended projects, students develop a deeper understanding of core engineering concepts and principles, while also honing essential skills such as communication, teamwork, and project management.

To examine the principles of Problem-Based Learning (PBL) and Design Thinking (DT) and their application in engineering education and practice, we must consider four key parameters: voluntary/compulsory participation and the distinct features of each methodology. Design Thinking, which is user-focused and iterative, contrasts with Project-Based Learning, which emphasizes teamwork and problem-solving. By analysing real-world examples and case studies, this paper demonstrates how both approaches can enhance problem-solving abilities, foster interdisciplinary collaboration, and drive innovation in various engineering domains. Furthermore, we discuss the challenges and opportunities associated with integrating DT into traditional engineering curricula and propose strategies to overcome barriers to adoption. The positive impact of voluntary and compulsory projects in both PBL and DT contexts underscores the potential benefits of these educational methodologies.

2. METHODOLOGY

2.1 Integration of Design Thinking and Project-Based Learning

The amalgamation of DT and PBL confers several significant benefits within educational contexts, enhancing student learning outcomes and cultivating vital skills essential for success in diverse professional domains:

1. Holistic Problem-Solving Skills: Combining DT and PBL encourages students to approach challenges holistically, fostering a multifaceted problem-solving mindset. By engaging in real-world projects structured around DT principles, students learn to identify complex problems, empathize with end-users, ideate innovative solutions, and iteratively prototype and refine their ideas through hands-on experimentation within a project-based framework [1,2].
2. Creativity and Innovation: The integration of DT and PBL nurtures creativity and innovation among students by providing opportunities for open-ended exploration and experimentation [10]. Students are encouraged to think outside the box, brainstorm diverse solutions, and take creative risks in designing and implementing their projects.
3. User-Centered Design: DT emphasizes empathy-driven design, placing the needs and experiences of end-users at the forefront of the design process. By integrating DT principles into project-based coursework, students learn to empathize with stakeholders, gain a deep understanding of user needs and preferences, and design solutions that are user-centric and tailored to address real-world challenges effectively [12].
4. Iterative Learning and Continuous Improvement: PBL emphasizes iterative learning and continuous improvement through cycles of project planning, execution, and reflection [8]. By integrating DT principles, students engage in iterative design processes, where they prototype, test, and refine their solutions based on feedback and evaluation.
5. Real-World Relevance: Combining DT and PBL enables students to engage in authentic, real-world projects that are relevant to their academic and professional aspirations. By working on projects grounded in real-world contexts, students gain practical experience, apply theoretical concepts to real-world problems, and develop skills that are directly transferable to their future careers [9].

Empirical evidence demonstrates that both PBL and DT significantly enhance educational outcomes, though they impact different areas of learning. PBL has been shown to improve critical thinking, problem-solving skills, self-directed learning, and knowledge retention, as evidenced by studies [4,17]. Conversely, DT fosters creativity, innovation, empathy, and interdisciplinary collaboration, several studies highlighting these benefits [7]. Integrating PBL and DT can yield synergistic effects, enhancing problem-solving and creativity while increasing student engagement and motivation [11]. Overall, combining these approaches provides a comprehensive and dynamic learning experience that leverages the strengths of both methodologies.

In essence, the integration of DT and PBL offers a powerful educational paradigm that not only enhances student learning outcomes but also equips students with the essential skills and competencies needed to thrive in today's dynamic and complex world.

2.2 Methodology based on Design Thinking and Project-Based Learning

At the University of Castilla-La Mancha, this integrative methodology was implemented within the academic domains of Components and Circuits (CC), as well as Fundamentals of Physics I (FF1), targeting first-year students pursuing a Bachelor's Degree in Telecommunication Technologies Engineering. Two important differences were made for both assignments, the CC project was compulsory within the continuous assessment and the FF1 project was optional.

These projects were meticulously curated to align with predetermined curriculum objectives, while concurrently providing an immersive experiential learning environment for students to engage in iterative experimentation and prototyping. Each project was meticulously orchestrated to adhere to the iterative stages of the DT paradigm, commencing with rigorous problem identification, followed by divergent ideation, prototyping, and culminating in systematic testing and validation.

For instance, within the Components and Circuits curriculum, students were tasked with conceptualizing and constructing electronic circuits tailored to address specific engineering challenges or fulfill user-centric requirements. Through this process, students were exhorted to embody empathy towards prospective end-users, fostering a milieu conducive to innovative ideation, and refining their designs iteratively in response to constructive feedback loops.

Likewise, within the Fundamentals of Physics I domain, students were afforded the autonomy to conceptualize and execute bespoke physics laboratory experiments. These experiments were meticulously designed to be both pragmatic and resource-efficient, with an emphasis on pedagogical efficacy and potential applicability within secondary education settings. Employing the principles of Design Thinking, students meticulously crafted experiments that were user-centric, operationally intuitive, and aligned seamlessly with predefined learning objectives.

2.3 Participants

All students enrolled in the first year of engineering, in In the Fundamentals of Physics I, were invited to participate in the study, which was carried out in the first term, but only 18 students, 66% of the total, participated in the project and only 10 students completed the evaluation, representing 55% of the participants. Participants were required to purchase a variety of materials to facilitate their work on the project. These materials included bibliographic resources, simulation software, electronic components and measuring instruments. On the other hand, students of the same course and during the same period, 70% of the students enrolled in the subject Components and Circuits participated in the project, 27 students who chose continuous assessment, of which data were collected from 24 students, 88.8% of the participants, who carried out the assessment process.

In addition, to data collection, various tools such as questionnaires and interviews were utilized throughout the project duration. Following the completion of the projects, a comprehensive 15-item questionnaire was administered to assess the perceived level of difficulty encountered, the degree of interest generated, and the overall satisfaction attained by participants. This evaluation process served to glean insights into the efficacy of the projects and to identify areas for improvement in future iterations.

2.4 Design Thinking-Project-Based Learning (DT-PBL) Methodology Proposal

2.4.1 Understanding User Needs:

Begin by conducting empathetic interviews and observations with students to understand their prior knowledge, interests, and learning preferences for the Fundamentals of Physics I project. For the Components and Circuits project, engage with engineering students to ascertain their understanding of filter design requirements and challenges.

2.4.2 Define the Problem:

Based on insights gathered, define clear project objectives and constraints. For the Physics lab project, the first-year university students have to design an engaging and accessible experiment that aligns to be used and presented in high school physics curriculum objectives. In the Components and Circuits project, define specific requirements for the filter design, considering factors such as frequency range, attenuation, and component limitations.

2.4.3 Ideation and Prototyping:

Brainstorm potential experiment ideas for the Physics lab project, considering hands-on activities, demonstrations, or simulations that cater to diverse learning styles. Prototype experiment setups and gather feedback from high school students.

For the Components and Circuits project, ideate various filter topologies and configurations using simulation software. Prototype designs using electronic circuit simulation tools, considering feasibility and performance parameters.

2.4.4. Testing and Iteration:

Pilot test Physics lab experiments with a small group of high school students, gathering feedback on clarity, engagement, and learning outcomes. Iterate on experiment design based on feedback to enhance effectiveness.

Test filter designs in simulation environments, evaluating performance metrics such as frequency response, gain, and stability. Iterate on designs to optimize performance and meet project requirements.

2.4.5. Implementation and Evaluation:

Implement finalized Physics lab experiments in high school classrooms, providing support and guidance to teachers and students as needed. Collect data on student engagement, comprehension, and interest in physics concepts.

Fabricate and test physical filter prototypes in the Components and Circuits project, documenting the design process and performance results. Evaluate project success based on adherence to specifications and overall learning outcomes.

2.4.6. Reflection and Continuous Improvement:

Reflect on project outcomes and stakeholder feedback to identify successes, challenges, and areas for improvement. Document lessons learned and best practices for future iterations of similar projects.

Encourage ongoing collaboration and knowledge sharing among participants to foster a culture of continuous improvement and innovation in both educational and engineering contexts.

2.5 Planification

The course has a duration of 13 weeks, a planning for the project entitled "Design of Passive Filters for Enhanced Signal Processing", with the following timetable:

Weeks 1-2: Understand

- Define the project scope and objectives, including target frequency range and filter specifications.
- Conduct initial research to understand the application requirements and user preferences.

Weeks 3-4: Define

- Synthesize research findings to define the design requirements.

Weeks 5-6: Ideate

- Facilitate ideation workshops or brainstorming sessions to generate innovative ideas. Prototype selected filter configurations using simulation software or breadboarding techniques.
- Test prototype designs in simulated or real-world environments to assess performance and feasibility.

Weeks 7-8: Prototype

- Develop prototypes based on initial simulation results and testing outcomes.
- Conduct iterative testing and refinement of prototype designs to enhance performance and robustness.

Weeks 9-10: Test

- Evaluate the performance of optimized filter prototypes through testing.
- Measure key performance parameters, including gain, phase shift, and impedance characteristics.
- Analyze test results to identify areas for further improvement and optimization.

Weeks 11-12: Implement

- Develop implementation plans for integrating the optimized filter designs into target electronic systems or applications.
- Collaborate with stakeholders to finalize implementation details and address any technical challenges and execute the implementation plan and deploy the optimized filter designs in real-world scenarios.

We**ek 13: Evaluate and Iterate**

- Evaluate the performance of deployed filter designs against predefined criteria.
- Solicit feedback from end-users and stakeholders.
- Reflect on lessons learned and identify opportunities for further innovation and refinement in future iterations.

3. RESULTS

3.1 Result of the surveys

The survey consisted of three parts. The first part asked for a rating from highest to lowest between 1 and 5 regarding the difficulty encountered, interest and satisfaction in different aspects. Results obtained are shown in figures 1-6, as well the answers have been grouped according to difficulty, interest, and satisfaction in all the questions.

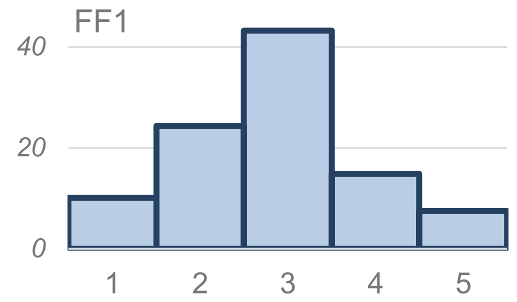

Figure 1. % Difficulty responses in voluntary.

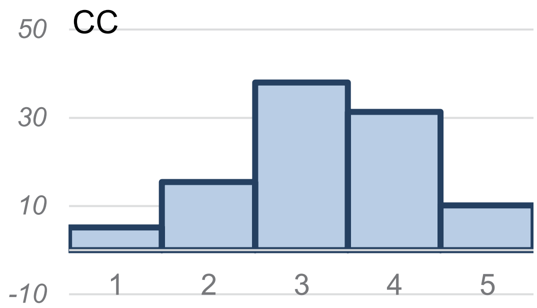

Figure 2- % Difficulty in compulsory

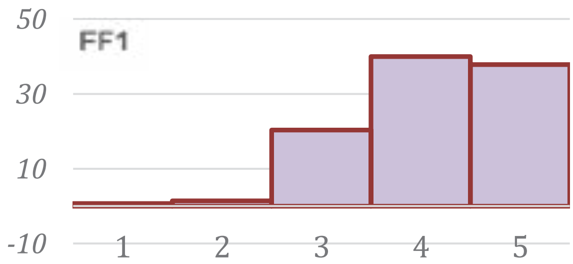

Figure 3. % Interest responses in voluntary

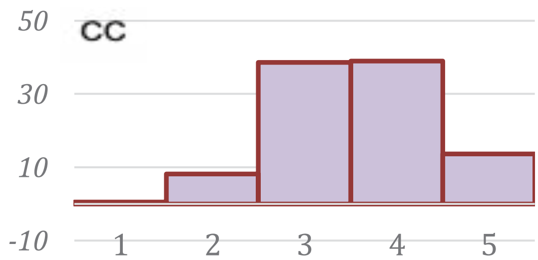

Figure 4. % Interest in compulsory

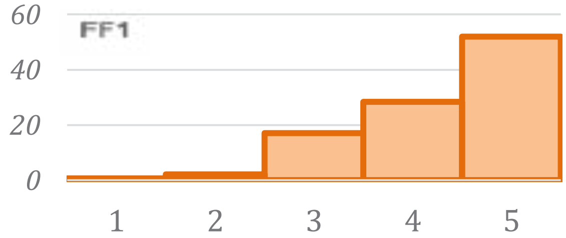

Figure 5. % Satisfaction in voluntary project.

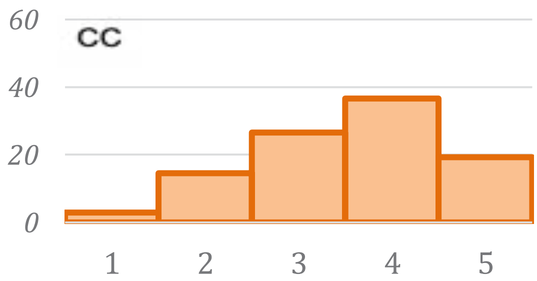

Figure 6. % Satisfaction in compulsory

The fact that the FFI the task was voluntary implies that they show more satisfaction and interest than in the case in which that was compulsory.

A second part of the survey asks students to comment on or seek advantages and disadvantages found in the project-based teaching methodology. Table 1 shows the comments given anonymously by the students.

What advantages do you find in using the project-based learning methodology?
That you feel in your own flesh what it is like to do a laboratory project with practically no reference of how to do it and to do it ourselves from scratch.
You are more self-motivated and it involves you to make memories.
You learn more and have the freedom to choose a topic.
It helps you to understand better what you have studied theoretically.
You learn and become more interested in the subject.
What disadvantages?

Well, some of the technical concepts needed to continue with the creation of the project were beyond our knowledge as students, but with the help of the teacher, they were solved.
it takes up a lot of your time because of a deadline
Lack of time
None
A lot of workload is accumulated due to other more methodical subjects.

Table 1. Advantages and disadvantages presented by students.

The results show that students acquired practical skills in the construction of electronic circuits and experiments based on physical principles. Students expressed their better understanding of the theoretical concepts of the subject through practical application and experimentation, their motivation improved, however, students for whom the project was compulsory expressed their higher time commitment to the subject. The results of the surveys showed that their interest and satisfaction was in all cases above 65%, being much higher in the case where the project was proposed on a voluntary basis (Figure 7)

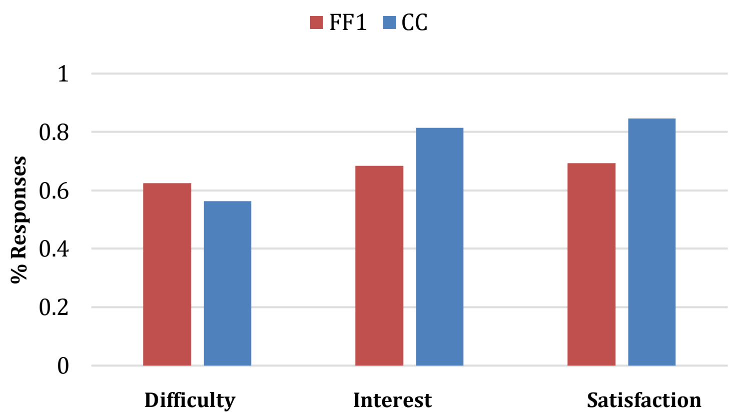

Figure 7. Average values of difficulty, interest and satisfaction in compulsory project carried out on the 24 student participants (CC) vs. voluntary for the 10 student-participants (FF1)

Finally, students are asked to self-evaluate the subject and the project in terms of their involvement and work. Figure 8 shows a graph relating the grade obtained in their self-assessment of the project to that of the subject, showing greater variability in the students who did the project on a compulsory basis (CC vs. FF1).

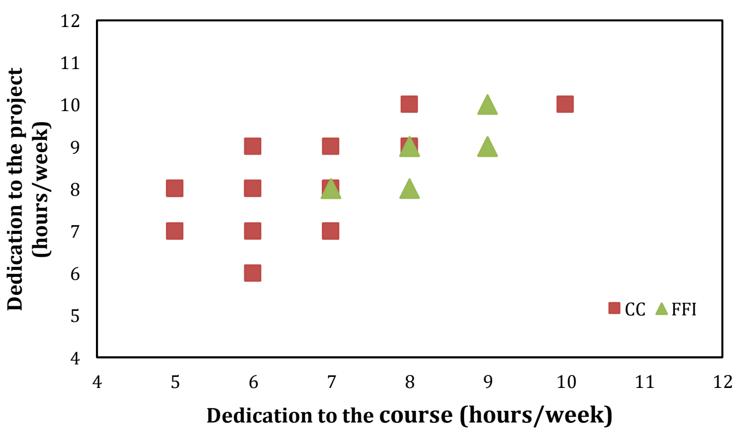

Figure 8. Students' self-assessment of the subject and the project in terms of their involvement and work

To better understand these results, a comparison between the marks obtained by the students in the project and their final marks in the subject. The score for the compulsory project increased the mark for the exam by 1.2 points. Being a voluntary project, non-participation in the project does not limit the final mark obtained by the students in the subject, but as can be seen, there is a highly positive effect between the students who participated in the project and the benefits obtained by the students in the final mark for the subject, with an average of 1.5 additional points. The students who were able to obtain a high mark in the project are those who obtained a good final mark for the subject in general. However, there are cases in which the completion of this project has allowed them to pass this subject. Studies show PBL enhances critical thinking, problem-solving, and knowledge retention [4,17]. Integrating PBL and DT in educational projects positively impacts academic performance, as evidenced by the improved marks among participating students, confirming empirical findings from both approaches.

4. SUMMARY AND ACKNOWLEDGEMENTS

The use of projects as a tool in university teaching and, above all, in technical courses such as this one, requires that the project be oriented towards the future world of work that awaits them. All the practices carried out in this project were oriented towards this end, within the possibilities and considering the limitations found in first semester students of this degree.

The response of the students was very explosive and with a risk of overflowing, here the importance lies in the teacher as project guide being able to guide the students correctly, trying to ensure that the self-imposed objectives of the students are feasible.

As conclusion, DT methodology can be a useful tool to improve the teaching of complex subjects in the Telecommunications Technology Engineering degree. The results show that when the work is done voluntarily, the difficulty is reduced, and the satisfaction and interest are higher. By encouraging creativity and problem solving in students, this project can help prepare them to face the challenges of the working world and succeed as telecommunications engineers.

REFERENCES

[1] Blumenfeld, P. C., Marx, R. W., Soloway, E., & Krajcik, J. (1996). Learning with peers: From small group cooperation to collaborative communities. *Educational Researcher*, *25*(8), 37-39.

[2] Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist*, *26*(3-4), 369-398.

[3] Charosky, G., Hassi, L., Leveratto, L., Papageorgiou, K., Ramos, J., & Bragos, R. (2018, October). Education for innovation: engineering, management and design multidisciplinary teams of students tackling complex societal problems through Design Thinking. In *4th international conference on higher education advances (HEAD'18)* (pp. 1081-1087). Editorial Universitat Politècnica de València.

[4] Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. Learning and Instruction, 13(5), 533-568.

[5] Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of engineering education*, *94*(1), 103-120

[6] Giacomin, J. (2014) What is human centred design? The Design Journal, 17(4), pp.606–623.

[7] Goldstein, R., & Gorsky, P. (2014). Facilitating the design thinking process in digital environments. *Design Thinking Research*, 1-20.

[8] Hajdas, Monika & Kleczek, Ryszard & Sylwia, Wrona. (2020). Wicked problems and project-based learning: Value-in-use approach. The International Journal of Management Education. 18. 10.1016/j.ijme.2019.100324

[9] Jiang, Cuiling and Yilin Pang. "Enhancing design thinking in engineering students with project-based learning." Computer Applications in Engineering Education 31 (2023): 814 - 830.

[10] Kolmos, A., Fink, F. K., & Krogh, L. (2004). The Aalborg PBL model. Aalborg Universitetsforlag.

[11] Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H. Y. (2015). Design thinking for education: Conceptions and applications in teaching and learning. Singapore: Springer.

[12] Krajcik JS, Shin N. Project-Based Learning. In: Sawyer RK, ed. *The Cambridge Handbook of the Learning Sciences*. Cambridge Handbooks in Psychology. Cambridge University Press; 2022:72-92.

[13] Mallibhat, Kaushik. (2020). Evaluating a First-Year Engineering Course for Project Based Learning (PBL) Essentials. Procedia Computer Science. 172. 364-369. 10.1016/j.procs.2020.05.056.

[14] Melles, G., Anderson, N., Barrett, T., & Thompson-Whiteside, S. (2015). Problem finding through design thinking in education. In Inquiry-based learning for multidisciplinary programs: A conceptual and practical resource for educators (Vol. 3, pp. 191-209). Emerald Group Publishing Limited.Llorente, J. (2020).

[15] Razzouk, Rim, and Valerie Shute. "What Is Design Thinking and Why Is It Important?" Review of Educational Research 82, no. 3 (2012): 330–48. http://www.jstor.org/stable/23260048.

[16] Savin-Baden, M., & Major, C. H. (2004). Foundations of problem-based learning. McGraw-Hill Education (UK).

[17] Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. Interdisciplinary Journal of Problem-Based Learning, 3(1), 44-58.

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LESSONS LEARNED FROM THE FIRST EDITION OF A LARGE SECOND-YEAR COURSE IN SOFTWARE CONSTRUCTION

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Conference Key Areas: *Teaching technical knowledge in and across engineering disciplines*
Keywords: *functional programming, software engineering, correctness*

ABSTRACT

This paper lays out a case study of *Software Construction*, a new course in the undergraduate computer and communication sciences curriculum at EPFL. We hope to share some generalizable lessons we learned from running its first edition in Fall 2023. The course targets three core concepts—functional programming, real-world engineering, and correctness—and its design is informed by four principles—students should learn by doing, assignments should be self-motivating, knowledge should be built incrementally, and students should see progress over time. We illustrate how we realized these concepts and principles with practical examples of course materials and teaching methods that we hope will serve as useful inspiration to others teaching similar courses. Lastly, we present some encouraging preliminary data about course outcomes and share our speculations about experiments for its future evolution.

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1 Introduction

Fall 2023 saw the first iteration of a new core course in the undergraduate computer and communication sciences curriculum at EPFL: *Software Construction* (CS-214). This practice paper describes the overarching course philosophy and how it was realized in course materials and teaching methods, particularly in their more unconventional and experimental aspects. We hope that others teaching similar courses will find it a useful case study.[2]

We begin with some background about how the course is situated within the curriculum (§ 2). Next, we lay out the three core concepts threaded throughout the course: functional programming, real-world engineering, and correctness (§ 3). We also describe a few informal pedagogical principles we tried to follow (§ 4). These concepts and principles are illustrated by a collection of practical examples, such as the design of an assignment or a lecture (§ 5). We present some preliminary data about course outcomes (§ 6) and conclude by speculating about possible experiments for future iterations (§ 7).

2 Background

Academic year 2023–24 was the first in which a complete redesign of the Computer and Communication Sciences (IC) undergraduate curriculum came into force. Among other objectives, the redesign consolidated some courses in response to complaints about fragmentation and high context-switching burden. *Table 1* summarizes relevant parts of the new curriculum (EPFL 2024). The new *Software Construction* incorporates elements of the three struck-out, discontinued courses. Between the two IC Bachelor's programs, our course is mandatory for Computer Science and optional for Communication Systems; our total enrollment in Fall 2023 was 383.

Table 1: Selected courses from the IC Bachelor's curriculum.

Year	Course
1	*Intro. to Programming* and *Practice of Object-oriented Programming* (Java)
	Advanced Information, Computation, and Communication I, II (discrete mathematics and information theory)
	Fundamentals of Digital Systems (digital design and architecture)
	general education requirements in linear algebra, calculus, physics (mechanics), and the humanities
2	***Software Construction***
	~~*Functional Programming* and *Parallelism and Concurrency* (both Scala)~~
	general education requirements, electrical engineering
	The Software Enterprise – From Ideas To Products (heavyweight project-

[2] Volumes have been written about programming and software engineering education; we do not aim or even attempt to survey the literature, rigorously evaluate its claims, or make novel research contributions. We merely present one possible instantiation of a set of coherent ideas.

3	based software engineering course) *~~Software Engineering~~* algorithms, compilers, parallelism and concurrency, and other computer and communication sciences electives

Note that the broad base of the first year lets us assume basic technical knowledge of all our students and, say, create assignments to implement a physics simulation or a compression algorithm. Further, we aim to prepare students for the courses that follow it—and for computing-related careers in general—by developing their core competencies in functional programming, real-world engineering, and correctness, giving them the confidence to build small but real software. We leave it to *Software Enterprise* to teach project management, collaboration, software architecture, and modern DevOps practices (Pirelli 2024).

3 Core concepts

The three core concepts that *Software Construction* targets are functional programming **λ**, real-world engineering 🛠, and correctness ✔. We will use these symbols to tag the examples in § 5 with the concepts relevant to each.

We teach functional programming **λ**, which we feel especially makes sense at EPFL for two reasons. First, EPFL is the birthplace and home of Scala, a programming language whose central tenet is to unify functional and object-oriented programming (Odersky, et al. 2021). Scala MOOCs and other educational materials have been developed at EPFL for over a decade. As Scala runs on the JVM with a Java-like object model, and as our students come in with two semesters of object-oriented Java programming experience, adding in functional programming with Scala next is a natural choice. The other reason we believe functional programming works well at this point in the EPFL IC curriculum is its conceptual connections to algebra and discrete mathematics. Our undergraduates build a substantial foundation in mathematics in their first year (as outlined in § 2) which lets us explain functional programming in terms of mathematical functions, rewriting, substitution, and so on.

Although our course is about building software in the small, we believe that two aspects of real-world engineering 🛠 are still relevant. One is common software engineering infrastructure, such as command-line interfaces, build tools, networks and filesystems, and version control. For instance, we teach uses of Git that students wouldn't otherwise self-learn online, such as investigating code provenance and collaborating via patches.[3] The other aspect is "external" libraries or frameworks that someone else (often the course staff) wrote, that the student is not expected to read or understand, but only interact with through an API; or students' own past work, that they can build upon with skills from intervening weeks. We hope to build students' confidence as they see themselves improve and encourage them to write code for humans as well as computers, including their collaborators and their future selves.

Correctness ✔ is our third core concept, referring to techniques to specify the absence of, prevent, catch, diagnose, and fix bugs. Diagnosing faults and

[3] These are instances of more general engineering skills in collaboration and version control that powerful tools like Git give us a golden opportunity to teach in the context of software (Wayne 2021).

troubleshooting is essential to any engineering discipline; debugging is the software counterpart, embodying a general scientific skill, viz., the scientific method (Agans 2002, Zeller 2009, Regehr 2010). Yet, it is seldom explicitly taught, and students generally lack competence in reasoning about (possibly faulty) programs (McCauley, et al. 2008, Fitzgerald, et al. 2008, Li, et al. 2019). We train students to systematically make observations about code, determine expected behaviors, make hypotheses for explaining discrepancies, and test them out with controlled experiments. Complementarily, they write automated regression tests to replicate and guard against identified bugs, documentation to record assumptions and expectations, and pre-/post-conditions to monitor them at run time. We later introduce a more formal notion of specifications and program correctness proofs, some checked by computer.

4 PEDAGOGICAL PRINCIPLES

This section describes some principles that inform how we teach the core concepts articulated above. Again, we tag each one with a symbol for later reference in § 5.

First, *students should learn by doing*. Right from the first week of the course until the final exam, students should build real, albeit small, pieces of software. Every topic should have a large collection of ungraded exercises (pencil-and-paper or short programming problems) of varying difficulties and should figure in a graded lab (programming assignment). Students should have plenty of opportunities to receive help as they work on these assignments to maintain confidence. "Active learning" of this form has been shown to improve student performance and reduce disparities in learning outcomes (Freeman, et al. 2014, Theobald, et al. 2020).

A complementary principle is that *assignments should be self-motivating*. A student should never have to wonder why they are being made to do a particular assignment, or whether a concept or skill will ever be relevant outside of class. Rather, each assignment should be fun in its own right, or useful for a realistic application (as opposed to contrived or toy applications), or ideally both. Labs should be self-contained pieces of software with visualizations and UIs whenever possible.

Another main principle is that *knowledge should be built incrementally*. This is in contrast to, say, introducing sets of new concepts in discrete units or modules, whereof the interconnections are addressed only *post hoc*, if at all. An incremental approach lets us build real software from scratch right from the start, with plenty of room to improve that we progressively explore. It also lets us clearly define what we expect students to know prior to the first week and not risk assuming further implicit background when switching between later topics. Anecdotally, this may be more inclusive of students with varied backgrounds—we were happy to find students among the top 5% who only started programming after they came to EPFL.

Lastly, as a corollary to the above, *students should see progress over time*: the progression of incrementally built knowledge should be brought to students' attention. Course materials, including assignments, should make explicit connections to previous ones. Students should have chances to revisit their own past work *in situ* and discover for themselves the improvement in their abilities over time, which we believe bolsters student confidence and reinforces the value of what is being taught.

5 Illustrative Practical Examples

Below, we illustrate the core concepts and pedagogical principles described in the two previous sections with some concrete instantiations from Fall 2023. Each is tagged as follows:

- functional programming λ,
- real-world engineering 🛠,
- correctness ✔;
- learning by doing 👩‍💻,
- self-motivating 💥,
- incremental knowledge 📚,
- visible progress 📈.

	λ	🛠	✔	👩‍💻	💥	📚	📈
`find`	●	●		●	●		
HOFs cards	●			●		●	●
`find` with HOFs				●	●		●
Incrl. abstraction			●				●
Music synthesis		●			●		
Computer proofs			●		●		●
Interview training		●			●		
Weekly debriefs							●

Lab assignment: the Unix `find` utility The first lab assignment 👩‍💻 is to write a highly simplified version of the Unix `find` utility that locates files in a directory tree matching criteria like 'last modified before Jan 1'. The value of such a tool is self-evident 💥, and upon completion, students are able to run their implementations to search their own computers. The key functional programming λ concept exercised is structural recursion. The directory tree is inherently a recursive structure, and even for students who may be scared of or uncomfortable with recursion, a recursive solution is far more natural than an iterative one—as opposed to traditional unary natural number recursion exercises like the factorial function (why not just iterate?), or trickier recursions like the Euclidean GCD algorithm (Krishnamurthi 2024). In addition, right from this first lab, we introduce realistic engineering ideas 🛠 like interacting with the filesystem using a library.

Index cards exercise for higher-order functions (HOFs) An early exercise involves a set of index cards with the definitions of simple recursive functions on integer lists, like `contains` or `product`. Working in small groups, students are first asked to draw similarities between purposefully chosen pairs (e.g. `collectEven` and `removeZeroes`), annotating the cards if they want to, and then to physically group the cards by extending the patterns they find (e.g., adding in `intersection`). Next, they are tasked with generalizing these patterns by writing HOFs λ. In the process, or by comparing with others, they may realize that some patterns are just special cases of others, and we expect them to eventually arrive at some versions of `map`, `filter`, and `foldRight` 👩‍💻 📈. We conclude by hinting that all the functions can actually be written as folds, and foreshadowing polymorphism (allowing for the same functions on strings) and generalized folds (e.g. on trees) 📚.

Lab callback: `find` with higher-order functions (HOFs) Soon after the above, students revisit their lab submission to realize 📈 that large parts of their `find` functions—`findBySizeGe`, `findByName`, etc.—were redundant. They rewrite `find` as a HOF that takes a Boolean predicate argument 👩‍💻. The utility of this refactoring that shrinks code by a factor of five is self-evident 💥. Similar callbacks throughout the semester build on past work with newly learned skills in clear increments.

Incremental abstraction and correctness Abstracting over predicates to turn `find` into a HOF is typical of the incremental progression of ideas in the course. After students define `mapInt` over (monomorphic) lists of integers and `mapString` for strings, we teach them variance and polymorphism to abstract over types; or after noting how functions like `map` and `flatMap` work similarly for lists, option types, and Futures, we introduce the abstraction of monads. Incremental program transformations elegantly lend themselves to incremental reasoning about correctness ✔. For instance, in a single exercise set, we have students (i) observe that some recursive functions perform redundant computation on subproblems; (ii) make careful, encapsulated use of mutable state to fix the issue with memoization; (iii) generalize to an arbitrary function memoizer; and (iv) further observe that it may be sufficient for the memo to record only some subproblems, i.e. convert the function into a *dynamic programming* problem.

Signal processing and music synthesis A compelling real-world application of lazy evaluation in functional style is music synthesis. Starting from just the Java Sound API, an hour-long lecture builds combinators for low-level processing like resampling, higher-level effects like echoing, amplitude envelopes, sequencing based on musical scores, and so on, to synthesize realistic snippets. The lecture is presented in literate style using Alectryon (Pit-Claudel 2020). Using Scala lazy lists bypasses problems with buffer boundary conditions, single-use streams, and variable source-driven sample rates, while letting us build an elegant, compositional library.

Computer-checked proofs In some early exercises, students write inductive proofs of functional properties (e.g. `append` is equivalent to `concat` with a singleton) as a series of rewrite rules ✔. This sets the stage for introducing computer-checked proofs based on the Lisa proof assistant (Guilloud, Gambhir and Kunčak 2023). Students experience first-hand how a computer can make checking proofs less tedious and error-prone and increase confidence in correctness.

Coding interview training In the final week, a lecture about coding interviews includes a mock interview where an instructor is given a programming puzzle and demonstrates how to approach the problem, think out loud, make progress in limited time, and answer questions about generalization and correctness.

Weekly debriefs Every week throughout the semester, we post a debrief on the course website with a summary of student questions that may be of broader interest, tips for exercises and labs, and additional relevant material. The content is informed by periodic class polls and individual student interactions to let students learn from their peers and witness their collective progress.

5.1 Supporting logistics

Below are some logistical details that let us better fulfill our educational objectives.

Computerized final exam The final bears special mention due to the fairness and logistics challenges posed by our large class size and the recent widespread availability of code-generating AI tools. The exam is a set of mini-labs, with no hidden tests, graded at scale with the same homegrown autograder infrastructure as for lab assignments. We conduct the exam on custom virtual machines in thin-client computer labs so that we can test students' abilities in isolation from external help. Students do not have Internet access but do have access to course materials (including any published solutions), their own submitted work, and a standard Scala development setup. They are given opportunities to get comfortable with this environment beforehand but their actions are not persisted.

Student assistant (SA) training workshop We run a workshop to help our SAs better help students during office hours in the spirit of the course's values. We have SAs read and discuss a short handout about professional and respectful conduct, how to enable active learning rather than simply answering questions, Pólya's problem-solving method (Pólya 1945), and other concordant guidelines, encouraging them to reflect on their own teaching and learning experiences. They also watch and respond to mock office-hours interactions of varying helpfulness. Finally, we recommend that they take a complementary SA training offered by CAPE.

6 PRELIMINARY DATA

Fall 2023's *Software Construction* was successful overall, despite being offered for the first time. Some quantitative metrics about the course were very encouraging: in the end-of-semester student course evaluations conducted by CAPE, the EPFL Teaching Support Centre, with a 25% response rate, 96% of respondents agreed or strongly agreed with the statement "Overall, I think this course is good." on a 4-point Likert scale. This was the highest rating among all large courses in IC.

Another set of metrics was designed to evaluate the course's high-level objective of "developing [students'] core competencies […] giving them the confidence to build small but real software" (from § 2). We asked students whether they "feel comfortable", "know how to", or "often" use the techniques and tools we taught, on a 5-point Likert scale. The questions were presented before the first week (alongside other questions about students' background) and after the final exam as part of CAPE's course evaluation survey (alongside their regular questions common to all courses). All data was anonymized and only aggregate, non-identifiable statistics are reported in Figure 1. Students broadly felt more confident along all axes. While our course was not our students' only activity during the semester, none of their concurrent courses addressed our topics[4], and second-years are not yet eligible to participate in research projects.

[4] *Computer Architecture* teaches some hardware programming; *Numerical Methods for Visual Computing and ML* uses Python as a means to use domain-specific libraries, and *Signal Processing* is largely theoretical with some Python assignments.

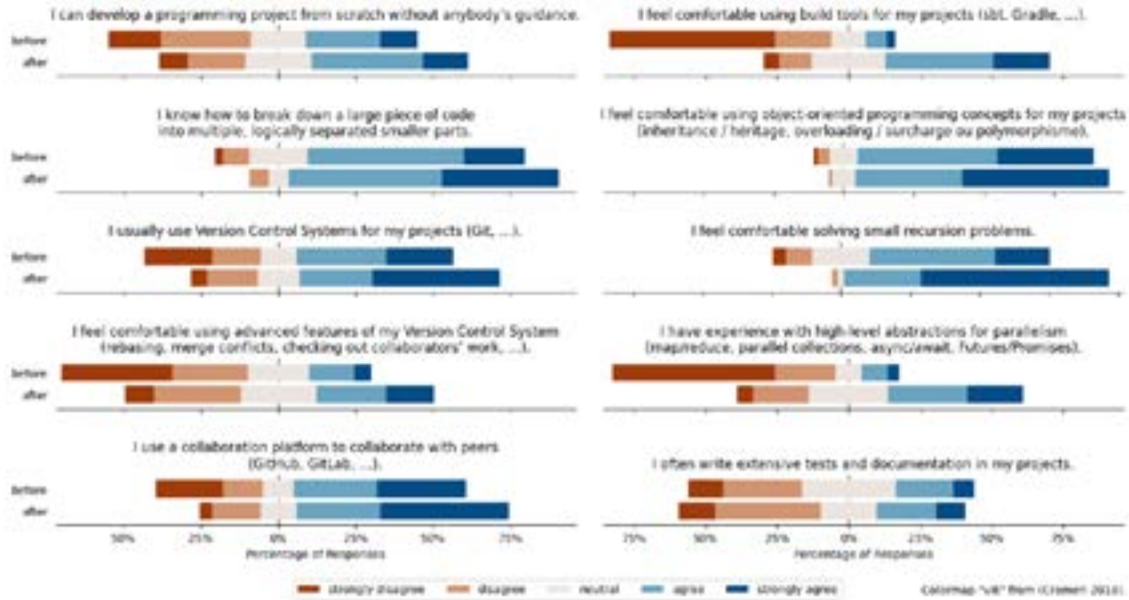

Figure 1: Respondents' answers to Likert-scale questions about skills Software Construction aims to develop, in a questionnaire posted on our LMS before the first week of classes ("before", n = 283), and in a questionnaire administered by CAPE after the final exam ("after", n = 97). Our class size was 383.

7 LOOKING AHEAD

Below, we outline some experiments that we didn't have the time for or hadn't thought of in Fall 2023. Grading is a common theme: our experience indicates that many students don't do assignments if they aren't graded, and don't feel that they learned a topic if it wasn't specifically targeted in grading.

Develop a capstone group project In Fall 2023, we laid the foundations in the form of a lab assignment for what we believe can grow into a fulfilling, open-ended capstone group project for the course: server-client webapps. Following a state-machine–based architecture, the webapp lab has students build two simple games, maintaining a single piece of server-side mutable state of which clients statelessly render projections. The framework is easy to extend to more complex applications, such as a chat room, an authentication meta-application, or classic board and card games. We envision these extensions being developed as group projects that students can showcase on a shared server at the end of the course. We plan to consult prior work on software capstone projects to make ours most effective (Tenhunen, et al. 2023), and in particular, for students not yet ready for full-blown project management techniques (Kuhrmann and Münch 2018, Marques, et al. 2017).

Evaluate code comprehension at scale Software engineering relies as much on understanding and reasoning about code as on writing it, and recent advances in AI will only make the former more relevant. We would like our grading strategies to reflect this. We already know how to automatically grade correctness judgements for small programs (MCQs on a paper exam), pre-/post-condition specifications (run-time monitoring), and some formal proofs of functional properties (Lisa). Beyond that, we could evaluate test writing by running students' tests for a lab assignment on a provided buggy implementation and on other students' submissions, and awarding points based on number of bugs identified, number uniquely identified across peers, code coverage, etc., learning from prior research on peer evaluation of software

(Groeneveld, Vennekens and Aerts 2020). Automated execution visualization tools in the style of PythonTutor (Guo 2013) may also be relevant. However, important skills we don't yet know how to evaluate automatically include debugging, documentation writing, program structure (e.g. types, class hierarchies), and code style.

Provide in-person feedback and evaluation Code comprehension and organization may be better suited to individual, human judgment. We find that one-on-one interactions with staff can be far more effective than other forms of evaluation and feedback—and secondarily, than other forms of detecting cheating. Back-of-the-envelope estimates suggest that such "checkoffs" may be feasible to scale, for, say, 1 out of every 2 weekly labs, if SAs have appropriate training.

Teach the teachers: SA training SAs play a key role in our vision for the course. Ideally, they would be able to judge a student's understanding of code, give design and style feedback, help fix bugs by teaching debugging rather than debugging themselves, answer questions without giving away answers, track and communicate common difficulties with other staff, and participate in developing new materials. (This would also take load off of time-constrained PhD students and let them assume a more supervisory role.) Being an SA is a challenging job—one that we hope to explicitly train them for, and one that we think is a worthwhile outcome of the course in its own right, whether or not they return as staff in subsequent years.

Highlight real-world engineering in labs Despite lab assignments having been the primary training ground for debugging, version control, working with libraries and other people's code, program design, and code evolution, these topics were not tested explicitly. Students consequently felt that labs didn't sufficiently exercise real-world engineering. We aim to address this discrepancy by calling out engineering topics where exercised in each lab and grading them when possible. For instance, for Git exercises, students could submit Git bundles for automatic grading. Other courses situated similarly to ours may have useful lessons, like (McBurney and Murphy 2021).

Reuse classic exercises Learning by doing is a principle shared by our colleagues in mathematics and physics, whose textbooks and course materials include dozens of small cut-and-dried exercises per topic. Students are typically assigned a few key exercises and are free to do more. We believe we can likewise supplement problems we design with others of exceptional quality from classic, highly acclaimed texts like *The Art of Computer Programming* (Knuth 2022) and *Structure and Interpretation of Computer Programs* (Abelson and Sussman 1996).

8 CONCLUSION

Software Construction served—and will continue to serve—as a testing ground for ideas about programming and software engineering education. In this first iteration, we identified a coherent set of ideas that work well together, targeting the three core concepts of functional programming, real-world engineering, and correctness (§ 3), and following some informal pedagogical principles (§ 4). We share some concrete illustrative examples in this paper with the hope that they will be useful for others trying to adapt our approach to their own contexts (§ 5). After presenting some preliminary quantitative data about course outcomes (§ 6), we identify avenues for future experimentation (§ 7). We hope the lessons we learned that we share in this paper will prove helpful to other educators just as they will help us iterate on the course in the future.

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REFERENCES

Abelson, Harold, and Gerald J. Sussman. *Structure and Interpretation of Computer Programs.* 2. Cambridge, MA: MIT Press, 1996.

Agans, David J. *Debugging.* USA: AMACOM, 2002.

Crameri, Fabio. "Scientific colour maps." Zenodo, 2018.

EPFL. "Study plans and regulations." *Study Management - EPFL.* 2024. https://www.epfl.ch/education/studies/en/rules-and-procedures/study_plans/ (accessed April 8, 2024).

Fitzgerald, Sue, et al. "Debugging: Finding, Fixing and Flailing, a Multi-Institutional Study of Novice Debuggers." *Computer Science Education* (Routledge) 18 (June 2008): 93–116.

Freeman, Scott, et al. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences* (Proceedings of the National Academy of Sciences) 111 (June 2014): 8410–8415.

Groeneveld, Wouter, Joost Vennekens, and Kris Aerts. "Engaging Software Engineering Students in Grading: The Effects of Peer Assessment on Self-Evaluation, Motication, and Study Time." Edited by Jan van der Veen, Natascha van Hattum-Janssen, Hannu-Matti Järvinen, Tinne de Laet and Ineke ten Dam. *Proceedings of the SEFI 48th Annual Conference*, 2020: 788–798.

Guilloud, Simon, Sankalp Gambhir, and Viktor Kunčak. "LISA - a Modern Proof System." Edited by Adam Naumowicz and René Thiemann. *14th International Conference on Interactive Theorem Proving (ITP 2023).* Dagstuhl, Germany: Schloss Dagstuhl – Leibniz-Zentrum für Informatik, 2023. 17:1–17:19.

Guo, Philip J. "Online Python Tutor: Embeddable Web-Based Program Visualization for Cs Education." *Proceeding of the 44th ACM Technical Symposium on Computer Science Education.* New York, NY, USA: Association for Computing Machinery, 2013. 579–584.

Knuth, Donald E. *The Art of Computer Programming: Volumes 1–4B.* Addison-Wesley Professional, 2022.

Krishnamurthi, Shriram. *How Not to Teach Recursion.* 2024. https://parentheticallyspeaking.org/articles/how-not-to-teach-recursion/ (accessed April 7, 2024).

Kuhrmann, Marco, and Jürgen Münch. "Enhancing Software Engineering Education Through Experimentation: An Experience Report." *2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC).* 2018. 1–9.

Li, Chen, Emily Chan, Paul Denny, Andrew Luxton-Reilly, and Ewan Tempero. "Towards a Framework for Teaching Debugging." *Proceedings of the Twenty-First Australasian Computing Education Conference.* New York, NY, USA: Association for Computing Machinery, 2019. 79–86.

Marques, Maíra, Sergio F. Ochoa, María Cecilia Bastarrica, and Francisco J. Gutierrez. "Enhancing the Student Learning Experience in Software Engineering Project Courses." *IEEE Transactions on Education* 61 (September 2017): 63–73.

McBurney, Paul W., and Christian Murphy. "Experience of Teaching a Course on Software Engineering Principles Without a Project." *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education.* New York, NY, USA: Association for Computing Machinery, 2021. 122–128.

McCauley, Renée, et al. "Debugging: A Review of the Literature from an Educational Perspective." *Computer Science Education* (Routledge) 18 (June 2008): 67–92.

Odersky, Martin, Lex Spoon, Bill Venners, and Frank Sommers. *Programming in Scala.* 5th. Walnut Creek, CA, USA: Artima Press, 2021.

Pirelli, Solal. "Scalable Teaching of Software Engineering Theory and Practice: An Experience Report." *Proceedings of the 46th International Conference on Software Engineering: Software Engineering Education and Training.* New York, NY, USA: Association for Computing Machinery, 2024. 286–296.

Pit-Claudel, Clément. "Untangling Mechanized Proofs." *Proceedings of the 13th ACM SIGPLAN International Conference on Software Language Engineering.* Virtual USA: ACM, 2020. 155–174.

Pólya, George. *How to Solve It.* Princeton University Press, 1945.

Regehr, John. *How to Debug.* July 4, 2010. https://blog.regehr.org/archives/199 (accessed April 7, 2024).

Tenhunen, Saara, Tomi Männistö, Matti Luukkainen, and Petri Ihantola. "A Systematic Literature Review of Capstone Courses in Software Engineering." *Information and Software Technology* 159 (July 2023): 107191.

Theobald, Elli J., et al. "Active Learning Narrows Achievement Gaps for Underrepresented Students in Undergraduate Science, Technology, Engineering, and Math." *Proceedings of the National Academy of Sciences* (Proceedings of the National Academy of Sciences) 117 (March 2020): 6476–6483.

Wayne, Hillel. "What engineering can teach (and learn) from us." *Hillel Wayne's blog.* January 22, 2021. https://www.hillelwayne.com/post/what-we-can-learn/ (accessed April 1, 2024).

Zeller, Andreas. *Why Programs Fail: A Guide to Systematic Debugging.* 2. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc., 2009.

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Exploring analytical frameworks to investigate power dynamics in collaborative learning in engineering education

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ABSTRACT

Previous research has examined patterns in women's team interactions within collaborative learning environments, highlighting potential barriers that hinder their full participation. This paper explores two analytical frameworks that could be beneficial in investigating power dynamics in such settings. Through a narrative literature review, we establish links between individuals' experiences and broader social or institutional practices, revealing underlying discourses and power relations. We identify a lack of evidence regarding discourses shaping attitudes and behaviours that perpetuate power inequities. Awareness of these dynamics could

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facilitate the provision of support and empathy to a more diverse group of students in engineering education.

1 INTRODUCTION

Project-based learning and other group-based pedagogies have proven to be valuable approaches for increasing engagement, self-motivation and performance in engineering courses (Du & Kolmos, 2009; Kolmos & de Graaff, 2014; Wu et al., 2021), factors that may ultimately lead to improved persistence, retention and graduation rates of students in the field. Nonetheless, other research has also indicated that students from underrepresented groups in engineering may encounter challenges or unfavourable outcomes from group work and team-based projects (Fowler & Su, 2018; Henderson, 2023; Hirshfield, 2018; Keough et al., 2021; Meadows & Sekaquaptewa, 2013). For example, Henderson (2023) reported incidents in team interactions related to power dynamics that undermine women's opportunities to participate in learning experiences, including being excluded from team decisions, patterns of interruptions when talking, or inequitable task allocation.

This paper responds to feedback on previously presented work (Cruz Moreno et al., 2023), which reported preliminary findings from a phenomenological analysis of women students' experiences in PBL settings. We aim to comprehensively understand the phenomenon by incorporating an analysis of power relations as intrinsic to examining identity and experience.

Within that context, this paper explores how the phenomenological analysis of collaborative learning environments could include the analysis of power dynamics. The purpose is to examine existing frameworks using an epistemic pluralist approach that combines phenomenology and poststructuralism as a means to improve the qualitative analysis of a dataset of interviews performed to date.

The research questions that guide this piece of the study are:

1. How do phenomenology and poststructuralist philosophies intersect to describe the human experience and knowledge production in collaborative learning environments within engineering education?
2. What existing analytical frameworks could be accurate for researching students' experiences and power dynamics in collaborative learning within the context of engineering education?

The article begins with a literature review summarising research on the lived experiences of women in collaborative learning environments in engineering courses, identifying the benefits and challenges they face regarding such pedagogies. A special focus is given to the literature related to power dynamics within collaborative learning contexts. Then, the theoretical foundations of phenomenology and post-structuralism are briefly described before we explore two analytical frameworks that combine both perspectives. The adaptability and impact of these frameworks aim to analyse power relations embedded in collaborative learning based on engineering education research (EER).

2 LITERATURE REVIEW

2.1 Collaborative pedagogies in engineering education

Within an educational context, collaborative learning is described as a pedagogical approach that entails collective intellectual efforts among students, or between students and their instructor (Stump et al., 2011). The teaching of professional skills through collaborative learning projects has become a common practice in undergraduate engineering programs. Vast research suggests that project-based learning (PBL) positively impacts students' understanding of engineering principles, students' ability to apply such principles to real-world problems, and students' skills with regard to social, ethical and organisational aspects of engineering (Picard et al., 2022). In a collaborative learning culture, students learn with, from and about each other via teamwork (Krishnan et al., 2011). Research on collaborative learning often suggests deeper student engagement than traditional lecture-based transmission methods. Although the effectiveness of the collaboration depends upon the dimension assessed, e.g., social aspects, cognitive aspects or student achievement (Stump et al., 2011), key concepts for successful engineering education teamwork have been identified; they include interdependence, trust and shared mental models (Borrego et al., 2013).

2.2 Women in collaborative learning environments in engineering education

Communication and teamwork are seen as key elements in the training of engineers (Beddoes, 2020), as decision-making in the field is often the result of collaborative contexts (Francis et al., 2022). However, gender dynamics and stereotypes often underpin socialisation processes of women in engineering or other STEM courses (Dancy et al., 2020; Henderson, 2023). This is particularly relevant considering that the cultural characteristics of engineering learning environments often revolve around competitiveness and masculinity (Kamanda et al., 2022). In this context, women students are at risk of underestimating or underreporting their skills during role negotiation in team projects, potentially affecting their academic motivation and performance (Henderson, 2023).

3 THEORETICAL FOUNDATIONS

There is a growing demand to broaden the epistemological perspectives used in engineering educational research. This call aims to promote advancements in both learning outcomes and learning experiences for groups of students who have been marginalized historically (Svihla et al., 2023). In this context, epistemic pluralism acknowledges the importance of exploring diverse theories to elucidate a particular phenomenon across various levels, employing a range of suitable conceptual methods (Wegerhoff et al., 2021).

This section addresses the first research question and aims to understand how phenomenology and poststructuralist methodologies should be integrated to develop a comprehensive theoretical framework for researching collaborative learning environments in engineering education.

3.1 Phenomenology: understanding subjective experiences

Classical phenomenology is concerned with the essential and invariant structures underlying the experience of everyday life from the first-person point of view

(Moustakas, 1994; Sokolowski, 2000). Thinking, reasoning and perception are not confined within the individual's mind but, rather, are related to the world in which the individual is embedded (Sokolowski, 2000), to look at how thoughts and experiences create our understanding of reality, and with it, knowledge (Dodd, 2020).

Furthermore, unveiling the structures of lived experiences requires references to the subjective meaning an action has for the actor (Schutz, 1971). Phenomenology falls short when attempting to interpret the connections between lived experiences of a given phenomenon and power structures that might not be part of the individuals' narratives (and awareness) of everyday life.

3.2 Poststructuralism: understanding power, discourses and knowledge

Poststructuralism, as a critical response to structuralism, challenges the idea of fixed systems of meanings shaped by social structures, in which people have little, if any, control (Savin-Baden & Major, 2012). It also denies that the structures of the experience can be described from a first-person point of view "without attending to the ways in which individuals are positioned in historical contexts that are largely dominated by power relations" (Magri & McQueen, 2023, p. 7). This argument implies the need for a methodological approach that explores beliefs and practices by searching in historical records, avoiding accepting taken-for-granted truths (Wuthnow et al., 1984).

Moreover, Foucault, an influential representative of this school of thought, explored relationships among power, knowledge and discourse and stated that "power and knowledge directly imply one another" (Foucault, 1995, p. 27), meaning that knowledge serves power, but also power produces knowledge. By creating dominant discourses, subjects are shaped with perceived truths (discourses) that emerge from the power-knowledge relationship. Their perception of phenomena (and the meaning they ascribe) varies depending on their standpoint towards power-knowledge.

Within this context, rather than a dichotomous definition of power as the influence or control of powerful entities over powerless ones, a common conceptualisation of power – based on Foucault's work – is defined as a relation to understanding how subjects relate to each other and how institutions are organised (Apple et al., 2010).

3.3 Intersections of phenomenology and poststructuralism

The credibility of phenomenology as a social research paradigm relies on a clear alignment between its philosophical foundations and the practical methods employed (Larsen & Adu, 2022), making it necessary to assess to what extent phenomenological methodologies can be combined with other approaches while maintaining a consistent logic among the theoretical frameworks.

For now, we observe two intersections that demonstrate epistemological coherence between these two theoretical perspectives, namely phenomenology and poststructuralism: (1) language serves as a regulatory system that provides evidence of meaning; (2) constitution of experience and subjectivity are key aspects with which both approaches are concerned. Nevertheless, there are also some methodological disagreements. A central one was mentioned above – related to investigating power structures to inform the understanding of our experiences, ourselves and our world. Critical assessments of classical phenomenology highlight the tacit presuppositions underlying the relationship between power, knowledge, discourse, and social experience (Magri & McQueen, 2023).

4 ANALYTICAL FRAMEWORKS TO RESEARCH GENDER AND POWER DYNAMICS

In this section, we address the second research question by exploring an analytical framework relevant to understanding students' experiences and power dynamics in collaborative learning environments.

Studies investigating the learning experiences of underrepresented minority students in EER have identified relationships between individuals' experiences and a range of structural factors, including social, economic and cultural contexts. These studies have employed diverse theoretical frameworks, methodologies and methods to explore these relationships across the spectrum.

We have chosen these frameworks because they provide conceptual tools to disclose power dynamics from lived experiences while also examining deep structures of inequality.

4.1 Gender at Work Analytical Framework

The Gender at Work Analytical Framework (Rao et al., 2016) explores power relations embedded in institutions and communities. It analyses two dimensions: the individual-systemic spectrum and the informal-formal spectrum. The combination of both dimensions forms four quadrants concurrently: (1) Consciousness and Capabilities; (2) Resources; (3) Rules and Policies; (4) Social Norms and Deep Structures. The framework helps to make explicit power dynamics of each quadrant that maintain barriers to gender equality (see Fig.1).

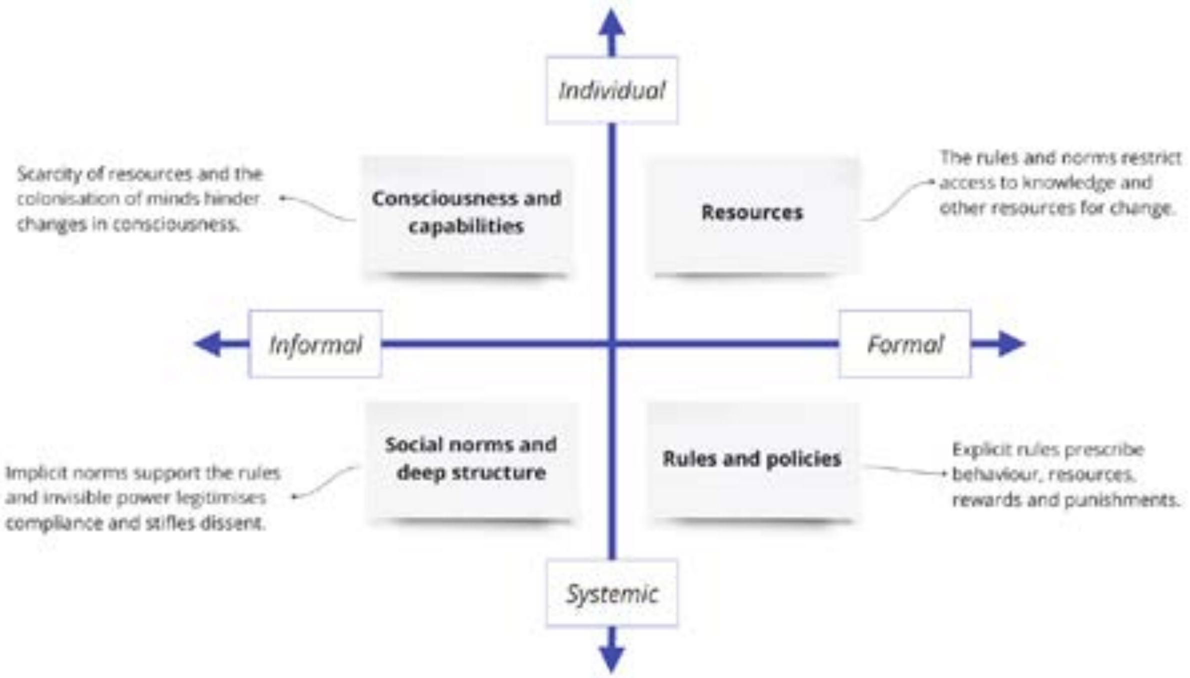

Fig. 1. Gender at Work Analytical Framework, including power dynamics of each quadrant that maintain gender inequality (Rao et al., 2016)

This analytical framework has informed research across various disciplines. For instance, Njuki et al., (2023) used the Gender at Work framework to meta-analyse gender-transformative research in diverse fields such as fisheries, small-scale mining, health, water and sanitation access, gender-based violence, and early marriage, encompassing studies from Africa, Asia, and Latin America. Perhaps the framework could prove useful in engineering education for understanding gender inequality, designing interventions for change, and mapping outcomes.

The relevance of this framework with regard to our research objective (i.e. achieving a comprehensive understanding of collaborative learning by incorporating analysis of power dynamics as intrinsic to the examination of experience) is twofold:

(1) In the context of micro-social interactions such as collaborative learning, the four quadrants of the Gender at Work Framework can be assessed, even at different levels, for instance, group, classroom, campus, university, etc.
(2) We observe that the Gender at Work Framework is compatible with the phenomenological approach, providing conceptual tools to comprehend how power dynamics shape individual experiences and enabling a deeper comprehension of the phenomenon under study.

4.2 Intersectionality

Intersectionality studies how an individual's experiences, constraints, and opportunities are the result of the intersection of multiple systems of power (Carrigan et al., 2023). Social identities (e.g., gender, race, class, etc.) are connected to systems where certain groups can exercise power and privilege and, therefore, are more likely to be heard. A helpful intersectional conceptual tool to make power relations explicit is offered by Collins and Bilge (2020) in the form of four interconnected domains of power concerning:

a. Structural practices. This domain refers to the fundamental structures of social institutions (Collins & Bilge, 2020, p. 7), including policy and policy-like practices (Svihla et al., 2023) .
b. Cultural practices. This domain explores the ideologies that structure power dynamics, creating a narrative about equal opportunities for all (Collins & Bilge, 2020, p. 9).
c. Disciplinary practices. This domain refers to how rules and regulations are differently applied to people based on their identities (Collins & Bilge, 2020, p. 12). This approach delves into how individuals influence and pressure one another to conform to established norms.
d. Interpersonal practices: This approach explores how individual experiences are influenced by social intersecting attributes such as gender, race, class, cultural background, age, etc (Collins & Bilge, 2020, p. 15).

Within those categories, we can distinguish two interconnected factors contributing to those power dynamics: (1) those related to individual identities and (2) those related to institutional structures and educational practices that may either reinforce or mitigate power differentials in students' lived experiences.

This paper's ultimate objective is to identify analytical frameworks beneficial for researching power structures that affect students' experiences in collaborative learning within the realms of engineering education. Such frameworks could prove valuable for researchers and practitioners involved with engineering education.

5 ADAPTABILITY TO THE CONTEXT OF ENGINEERING EDUCATION

Through a narrative literature review (Saunders-Smits & NI, 2024), we have examined 19 references concerning students' experiences within the field of engineering, identifying power dynamics elucidated in these studies and categorising them according to the analytical frameworks outlined in the preceding section. Following that, we attempt to unravel the experience within its context to identify perceived behaviours that account for power relations and the discourse behind those behaviours. This analysis aims to find connections (and contradictions) between individuals' experiences and broader social or institutional practices.

5.1 Social identities and relational habits in collaborative learning

Both analytical frameworks explore the individual's personal mindsets and emotions as well as collective identities and cultures as foundations for analysing the power dynamics. In the realms of engineering education, research indicates that students' feelings of isolation or not fitting into engineering stem from experiences of exclusion or barriers hindering their full participation based on gender and race (Campbell-Montalvo et al., 2022; Dancy et al., 2020; Powell et al., 2009; Stump et al., 2011). The most commonly reported findings in research on collaborative learning, when viewed through the lens of social identity, include examples of discriminatory behaviour, microaggressions and harassment as a response of stereotypical attitudes (Aeby et al., 2019; Hirshfield, 2018; Keough et al., 2021). Such identity politics are often enacted to confine group members by providing them acknowledgement while also serving to further exclude those who do not fit the group identity (Apple et al., 2010, p. 134).

Given this context, frequently students from underrepresented minority groups perform strategies to fit in the dominant group, with one of them involving downplaying the disadvantages associated with being part of the minority group (Powell et al., 2009), a pattern that could be seen as a discrepancy between perception and experiences, for instance witnessing and accepting micro aggressive acts against other students from minority groups (Campbell-Montalvo et al., 2022).

Nevertheless, a prominent discourse masking inequities based on social identities is the claim that engineering is free of sexism and racism (Campbell-Montalvo et al., 2022; Dancy et al., 2020). This asseveration not only reproduces the ideology but also fosters privilege-blind bias.

5.2 Social norms and culture in engineering education

The collective patterns of action and thinking in collaborative learning shed light on a shared understanding of the engineering culture beyond educational settings. These social norms and culture shape the discourses of what is normal and acceptable (Rao et al., 2016). For instance, Kamanda et al., (2022) found that students may imitate behaviours they perceive as indicative of engineering success, such as consistently staying late in the computer lab, to signal such expectations to their peers. Eventually, students collaborating will position and be positioned by others. These patterns of behaviour will often lead to shape role identities, such as "the one who usually knows how to do it", "time organiser", "the one who always needs help", or "the creative thinker" (Holland & Lave, 2001, as cited in Nolen et al., 2024).

Furthermore, given that engineering environments often emphasise competitiveness and masculinity (Kamanda et al., 2022), students may be reluctant to collaborate due to the pressure to outperform their peers (Stump et al., 2011). Regarding masculinity, research also reveals that women students experience offensive behaviours (often veiled as mere jokes), which prompt them to question their choices, capabilities, and aptitudes (Powell et al., 2009). The notions that women engineers are unattractive, insufficiently intelligent, or relegated to the easiest subfields are just a few examples of how the culture within engineering may perpetuate a power dynamic that systematically undermines women in the field. Some implications of it are that women students perform less technical aspects of the project, which might mean restrictive access to equipment and decision-making, and the reproduction of gendered valuation of skills (Aeby et al., 2019; Fowler & Su, 2018; Henderson, 2023).

5.3 Formal structures and policies for equality

Institutional policies and educational practices impact individuals in varying ways depending on their social and role identities. For example, in a study exploring black students' experiences, the research team recognised that negative perceptions toward their race extend beyond the engineering field and are embedded in the broader campus climate (Campbell-Montalvo et al., 2022). In a separate study, researchers discovered that students from privileged backgrounds might view themselves as part of a disadvantaged group. This perception could arise in response to policies and practices, such as affirmative action, designed to address inequality (Stump et al., 2011). Similarly, feelings of rejection or imposter syndrome may arise among women students when they hear messages implying that institutional policies for diversity, equity, and inclusion are the reason for women's participation in engineering fields.

Throughout the analysis, we encountered extensive research elucidating students' emotions and experiences within collaborative learning environments, as well as the social behaviours precipitating these experiences. However, we noted a scarcity of evidence regarding the discourses underpinning attitudes and behaviours perpetuating power inequities. Moreover, evidence of how institutional structures and educational practices may reinforce or mitigate power differentials is much less addressed, a shortage that justifies linking phenomenological and post-structural methodologies for our own research. By labelling these 'truths' in our own terms, we broadened our perspective to explore structural contexts and fostered critical reflection on the challenges of experiencing collaborative learning in engineering.

Finally, a limitation of the Gender at Work Framework consists in the absence of explicit concepts to analyse multiple aspects of identity besides gender.

6 CONCLUSIONS AND IMPLICATIONS FOR RESEARCH AND PRACTICE

Proactively developing collaborative learning environments in engineering is crucial (Beddoes, 2020). Examining students’ experiences and identifying the inherent power dynamics and dominant discourses is essential for addressing the interplay of knowledge, power, and discourse that often perpetuates inequities in engineering education. The assumption that students will work effectively and automatically when placed in teams is incorrect and risky if power dynamics are not acknowledged (Fowler & Su, 2018; Hirshfield, 2018).

Thus far, our research team has faced challenges in finding a method or approach that effectively integrates the emotional depth described in our interview dataset with the broader contextual aspects of learning. An epistemically pluralist approach acknowledges that a single methodology does not promote a comprehensive understanding of the phenomenon and its complexity theoretically and in practice (Wegerhoff et al., 2021). We have thus embarked on an exploration combining phenomenology and poststructuralism to gain a deeper understanding of collaborative learning in engineering education. In this pursuit, we began by exploring analytical frameworks to analyse the power dynamics inherent in students' experiences, constituting this paper's primary contribution to the field.

Based on the research reviewed, further work could address the development of a theoretical framework to support the further analysis of gender and other intersectional inequalities in engineering educational practices. Research on the unseen challenges that engineering students face in collaborative settings due to power dynamics can be instrumental in making these issues visible, fostering support and empathy, and developing a more welcoming learning environment for diverse groups in the field

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REFERENCES

Aeby, P., Fong, R., Vukmirovic, M., Isaac, S., & Tormey, R. (2019). The Impact of Gender on Engineering Students' Group Work Experiences. *International Journal of Engineering Education*, *35*(1), 756–765.

Apple, M. W., Ball, S. J., & Gandi, L. A. (Eds.). (2010). *The Routledge International Handbook of the Sociology of Education*. Routledge.

Beddoes, K. (2020). Interdisciplinary teamwork artefacts and practices: A typology for promoting successful teamwork in engineering education. *Australasian Journal of Engineering Education*, *25*(2), 133–141. https://doi.org/10.1080/22054952.2020.1836753

Borrego, M., Karlin, J., McNair, L. D., & Beddoes, K. (2013). Team Effectiveness Theory from Industrial and Organizational Psychology Applied to Engineering Student Project Teams: A Research Review. *Journal of Engineering Education*, *102*(4), 472–512. https://doi.org/10.1002/jee.20023

Campbell-Montalvo, R., Kersaint, G., Smith, C. A. S., Puccia, E., Skvoretz, J., Wao, H., Martin, J. P., MacDonald, G., & Lee, R. (2022). How stereotypes and relationships influence women and underrepresented minority students' fit in engineering. *Journal of Research in Science Teaching*, *59*(4), 656–692. https://doi.org/10.1002/tea.21740

Carrigan, C., Tanguay, S. K., Yen, J., Ivy, J. S., Margherio, C., Horner-Devine, M. C., Riskin, E. A., & Grant, C. S. (2023). Negotiating boundaries: An intersectional collaboration to advance women academics in engineering. *Engineering Studies*, *15*(1), 9–29. https://doi.org/10.1080/19378629.2023.2169613

Collins, P. H., & Bilge, S. (2020). *Intersectionality*. Polity Press. https://books.google.ie/books?id=5qe7yAEACAAJ

Cruz Moreno, S. I., Chance, S., & Bowe, B. (2023). *Exploring Women's Teamwork Experiences In Engineering Education: A Phenomenological Analysis*. https://doi.org/10.21427/HYDG-MC82

Dancy, M., Rainey, K., Stearns, E., Mickelson, R., & Moller, S. (2020). Undergraduates' awareness of White and male privilege in STEM. *International Journal of STEM Education*, *7*(1), 52. https://doi.org/10.1186/s40594-020-00250-3

Dodd, J. (2020). Transcendental. In D. De Santis, B. C. Hopkins, & C. Majolino (Eds.), *The Routledge Handbook of Phenomenology and Phenomenological Philosophy* (1st ed., pp. 388–395). Routledge. https://doi.org/10.4324/9781003084013

Du, X., & Kolmos, A. (2009). Increasing the diversity of engineering education – a gender analysis in a PBL context. *European Journal of Engineering Education*, *34*(5), 425–437. https://doi.org/10.1080/03043790903137577

Foucault, M. (1995). *DISCIPLINE AND PUNISH* (A. Sheridan, Trans.; 2nd ed.). Vintage books.

Fowler, R. R., & Su, M. P. (2018). Gendered Risks of Team-Based Learning: A Model of Inequitable Task Allocation in Project-Based Learning. *IEEE Transactions on Education*, *61*(4), 312–318. https://doi.org/10.1109/TE.2018.2816010

Francis, R. A., Paretti, M. C., & Riedner, R. (2022). Theorizing Engineering Judgment at the Intersection of Decision-Making and Identity. *Studies in Engineering Education*, *3*(1), 79. https://doi.org/10.21061/see.90

Henderson, T. S. (2023). Understanding Access to Learning Opportunities in Collaborative Projects: Gendered Social Hierarchies in Student Teams. *Studies in Engineering Education*, *4*(1), 90–114. https://doi.org/10.21061/see.101

Hirshfield, L. J. (2018). Equal But Not Equitable: Self-Reported Data Obscures Gendered Differences in Project Teams. *IEEE Transactions on Education*, *61*(4), 305–311. https://doi.org/10.1109/TE.2018.2820646

Kamanda, H., Walther, J., Wilson, D., Sochacka, N., & Huff, J. (2022). Professional Engineering Socialization at the Intersection of Collective Constructions of Expectations and Individual Shame Experiences. *Studies in Engineering Education*, *3*(1), 1. https://doi.org/10.21061/see.83

Keough, M., Hirshfield, L., & Fowler, R. (2021). How Male Students Talk About the Female Student Experience on Teams. *2021 ASEE Virtual Annual Conference Content Access Proceedings*, 37256. https://doi.org/10.18260/1-2--37256

Kolmos, A., & de Graaff, E. (2014). Problem-Based and Project-Based Learning in Engineering Education: Merging Models. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (1st ed., pp. 141–

160). Cambridge University Press. https://doi.org/10.1017/CBO9781139013451.012

Krishnan, S., Gabb, R., & Vale, C. (2011). Learning Cultures of Problem-Based Learning Teams. *Australasian Journal of Engineering Education*, *17*(2), 67–78. https://doi.org/10.1080/22054952.2011.11464057

Larsen, H. G., & Adu, P. (2022). *The theoretical framework in phenomenological research: Development and application*. Routledge, Taylor & Francis Group.

Magri, E., & McQueen, P. (2023). *Critical Phenomenology: An Introduction*. Polity Press.

Meadows, L., & Sekaquaptewa, D. (2013). The Influence of Gender Stereotypes on Role Adoption in Student Teams. *2013 ASEE Annual Conference & Exposition Proceedings*, 23.1217.1-23.1217.16. https://doi.org/10.18260/1-2--22602

Moustakas, C. E. (1994). *Phenomenological research methods*. Sage Publications.

Njuki, J., Melesse, M., Sinha, C., Seward, R., Renaud, M., Sutton, S., Nijhawan, T., Clancy, K., Thioune, R., & Charron, D. (2023). Meeting the challenge of gender inequality through gender transformative research: Lessons from research in Africa, Asia, and Latin America. *Canadian Journal of Development Studies / Revue Canadienne d'études Du Développement*, *44*(2), 206–228. https://doi.org/10.1080/02255189.2022.2099356

Nolen, S. B., Michor, E. L., & Koretsky, M. D. (2024). Engineers, figuring it out: Collaborative learning in cultural worlds. *Journal of Engineering Education*, *113*(1), 164–194. https://doi.org/10.1002/jee.20576

Picard, C., Hardebolle, C., Tormey, R., & Schiffmann, J. (2022). Which professional skills do students learn in engineering team-based projects? *European Journal of Engineering Education*, *47*(2), 314–332. https://doi.org/10.1080/03043797.2021.1920890

Powell, A., Bagilhole, B., & Dainty, A. (2009). How Women Engineers Do and Undo Gender: Consequences for Gender Equality. *Gender, Work & Organization*, *16*(4), 411–428. https://doi.org/10.1111/j.1468-0432.2008.00406.x

Rao, A., Sandler, J., Kelleher, D., & Miller, C. (2016). *Gender at work: Theory and Practice for 21st Century Organizations*. Routledge. https://doi.org/10.4324/9781315693637

Saunders-Smits, G. N. & Nl. (2024). *Towards a Typology in Literature Reviews in Engineering Education Research – Using the right review for the job*. https://doi.org/10.13140/RG.2.2.15048.74241

Savin-Baden, M., & Major, C. (2012). *Qualitative research: The essential guide to theory and practice*. Routledge.

Schutz, A. (1971). *Collected Papers, vol. II, Studies in Social Theory* (A. Brodersen, Ed.). Martinus Nijhoff.

Sokolowski, R. (2000). *Introduction to phenomenology*. Cambridge University Press.

Stump, G. S., Hilpert, J. C., Husman, J., Chung, W., & Kim, W. (2011). Collaborative Learning in Engineering Students: Gender and Achievement. *Journal of Engineering Education*, *100*(3), 475–497. https://doi.org/10.1002/j.2168-9830.2011.tb00023.x

Svihla, V., Davis, S. C., & Kellam, N. N. (2023). The TRIPLE Change Framework: Merging Theories of Intersectional Power, Learning, and Change to Enable Just, Equitable, Diverse, and Inclusive Engineering Education. *Studies in Engineering Education*, *4*(2), 38–63. https://doi.org/10.21061/see.87

Wegerhoff, D., Ward, T., & Dixon, L. (2021). A pluralistic approach to the definition, classification, and explanation of gangs. *Aggression and Violent Behavior*, *58*, 101546. https://doi.org/10.1016/j.avb.2020.101546

Wu, L. L., Fischer, C., Rodriguez, F., Washington, G. N., & Warschauer, M. (2021). Project-based engineering learning in college: Associations with self-efficacy, effort regulation, interest, skills, and performance. *SN Social Sciences*, *1*(12), 287. https://doi.org/10.1007/s43545-021-00286-4

Wuthnow, R., Hunter, J. D., Bergesen, A. J., & Kurzweil, E. (1984). *Cultural Analysis: The Work of Peter L. Berger, Mary Douglas, Michel Foucault, and Jürgen Habermas*. Routledge & Kegan Paul.

USING 'DESIGN SHORTS' TO ENGAGE ENGINEERING STUDENTS IN SELF AND PEER SUPPORTED PROBLEM BASED LEARNING

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ABSTRACT

Large engineering modules containing a diverse array of technical and design content can cause students to both disengage and treat taught content as silos. By not understanding the wider context and inter-linkage between diverse technical content, solving authentic design problems becomes problematic for students and staff. These deficiencies were addressed through repackaging our original engineering problems into smaller but authentic group based 'design shorts'. These smaller problems purposely connect a diverse range of structural engineering topics using formative assessment to facilitate self and peer supported student learning. Constructive feedback and dialogue were key elements to ensure successful student outcomes and attainment of learning outcomes. The impact of these design shorts on student engagement and module results over a six-year period is reviewed. Importantly, these 'design shorts' introduced a strong ethos of 'thinking', self and

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group peer supported learning and curiosity when addressing structural design problems.

1 INTRODUCTION

1.1 Overview of need

Most teaching practice in engineering revolves around students learning through the acquisition of facts or procedures. Content taught within a module does not usually migrate across that module nor onwards to other modules, let alone across years of study. Students seemingly view taught content and modules as silos, independent of each other and not obviously inter-related. This is contrary to the belief of staff who struggle to understand why students cannot interconnect technical knowledge across diverse content areas.

Our second year BEng/MEng students (FHEQ Level 5; QAA 2014) within the Department of Civil Engineering in the School of Engineering at Cardiff University take a year-long 40-credit module titled ‘Structural Analysis and Design’, equally split between the Autumn and Spring semesters. This large module was formed from separate and smaller courses covering the design of steel and concrete structures, structural analysis, solid mechanics and failure theories content, as well as the detailed design of a multi-storey building in steel and reinforced concrete.

This module was delivered over a 7-hour day every week for both semesters. Traditional lectures were timetabled in the morning and covered fundamental content, with the afternoons being practical workshop sessions held in a large baseroom. The baseroom environment was meant to apply previously taught technical theory to authentic problems initially posed within tutorial sheets. However, students really struggled to connect with the inter-related content, resulting in a decline of engagement and satisfaction.

Pedagogical interventions were introduced over a six-year period with a view to improve student engagement and understanding of structural behaviour. Due to the breadth of taught content and mode of delivery, students struggled to link their learning across these topics and had little intuition on whether solutions to structural problems were viable or not.

The interventions were aimed at moving away from individuals undertaking tutorial sheets and to provide a series of formative group assignments timetabled at regular intervals during the semesters based on previously taught content. These assignments further created a sequence of directed feedback opportunities to enhance students’ understanding of structural behaviour and introduced a self-learning ethos. These assignments became known as “design shorts” which were planned to purposely interlink content across this module and to create a “thinking” culture amongst students.

1.2 Pedagogical reasoning for group ‘design shorts’

Our teaching philosophy within engineering has transformed and evolved over the years, moving away from teacher-focussed approaches to student-centred activities (Trigwell et al 1999). This is important because there is a strong relationship between how teachers teach and how learners learn (Monroy and Gonzalez-Geraldo 2018). The transferable skills involved in creating ‘thinkers’ and for ‘learning to learn’ are vitally important in today's society and engineering practices, as noted by Hacker et al (2009).

Staff began to embrace this 'changing as a person' approach, as highlighted by Marton et al (1993), where learning is about transitioning students to 'think' about their learning and to become self-motivated. Since group work forms a critical aspect of an engineer's life, 'learning-together' would strengthen our existing 'problem-led' teaching practice, which was based on the Universal Design for Learning (UDL) guidance (CAST 2018). This new approach to empowerment also provided opportunities for students to benefit from peer support and provided scaffolding in their early learning journey ie by creating a 'Communities of Practice' environment and a peer-support (Lave and Wenger 1991; Wenger-Trayner 2015) structure. These approaches allowed the introduction of further aspects of cooperative and collaborative learning into group work.

Whilst transforming our own teaching practice and that of others, how students approach studying (van Rossum and Schenk, 1984) can be influenced by their own conceptions of learning. Many students use a surface approach, memorising content for assessment. However, their learning becomes superficial with little appreciation of engineering principles beyond answering specific questions posing as assessment. Whilst trying to promote a deeper approach to study with students, the diverse needs of students focused on understanding the wider learning context and accommodating student circumstances.

After some false starts, our pedagogical approach developed to that best defined as being Andragogy - more independent, learner-directed and self-motivated student learning – with teaching becoming more of a mentoring role (Delahaye et al 1994). The common one-way 'zone of proximal development' (ZPD) model (Vygotsky's 1987) approach modified over time, becoming an authentic two-way collaborative learning environment, which is better known as the 'intermental development zone' (IDZ). Hence, utilising more open-ended and authentic problem-based approaches to promote discursive talk (Fernandez et al 2002) have elicited very favourable student comments. Uncertainty was purposely introduced into the technical "design shorts" to promote discussion and deeper evaluation of solutions.

As noted earlier, a goal of our teaching practice was to create 'self-learning' graduates with the skills for 'asking the right questions'. Is content and subject knowledge more important than 'knowing how to learn'? It is important to facilitate learning, as noted by the various roles ascribed by Bates (2014) and more recently Perryman (2019) to the 21st century educator, such as 'teacher for learning', 'experimenter' and 'educator for everyone'. These metaphors formed the ethos for our teaching practice on this module, promoting 'assessment for learning' and not 'learning for assessment' through our challenging "design shorts".

Feedback is also a crucial aspect of student learning and is one of the most important influences on learning gain (Hattie 1999). However, very few students effectively engage in this process. Feedback is inseparable from assessment, especially when it is relevant, constructive, accessible and timely. To better engage students and develop their curiosity, feedback became a core mechanism for promoting self and peer supported learning within the module. Feedback ideally needs to be done immediately rather than much later and its relevance understood by students as being a key aspect of learning.

2 DESIGN SHORT STRATEGY

2.1 Group work rationale

Group work should be a positive and harmonious experience for students and staff but this often requires careful and detailed planning. Providing clear instructions and guidance on undertaking group work is essential, together with outlining expectations and support on how to assign tasks across group members and how to work as a group, which is not always straightforward. When conflict arises, we defined alternative work for smaller groups and individuals from the onset which we found to be good practice; just knowing there is another route when problems arise can provide reassurance and aid the wellbeing of students (McPherson et al. 2019).

Groups were randomly allocated and normally consisted of six students. To create the team working and self/peer learning environment, the “design shorts” continued to take place in a large open plan baseroom which consists of chairs and tables arranged to allow group members to face each other. This module typically has circa 120 to 140 students, so 20+ groups are formed which require between four and six staff members to purposely interact during the 3-hour long workshops and especially for the feedback sessions.

Our learning pedagogical goals coupled with the diverse structural engineering content directed our thoughts to developing four ‘design shorts’, each being particular to a structural engineering problem that spanned across different taught content and created to enrichen the student learning experience. Each design short takes 3-4 weeks to complete, with findings presented to staff in a design office format within the baseroom. The first week for each design short involves a short introductory talk followed by a baseroom session which then continues over the following 2 weeks. The formative assessment takes place in the fourth week, with each group having 30 minutes to present their solutions to staff via calculation sheets, to discuss arising issues and receive feedback.

The design shorts were also conceived to guide students to explore, compare, validate and verify solutions based on a variety of structural analysis techniques or assumptions made in the behaviour of a structure. Although the individual reasoning behind the design shorts is not the purpose of this paper, an outline of each is provided below for context.

2.2 Design shorts

The first design short investigates load paths in various braced and unbraced 2D and 3D frames using physical K’Nex’ models and utilises quantitative reasoning to provide qualitative answers. Figures 1 to 4 show some typical examples of Design Short 1 tasks. Continuity within the frames and stiffness of components adds to the complexity of calculating values but observation aids students to identify the direction of loads, flexural behaviour and the possible range of support reactions. This is important in appreciating and validating output from computer analysis.

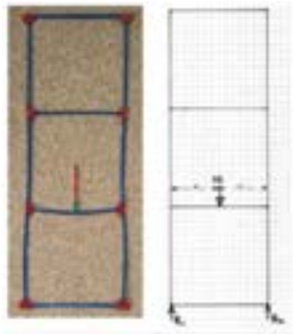

Fig. 1. Design Short 1 - 2D plane frame (R1=R2=5)

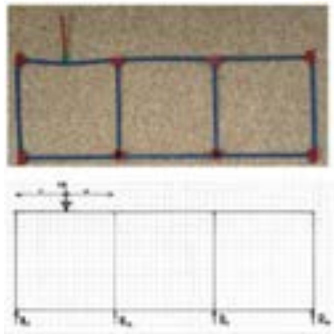

Fig. 2. Design Short 1 - 2D plane frame (R1 ≤ 5;R2 ≥ 5;R3 ≤ 0;R4 ≥ 0)

Fig. 3. Design Short 1 - 3D steel frame equivalent model

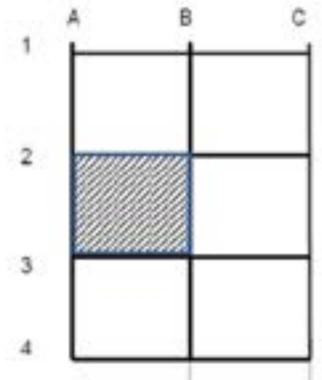

Fig. 4. Design Short 1 – 3D model patch load of 120 units on the first floor

The remaining three design shorts compare and evaluate structural analysis results for indeterminate frame structures. For each task, different analysis techniques such as energy methods and matrix stiffness analysis, as well as linear-elastic structural software (LUSAS) and code of practice design guidance are utilised and compared.

Design Short 2 concerns an indeterminate bridge structure (shown in Figures 5 and 6) and asks students to identify the maximum unfactored variable load (kN/m^2) on the two-span continuous beam bridge, considering the capacity of the beams in bending and shear only. Students were required to use Energy Methods (Castigliano’s Second Theorem) and Design Guidance from the IStructE (2009) to determine the bending moments and shear distribution for the bridge beams. Full calculations were required showing the maximum unfactored variable load determined from the two analysis methods and a brief commentary on any differences in results.

Discussion points to consider included pattern loading, understanding the concept of an ‘envelope’ of results, unequal span lengths, location of span moments and redistribution of moments. Students were also asked to quickly check their results by using fixed end moments (FEMs) or other means.

Design Short 3 builds on Design Short 2, with inclined steel struts being introduced (see Figure 7) to increase the variable load capacity of the bridge. Using LUSAS (structural analysis software) and Design Guidance from the IStructE (2009) the maximum unfactored variable load is again determined based on the resistance of the beams in bending and shear and reactions used for sizing the steel section struts. The struts are partially restrained in direction at both ends.

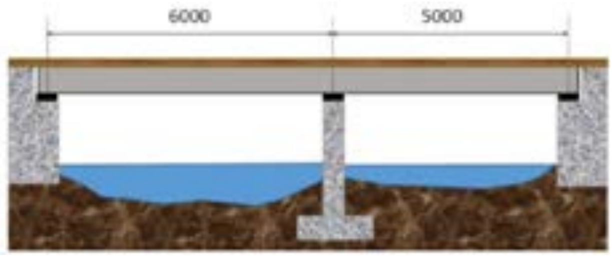

Fig. 5. Design Short 2 – bridge elevation

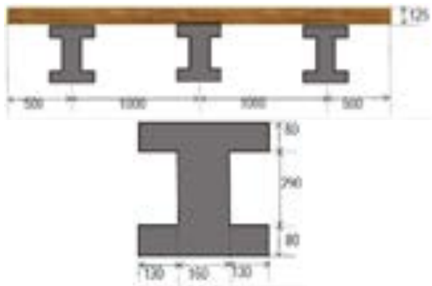

Fig. 6. Design Short 2 – bridge cross-section and beam dimensions

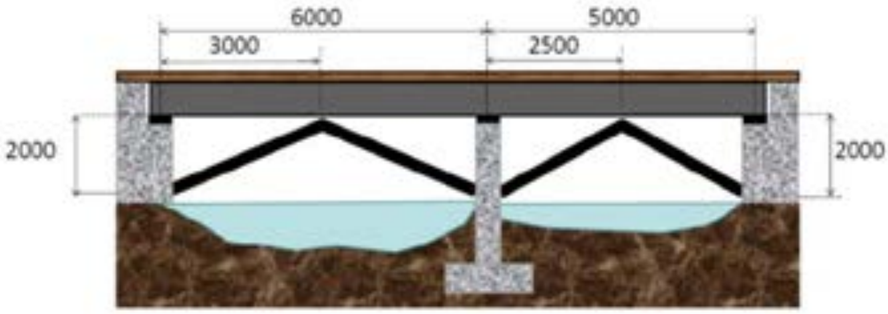

Fig. 7. Design Short 3 – bridge elevation showing inclined struts

LUSAS output had to be quantified against other reliable solutions ie design guidance and utilising FEMs. It is highlighted that results are only as good as the input data and the assumptions made when setting up the analysis model.

Design Short 4 culminates in the detailed design of both a concrete and a steel structural multi-bay single storey frame (see Figures 8 and 9) which is used to infill a space between two existing but adjacent buildings. The frames were spaced at 5m centres and support a pre-cast concrete roof deck.

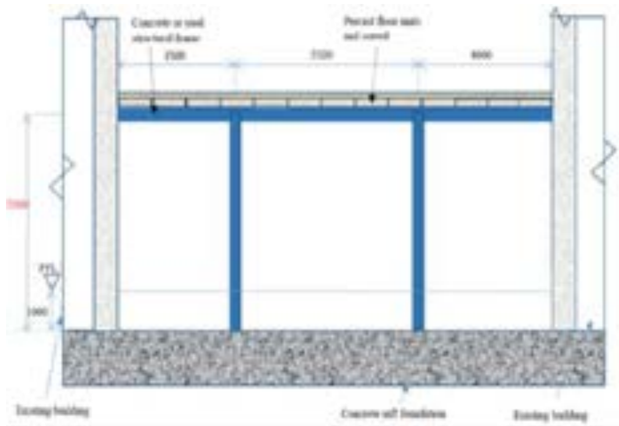

Fig. 8. Design Short 4 – multi bay frame elevation

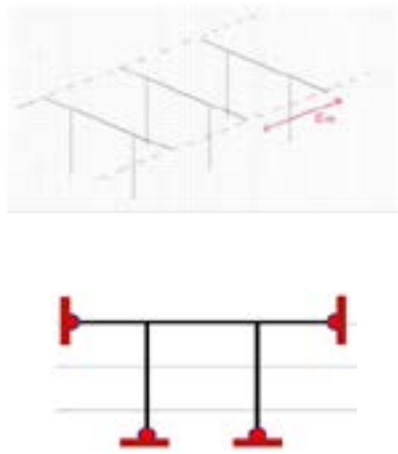

Fig. 9. Design Short 4 – multi bay frame spacing and supports

Students were tasked to use stiffness-based matrix analysis methods to undertake a series of structural analyses. Details provided to students include detailed loading values, support arrangements and foundations. Beam-connections were considered continuous ie moment carrying. Full calculations and sketches were required to support solutions. Commentary on the frame analysis results and verification by other unspecified means was also requested.

2.3 Why formative assessments?

Understanding the ‘assessment for learning’ strategy (CAST 2018) provided staff with student feedback to address any areas where further development or support was needed, while allowing students to determine which areas of their study required additional attention. The importance of discussion and feedback is critical and formative assessments provide a safe environment for student learning while getting rid of the ‘do I get a mark for this’ response. Hence, this module was redesigned to explicitly include formative assessment events aligned with the benefits of a mentoring approach with planned feedback loops. The goal was to have dialogue with students as they tackled problems and how they understood structural behaviour rather than a better-intentioned monologue from staff.

Care is needed in designing these assessments since they can easily become atomised, focussing on the micro-level of what is easy to assess while failing to integrate and assess complex, higher-order learning. Fundamentally, the sum of parts not adding up to making the intended whole. As Lipman (2013) noted, ‘students acquire bits of knowledge that, like ice cubes frozen in their trays, remain inert and incapable of interacting with one another.’

All students were required to attend formative group assessment presentations. Assessments do not carry any marks but are a qualifying element ie they need to achieve a certain standard to pass. Students presented their solutions to a member of staff as part of a round-table discussion; all group members need to present their own work and be prepared to answer questions on any aspect of the design short.

Solutions and all workings have to be presented on calculation sheets and clearly define units, reference to previous calculations and any notes or guidance used. Calculations need to be clear and well presented to allow easy checking, using annotated sketches to quickly explain assumptions, equations, theories or output and to illustrate dimensions, sizes, loads and elements being analysed or designed.

3 OUTCOMES

3.1 Student reaction and results

Students have found these design shorts to be very impactful on their learning. Having to validate and verify different results arising from various analysis techniques applied to the same problem introduced uncertainty and then a deeper appreciation of why solutions differed. Students gradually moved away from asking ‘what is the right answer’ to ‘how do I know that this is correct’ onto ‘Ah, I can see why I got that result’.

Overall, the design shorts bridged content that was evidently inter-connected in the minds of staff but were islands of knowledge for students. This simple change in approach did yield improved module results and student progression by 8% and 5% on average respectively. Individual technical structural engineering examination results over the six-year period showed an increase of up to 8.4%. Covid 19 did disrupt our learning and teaching between 2019-2021, with these examinations changing to being online and split to smaller manageable assessments timetabled over a longer exam period.

Qualitatively, student comments over this period have highly praised our design short approach. Typically, students mentioned that ‘it was a challenge, and the design shorts were good real-life applications of engineering’ and ‘the design shorts engaged you throughout the year and provided constant feedback from the lecturers on results and personally on progressive understanding of the content’ and being applied ‘to a real-life situation’. The workshops and formative assessments also gave ‘a little insight into a design office, (albeit in university) environment’ and ‘improved my teamwork skills’.

Importantly, learner autonomy and empowerment were also observed (Nunn and Nunn 1993; Freire 1998) within the design shorts, where the ‘traditional’ educational model of transmitting knowledge moved towards an environment of dialogue between staff and student but also between students – a two-way learning experience for all.

4 SUMMARY AND ACKNOWLEDGEMENTS

This design short approach has certainly improved student learning and been far more effective in addressing the module learning outcomes than some of our traditional examinations. Development work continues since there is no ‘perfect’ learning model but it is pleasing to note that this pedagogical approach is now being adopted in other large engineering modules within Cardiff University and the wider university.

More satisfaction has been garnered in later years of study where the greatest impact staff found was that students began to show a stronger self-learning ethos and an enthusiasm to ask questions to their previous experiences. The skills involved in undertaking these ‘design shorts’ has created more effective student ‘thinkers’ and fostered ‘learning to learn’ attributes that are vitally important in their engineering career.

REFERENCES

Bates, S. “Anatomy of 21st century educators.” 2014. https://www.slideshare.net/EdPER_talks/the-anatomy-of-the-21st-century-educator.

CAST (2018). “Universal Design for Learning Guidelines version 2.2.” 2018. http://udlguidelines.cast.org.

Delahaye, B. L., Limerick, D. C., and Hearn, G. “The relationship between andragogical and pedagogical orientations and the implications for adult learning.” *Adult Education Quarterly*, Summer, 44, 4 (1994): 187-200.

Fernández, M., Wegerif, R., Mercer, N., & Rojas-Drummond, S. “Re-conceptualizing “scaffolding” and the zone of proximal development in the context of symmetrical collaborative learning.” *Journal of Classroom Interaction*, 36, 2-1 (2002): 40-54, ISSN 0749-4025.

Freire, P. *Pedagogy of Freedom*. Maryland: Roman and Littlefield, 1998.

Hacker, D. J., Dunloseky, J. and Graesser, A. C. *A Growing Sense of Agency: Handbook of Metacognition in Education*. Routledge, 2009: 13–16.

Hattie, J. *Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement*. Abingdon, UK: Routledge, 1999.

IStructE - Institution of Structural Engineers. *Manual for the design of concrete building structures to Eurocode 2*. IStructE, London: 2009.

Lave, J. and Wenger, E. *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press, 1991.

Lipman, M. *Thinking in education*. 2nd Edition. New York: Cambridge University Press, 2013.

Marton, F., Dall’Alba, G. and Beaty, E. “Conceptions of learning.” *International Journal of Educational Research*, 19 (1993): 277–300.

McPherson, E., Collins, T. and Gallen, A. M. “Inclusive Group Work for Module Designers.” 2019. https://weblab.open.ac.uk/incstem/incstem-data/uploads/2019/11/designing-group-work-guidance.pdf.

Monroy, F. and González-Geraldo, J. L. “Measuring learning: discrepancies between conceptions of and approaches to learning.” *Educational Studies*, 44, 1 (2018): 81–98.

Nunn, G. D., and Nunn, S. J. “Locus of control and school performance: Some implications for teachers.” *Education*, 113, 4 (1993): 636–41.

Perryman, Leigh-Anne. “Open with care: Socially-responsible, culturally-responsive and equitable open pedagogy for a diverse world.” Paper presented at *Creative Commons Global Summit 2019, Lisbon, Portugal, 9-11 May 2019*.

QAA - Quality Assurance Agency (2014). “UK Quality Code for Higher Education - Part A: Setting and Maintaining Academic Standards - The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies.” 2014. https://www.qaa.ac.uk/the-quality-code/qualifications-frameworks.

Trigwell, K., Prosser, M. and Waterhouse, F. “Relations between teachers’ approaches to teaching and students’ approaches to learning.” *Higher Education*, 37 (1999): 57–70.

van Rossum, E.J. and Schenk, S. M. (1984). “The Relationship between Learning Conception, Study Strategy, and Learning Outcome.” *British Journal of Educational Psychology*, 54, 1 (1984): 73–83.

Vygotsky, L. S. (1987). “The development of scientific concepts in childhood (trans. Minick, N.).” Rieber, R. W. and Carton, A. S. (eds), The Collected Works of L. S. Vygotsky, 1 (1987): 167–243, New York, Plenum Press, 1987 (original publication, 1934, written between 1929 and 1934).

Wenger-Trayner, E. and Wenger-Trayner, B. (2015). “Communities of practice: a brief introduction.” 2015. http://wenger-trayner.com/wp-content/uploads/2015/04/07-Brief-introduction-to-communities-of-practice.pdf.

EMPOWERING TOMORROW'S INDUSTRIAL DESIGN ENGINEERS: A CURRICULUM REFORM JOURNEY AT THE UNIVERSITY OF TWENTE'S FACULTY OF ENGINEERING TECHNOLOGY

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ABSTRACT

The Bachelor program in Industrial Design Engineering (IDE) at the University of Twente's Faculty of Engineering Technology is undergoing a transformative journey. Recognizing the need for an update to reflect the evolving landscape of industrial design engineering and its impact on society, the program staff is redesigning the curriculum. Emphasizing the role of design engineers in building a sustainable future,

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the reform aims to empower students by offering more choice, enhancing coherence, and integrating more reflection into the learning process.

In collaboration with students and staff, the reform prioritizes ownership of learning, coherence of the program, and relevance to real-world challenges. The curriculum emphasizes hands-on learning through project-based modules, gradually increasing complexity and autonomy for students. Additionally, the program integrates academic and professional skills, encourages continuous reflection and more attention for design and research strategies.

Aligned with the Dutch Ministry of Education's pilot for a smarter academic year, the IDE curriculum reform aims to create a learning environment that fosters student growth and intrinsic motivation, by providing a challenging but feasible program that supports students with formative feedback in the learning process. By embracing these principles, the program prepares students to become responsible design engineers equipped to address the complexities of our changing world.

1. INTRODUCTION

The curriculum of the Bachelor program of Industrial Design Engineering at the University of Twente, within the faculty of Engineering Technology, is currently undergoing a redesign. The staff initiated this process to update the programme, in line with the many developments in the field of Industrial Design Engineering. Such developments relate to technological developments, the ability to focus more on sustainable products, but also the changing role of industrial design engineering in building a socially and environmentally sustainable society. The previous accreditation made recommendations regarding learning outcomes, student guidance and development-oriented feedback and support. These suggestions were reflected in the aims of the reform, which focus on the coherence of the program and providing opportunities for students to take more ownership of their learning. This is achieved through activities that encourage reflection and by offering more electives within the program, with the overarching goal to educate responsible design engineers. Furthermore, the program reform will focus on more explicit attention for design and research approaches, as well as on updating program intended learning outcomes. The aim is to embed the program in a strong learning and teaching community that fosters cohesion and inherently integrates academic and professional skills in the program.

This practice paper provides an overview of the work-in-progress of the curriculum reform. In this context, it is relevant that the IDE program participates in a pilot project of the ministry of education (OCW) that focuses on the problem of high workload for students, teachers, and researchers. The OCW pilot enables a number of universities to organize educational activities in their educational programs in a smarter way, so that more 'rest and space' is created for students and lecturers during the academic year. For the new IDE curriculum, it is imperative that staff and students are able to perform at a high level, for which the feasibility of teaching and studying within the program is an essential prerequisite. In this paper, we will explain how the OCW pilot is contributing to the redesign of the IDE curriculum to make the new academic program smarter, with more feasibility for staff and students. Whereas this approach is described in the context of the IDE programme as a case study, its applicability is not limited to this context. The approach is, for example, is also taken over for the overhaul of the BSc. programme in Mechanical Engineering.

2. THE CURRICULUM REFORM

Industrial Design Engineering at the University of Twente started in 2001 (Van Houten, 2002). It originally initiated from Mechanical Engineering, which is (still) a program at the faculty of Engineering Technology, where IDE is hosted as well. IDE has a bachelor's degree program with an average of 120 students per year. The total number of students is about 450 students. The program also has a master's program with about 250 students. The influx of students is a mix of international and Dutch students, with about 50% of the students coming from outside The Netherlands

The last accreditation was in 2019 (NVAO, 2020), and both the MSc. and the BSc. programs met all NVAO quality standards. Still, the committee did make recommendations to improve the program, suggesting that the learning outcomes should make more explicit reference to the international dimension, that the opportunities for staff to advise and coach students could be expanded, that the relationship between the intended learning outcomes and the thesis assessment could be made more explicit, and that development-oriented feedback to students could be incorporated more systematically.

In 2022, a steering committee of IDE staff was set up, to develop a blueprint for the reform. The mission of IDE's Bachelor's programme was defined: to educate responsible design engineers who integrate societal needs, technological developments, and academic insights. IDE aims to be a top-rated program by fostering a teaching and learning community that prepares graduates for an ever-changing world. Central to the curriculum reform is the proficiency of students to take ownership of their own learning journey. The program aims to cultivate intrinsic motivation, curiosity, and passion for industrial design engineering, enabling students to become the industrial design engineers they aspire to be.

3. A SMARTER ACADEMIC YEAR

The Ministry of Education in The Netherlands initiated a pilot project for a 'smarter academic year' in 2023 (*UToday*, 2023). The rationale behind this pilot is the observation that that the Dutch academic year is relatively long and intensive compared to other countries. This results in a high workload for students, teachers, and researchers, having implications for research and other core scientific tasks.

The aim of the pilot project is to responsibly reduce the number of weeks of education/ examinations and/or to organize existing educational activities in a more resourceful way, so that more 'piece and quiet' is created for students and lecturers during the academic year. This also creates more space for improving and innovating education, conducting research, participating in (scientific) conferences, and attending training and courses. For students this could generate more options in terms of the timing, pace and moments of exams, extracurricular activities, summer schools, internships, visits abroad, and better options to balance study, job and private life.

The pilot is foreseen for four years: 2023 - 2026. The pilots will be evaluated and monitored by the participating institutions and nationally by the leading universities: University of Amsterdam and Erasmus University Rotterdam. Particular attention will be paid to the impact on the workload of students, lecturers, and supporting staff, as well as to the quality of education.

The aims of the pilot are in line with the ongoing IDE curriculum reform. The IDE program, therefore, made a proposal to participate in the Smarter Academic Year pilot, which was granted. The pilot aims to contribute to the program to establish a learning experience in which students can flourish and become the best they can be. For the program it is important that it encourages students to work for their own development and growth - rather than to pass exams. Students pass the regular test at the end of a module, with resits being the exception. The program is also designed to be feasible, which means that students have enough time to study seriously and hard. The program should therefore have well-distributed and sparse deadlines throughout the modules. Next to the summative exams for the courses, formative assessments form an important element what would support learning.

From this list of aspirations relevant for the Smarter Academic Year pilot, several guiding questions emerged that enabled work on the curriculum and program reform:

1. Encourage students to study for their own development: How can students be encouraged to study for their own development, building on intrinsic motivation that leads to curiosity and passion in learning (i.e. Ryan & Deci, 2000)?
2. Sufficient time to study: How can the program be organised in such a way that adequately prepared students (in general) can pass exams/assessments, while having time to study, avoid study overload, and have limited and well-distributed deadlines in the modules (i.e. De Jonge Akademie, 2021)?
3. Include formative practices including formative assessment, giving feedback and build on it: How can formative assessment be incorporated in the modules and the program (e.g., Dirkx, Joosten-ten Brinke & Camp, 2010)?

These questions were used in the operationalisation of the curriculum and program reform, which the next section elaborates on.

4. THE CURRICULUM REFORM JOURNEY

The IDE programs at the UT, at Delft University and Eindhoven University of Technology all make use of the Domain Specific Reference Document for the Academic Industrial Design Engineering Programme (QANU, 2014), which was defined more than 10 years ago. This reference document has its origin in the Academic Criteria for Bachelor and Master Curricula (Meijers, Overveld, & Perrenet, 2003). In the reform, the program intended learning outcomes were updated, while still originating from the original set; they address designing, the disciplines relevant to IDE, as well as research and the scientific approaches to be learned. They also address intellectual skills, the ability to deal with temporal, social and personal contexts, collaboration, and communication. As it is identified as an important new aspect of the programme, a new learning outcome explicitly refers to students becoming responsible professionals who can work in international and intercultural contexts.

At the University of Twente, the TOM-model (Visscher-Voerman & Muller, 20217) is the prevailing educational approach. The core of the approach is that the BSc. curriculum consists of modules of 15EC, each consisting of a project and integrated/related courses. This project orientation aims to give students more control over their learning process. When IDE started (before TOM was introduced), it already was project based (Eger, Lutters, & Van Houten, 2004). The project-based approach implies that the learning environment allows students to work on the knowledge and skills that make them better design engineers. The project-oriented education focuses explicitly on student development by providing realistic engineering environments, which contributes to student motivation and the learning attitudes.

In the reformed curriculum, project work will continue to be a core part of each 15EC module, emphasizing hands-on learning through challenging, relevant projects, balancing real-world complexity with structured support. Initially guided by different design engineering perspectives, students will gradually explore and incorporate additional viewpoints, cultivating a conscious and confident understanding of their role in the field. In the first two years in the BSc. programme, modules increase in complexity, integrating thematic projects with courses that encourage analytical thinking, creativity, technological insight, and affinity with users. In the second year, students have the autonomy to choose specific tracks, roles, and courses in the modules, tailoring their learning experience to their interests and needs. In the third year, students further personalize their path by choosing a minor program that matches their interests. They culminate their studies with an individual final project that showcases their unique skills as an Industrial Design Engineer. The IDE program at UT prepares students for diverse professional contexts, fosters pride in their identity as Industrial Design Engineers, and equips them for their chosen career paths.

In meetings with staff, but also in close collaboration with students and the program committee, a set of curriculum requirements have been formulated to shape the redesign. Within the curriculum the following principles are seen as leading:

A. ***Become the IDE-er you want to be:*** A core element of the curriculum reform is student involvement and ownership of learning. The aim is to create a learning environment and a learning experience that enables students to become the IDE-ers that they want to be, help them to have a clear idea of their own identity and give them (more) responsibility and ownership in their learning journey. The program is challenging, it develops intrinsic motivation, curiosity and passion for industrial design engineering and eagerness to master new and complex content.
B. ***Integration/coherence, being a learning community:*** One of the main targets in the new curriculum is to increase the coherence of the program, based on a strong learning community of lecturers and students. Lecturers in each module develop an explicit vision on how their module fits into the curriculum as a whole. Module teams know what students have learned in previous modules, and (where appropriate) refer to and build on that. They can explain to students what the intended learning outcomes are, how they relate to the programme outcomes and how this relates to previous and subsequent modules.
C. ***Connection with (real) world (issues):*** Another important paradigm in the program reform is that the curriculum will be (and will evolve to stay) up-to-date, with a strong link with the (challenges in the) real world. Hence, currently relevant developments are integrated into the learning activities on an ongoing basis. The integration of academic and professional skills, as well as the relation to practically relevant challenges will make the program more appealing for students, and it will help them to become future problem solvers.
D. ***More explicit attention to research and design approaches:*** In the new curriculum, each module will (more) explicitly introduce specific research and design approaches in relation to the project themes. Students will fill their ‘IDE toolbox’ with expertise and experience, thus they will progressively be able to

formulate what research and design approaches are relevant to the different engineering design challenges they are working on.

E. ***Integrated academic and professional skills/competences:*** Students need academic skills to be successful in their learning. Professional skills prepare students for their futures as professionals. In each module, students work on these skills in the context of the module theme. The importance of the academic and professional skills/competences is reflected by their positioning in the modules, courses, and project learning outcomes and in their assessment.
F. ***Continuous reflection:*** Reflection is an important element of each module. The modules incorporate activities in which students reflect on the research and design approach(es) that have been introduced in this or previous modules. Also, reflection activities are planned for the academic and professional skills. At the beginning and at the end of each module, time is planned for explaining, discussing, and reflecting on how the intended learning outcomes of a module relate to the learning paths of individual students in relation to the programme outcomes, to previous modules, and to subsequent modules. The activities planned in the module result in contributions to the individual student portfolio that captures a student's identity and incites the development of a student throughout the entire bachelor program.

The guiding questions mentioned in section 3 have a clear relation to the principles mentioned here. For example, involvement and ownership of learning (A) and continuous reflection are strongly related to guiding question 1 - study for own development. Simultaneously, reflection (F) requires some distance, and therefore sufficient time to study - question 2. Question 1 also calls for the learning community (B) that is invested in, as students and staff working together strengthens a better understanding and ownership of the program, the activities, the outcomes and the mutual relations between these. In this, formative practices (question 3), are core to prepare students for real world issues (C), while employing academic and professional skills (E)."

The principles were important for the elaboration of the different steps in and levels of the development of the renewed curriculum: from the blueprint level to the design of learning activities, materials, teacher and student roles, resources, time, and assessment (Thijs & Van den Akker, 2009).

The blueprint made in 2022 included topics for each of the 12 modules in the 3-year programme, as well as proposed design and research approaches. Table 1 depicts the themes as well as the research and design approaches of each module.

Table 1. Themes and the research and design approaches of each module

Module	**1. Ideation**	**2. Prototyping**	**3. The human perspective**	**4. Mass-production**
Design approach	Diverging and Converging	Design for functionality	Iterative design, participatory design	Systematic design engineering
Research approach	Desk research	Experimental validation	Usability testing, user evaluation	Market research, text
Module	**5. Data driven design**	**6. Design for value**	**7. Sustainable futures**	**8. Product Service Systems**
Design approach	System thinking	Integrated product development	Tool & techniques	Grounded theory
Research approach	Technology adaption/ acceptance	Decision making	Analysis (LCA) and impact analyses	Desk research, structured interviews
Module	**9. Minor**	**10. Minor**	**11. Design for transitions**	**12. Bachelor Thesis**
Design approach			Futuring, participatory design	
Research approach			Research through design	

For each module, a design team has been established, and regular workshops have been organised in 2023 and 2024. Where the process of the curriculum renewal is very intensive, the module teams, together with the steering team meet in workshops every month, to further develop and detail the new program. In parallel to these content-oriented activities, a lot of more organisational and administrative preparations take place, for example in co-operation with the programme committee, the examination board, study-advisors, and educational support staff. In the spring of 2024, the proposal for the new curriculum is intensively discussed with the (newly installed) work-field committee, the faculty council, and the program committee, so that the first year of the new programme can start in the new academic year (24/25).

5. A TEACHING AND LEARNING COMMUNITY

Projects, courses and other TLAs carry the content of a curriculum, but the physical environment and facilities are also crucial to the success of the reformed programme and its teaching and learning community. Particularly for an academic programme such as IDE that is closely linked to (industrial) practice and constantly seeks to combine research and teaching, it is essential that students and staff can work together in dedicated and inspiring settings. This includes, for example, some kind of community space that challenges all stakeholders to focus on design processes at all stages and with all aspects - while transcending individual projects, courses, and student cohorts. In such a space, a contemporary master-apprentice approach (Lutters and Damgrave, 2023) plays an important role, while strengthening the learning and teaching community. Currently, a community space is being designed and its integration into the academic organisation, infrastructure and budget is being prepared. This master-apprentice approach also is a guiding principle in the development of a so-called learning factory (Abele et al 2024; Lutters and Damgrave, 2023) that is currently being built. This learning factory will include, for example, a metalworking shop floor, model making, woodworking and assembly environments, but also a virtual reality lab, a tinkering lab, and a rapid prototyping facility, as well as an environment for flexible production, assembly, and packaging lines. With its different environments, it integrates many themes, stakeholders, perspectives, and facets that make up a flexible, dynamic, and evolving production facility. As such, it will host a teaching, learning and research community for different disciplines and levels of aggregation - from first year students learning about production processes to PhD students focusing on topics such as factory layout. In this approach, both contribute to the formative practices that are mentioned in the guiding questions, as well as in creating an environment that helps students to study for own development.

6. IMPLEMENTATION

Presently, the programme reform is still in full swing, with the courses/projects in the first year already being detailed, whereas the learning activities for the second and third year are still defined at a more abstract level. An important change in the new planning of the reform is that the coherence of courses within the modules is improved, and as an effect of that, lesser courses per module are foreseen. This has a positive effect on the number of summative assessments and deadlines, which of course contributes to the “study-ability” of the program (see guiding question 2: sufficient time to study).

Working on so many inter-related changes requires strategies to control the quality. From the start of the reform trajectory, quality assurance and educational evaluation are integrated in the work of the steering committee and the module teams. After all, measuring and controlling the effectiveness and efficiency of a significant program overhaul, its facilities and its learning & teaching community is no simple task. For that, a purposeful set of metrics, methods, or approaches is needed. Consequently, in the program reform a pragmatic and straightforward approach, such as PDCA can be of great value to rely on available evaluation techniques from educational sciences, encompassing surveys, focus groups, panel meetings, expert visits, but also more quantitative/statistical tools to compare outcomes and results of the reformed program to the previous program.

One of the innovations that was observed as an essential element within the efforts to support students to study for own development is the implementation of so-called Development Coaches. Starting in September 2024, key staff of the programme will each guide a small group of students in group and individual sessions throughout their Bachelor. The main aim is to interact with the students on explicating their focus and reflection on the learning trajectory and their personalised formulation of their envisaged future learning goals. In this, students are supported and challenged to take (more) ownership in their learning process. This approach is seen as an exiting journey in which we, as a teaching community, also will learn a lot about our students, our programme, and probably: about ourselves.

Interesting in this respect is that all stakeholders in the IDE program, and especially teaching staff and students, have additional evaluation approaches to their avail. After all, IDE is a design program, which means that that the teaching staff and students foremost see the reform as a re-design project, which allows them to employ the entire toolbox of reflections, evaluations, and assessments that product designers habitually use in their design processes and in their interactions with 'the client'. Bringing together such tools from the IDE-field with the educational approaches enables a setup of comprehensive tests and evaluations to measure the success of the reformed program, to adjust the program based on the findings, and to prepare for continuous improvement as well as for staying up-to-date with technological and societal evolvements. Moreover, in the reform process, the amalgamation of design and educational evaluation approaches has already proven to be instrumental, for example, as it has been – and is – a very strong instigator in forming the teaching and learning community that will be the core of the reformed program.

7. CONCLUDING REMARKS

The curriculum reform for the IDE Bachelor Programme aligns with the objectives of the Ministry of Education's pilot for a smarter academic year. The program aims to improve student development, by programming in such a way that students are given sufficient time to study, by integrating formative practices, and by fostering a strong learning community. IDE aims to create a curriculum that prepares students to be responsible design engineers, well- equipped to address real-world challenges.

In the ongoing process of implementing the blueprint and curriculum reform requirements, experiences and educational research/evidence will be used to discuss and decide on how the program evolves in response to issues encountered. It is important to continue to implement the guiding principles in the courses and projects. For the modules of the first year in the programme, this implies that the plans are currently in the detailing phase, as the first module will start in September 2024. For these first modules, this implies that planning and decision-making has moved from tactical to operational level. As the new programme is implemented based on a rolling horizon, the other modules are still at more tactical level. The reasons relate to the available development and teaching capacity, to the time available, but certainly also to the opportunity to still learn from the findings of the commissioning of the modules in the first year. Our journey will provide relevant insights that also will be of interest for engineering programs that have similar ambitions. We are dedicated to systematically keep on learning and sharing our experiences with the engineering community.

REFERENCES

Abele, E., Metternich, J., Tisch, M., & Kreß, A. (2024). *Learning Factories - Featuring new concepts, guidelines, worldwide best-practice examples*. 2 ed., Switzerland: Springer Cham.

De Jonge Akademie (2021). *A Smarter Academic Year.* Amsterdam.

Dirkx, K., Joosten-ten Brinke, D., & Camp, G. (2010). *Ontwerprichtlijnen voor formatieve toetsen (Design Guidelines for Formative Assessments)*. Welten Instituut, Open Universiteit, Heerlen.

Eger, A.O., Lutters, D., & van Houten, F.J.A.M. (2004). "Create the future ": An environment for excellence in teaching future-oriented Industrial Design Engineering. *In Proceedings of the International Engineering and Product Design Education Conference*, September 2-3, 2004, Delft, The Netherlands.

NVAO. (2020, March 30). *B Industrial Design Engineering. Accreditation NL*. Retrieved from URL.

Lutters, E., Damgrave, R.G.J. (2023). Digital twinning as the basis for integration of education and research in a learning factory. *Procedia CIRP*, 120, 1463-1468.

Meijers, A.W.M., Overveld, C.W.A.M., & Perrenet, J.C. (2003). *Academic Criteria for Bachelor and Master Curricula*. Publisher: Technische Universiteit Eindhoven.

QANU. (2014). *Visitation Report of Industrial Design, Faculty of Engineering Technology, University of Twente.* Utrecht: QANU.

Ryan, R.M., & Deci, E.L. (2000). *Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being*. American Psychologist, 55, 68-78.

Thijs, A., & van den Akker, J. (Eds.). (2009). *Curriculum in Development.* Enschede: SLO Netherlands Institute for Curriculum Development.

UToday. (2023, 3, 30). *Opluchting over komst 'slimmer' collegejaar (Relief over arrival of 'smarter' academic year).* Retrieved from URL.

Van Houten, F.J.A.M. (2002). The development of a curriculum in industrial design. In *Proceedings of the First CIRP International Manufacturing Education Conference* (pp. 157–166). Enschede, The Netherlands: University of Twente.

Visscher-Voerman, J.I.A., & Muller, A. (2017). *Curriculum Development in Engineering Education: Evaluation and Results of the Twente Education Model (TOM).* In Proceedings of the 45th SEFI Conference, September 18-21, 2017, Azores, Portugal.

The contribution of Debate to Faculty Development: The Italian case study of the Faculty of Engineering at Cattaneo University

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ABSTRACT

Debate is a transversal, active, cooperative, and problem-based learning methodology and its use is positively and effectively documented also within the field of engineering education to boost transversal skills. The significant and acknowledged contribution to educational innovation that debate can offer in the current university context and in engineering education in terms of content learning and skill development, however, tends to overshadow its broader potential for Faculty Development. Assuming that Faculty Development can encompass at least broad dimensions such as professional, curricular, and institutional development, this article explores with a case study and qualitative methodology how debate can be fruitfully adopted for supporting Faculty Development in engineering faculties. The experiences conducted at the Faculty of Engineering of the Cattaneo University – LIUC – a systematic adoption of debate in didactics and a national university tournament on Sustainable Development Goals entitled *Debating Agenda 2030*, among others – show how debate can enrich Faculty Development by providing

opportunities for professional and curricular development while fostering learning and collaboration among students, institutions, and communities.

1 INTRODUCTION

In today's work-professional landscape, engineers are increasingly called upon to acquire soft and professional skills in addition to their solid technical knowledge base. These skills include critical thinking and problem-solving, effective communication, and teamwork and collaboration skills, among others (Klaassen, 2019; University College London, 2019; Winberg et al. 2020). However, integrating the development of transversal skills with technical specialization requires an innovative and as comprehensive as possible institutional approach so that the impacts are stable and widespread. This approach is not without challenges. This entails the introduction of innovative teaching and learning methodologies that integrate both technical content and transversal skills development. In this context, debate emerges as a promising approach because debate not only fosters these skills but can also serve as a tool for Faculty Development, helping to enhance teachers' ability to integrate transversal skills into the engineering curriculum as well as institutional development in terms of internal and external community building and relations. Therefore, this paper aims to investigate this relationship, seeking to answer the following research question: how can debate be fruitfully adopted for supporting faculty development in engineering faculties?

2 THE THEORETICAL FRAMEWORK

2.1 Debate methodology between traditional and innovative teaching approaches

Debate is a reasoned and regulated confrontation between two teams on a controversial topic before a panel of judges (Branham, 2013; Anonymous, 2014). It is a transversal teaching methodology, used at all educational levels and across disciplines. As an active method, it engages students in their learning process. It is cooperative, requiring student collaboration despite its competitive nature, and it is centered on problem-based learning, addressing significant, complex problems with no single solution (Freeley & Steinberg, 2013).Debate is promoted as an innovative teaching methodology, yet it has deep roots in Western culture, beginning with ancient Greek dialectical meetings codified by Aristotle in his book *Topics*. In the Middle Ages, debate became a key university teaching method through disputations, including public events like *quodlibetal disputations* (Novikoff, 2013). Since the 18th century, it has spread from Anglo-Saxon universities to global education systems, aimed at developing civic and soft skills (Potter, 1944; Snider and Schnurer, 2002).Currently in Italy, debate is promoted not only by the school government transformation movement *Avanguardie Educative* (INDIRE) but also by the Ministry of Education and Merit through the national competition for excellence, *Campionati Nazionali di Debate* and at university level, by non-governmental organization *Società Nazionale Debate Italia* (SNDI) which promotes the *Italian Youth Debate Championship - University*.

Since the 1980s, debate has shaped academic research by redefining objectives from developing transversal skills (Allen et al., 1999) to enhancing social and civic competencies and academic success (Mezuk et al., 2011; Rogers, Freeman, and Rennels, 2017). Currently, it focuses on assessing competencies in secondary and university education (Refrigeri and Russo, forthcoming), considering the impact of generative AI. But is debate adopted in engineering education, and if so, how?

2.2 Debate in engineering education

The adoption of the debate in engineering is attested in a variety of resources ranging from at least academic papers to international engineering associations or councils. Just as the resources are varied, the educational objectives for which debate is employed are diversified. This aspect demonstrates the versatility of the debate teaching method and offers significant information for reflection regarding its use in universities.

Debate in engineering education is primarily used for acquiring disciplinary and cultural knowledge. It is particularly emphasized in engineering ethics (Takanokura and Hayashi, 2007), as ethical dilemmas help students explore conflicts and apply lecture knowledge (Borgaonkar et al., 2020; Takanokura and Hayashi, 2008). Debate fosters understanding of the technology-society relationship by considering problems from multiple perspectives (Pellicer and López-Mateu, 2021) and encourages active citizenship (Holik, 2023). It is suitable for learning sustainability topics (Rodriguez-Dono and Hernández-Fernández, 2021) and all curricular engineering content (Alford and Surdu, 2002; Chang and Cho, 2010). Debate promotes active knowledge development (Jodłowski and Sztekler, 2017; Scholte, Vasileiadou, and Petersen, 2013) through research, discussion (Hassan, 2014), and increased motivation (Angeli et al., 2020; Hamouda and Tarlochan, 2015). Case studies enhance these processes by providing practical, dilemmatic situations for debate (Gravitt, 2017; Takanokura and Hayashi, 2007).

Debate facilitates the development of various skills, including high-level information research, technical skills, teamwork, time management, critical thinking, and oral and written expression in different languages (Buluev and Fedorov, 2015; Eunice and Pattawan, 2008; Gravitt, 2017; Kirkland et al., 2022; Pellicer and López-Mateu, 2021; Sidorenko and Rybushkina, 2014). It challenges students, including top performers, to step out of their comfort zones (Taly, 2018). By promoting argumentation and persuasive skills, debate enhances logical thinking, scientific understanding, and leadership abilities (Bruschke, 2016; Chang and Cho, 2010; Scholte, Vasileiadou, and Petersen, 2013). It is also an effective assessment method for argumentation, typically presented in written or monological forms (Mackay, Thomas Miller, and Benson, 2022). During the pandemic, debate proved valuable for skill development when online education risked becoming too lecture-based (Borgaonkar, Wang, and Sodhi, 2021; Heesun, 2021; Pellicer and López-Mateu, 2021). These skills, considered transversal competencies, are crucial for engineering education and are effectively promoted through debate (Rodriguez-Dono and Hernández-Fernández, 2021).As the research shows, the educational implications of debate are numerous. However, these studies often present debate as a methodology used by individual teachers or small groups rather than as a faculty-wide strategy. This narrow, compartmentalized approach overlooks many potential benefits, which are only evident in a few rare cases. For example, Crawley et al. (2014) view debate as a tool for cultural change and organizational development within universities, suggesting its use among faculty to address faculty development issues. Similarly, Gabriel et al. (2016) from the University of Aveiro's Department of Mechanical Engineering use debate in an open think-tank on engineering education, fostering face-to-face discussions among stakeholders. Given its limited presence in literature and the potential benefits of linking debate with faculty development, we advocate for a more inclusive Faculty Development framework for integrating and utilizing debate within universities.

2.3 The multiple dimensions of Faculty Development

In literature, «Faculty Development» encompasses many meanings. Not only it is referred to by various interchangeable terms. Fraser, Gosling and Sorcinelli (2010), for example, authors who have conducted research in the field of educational development across continents consider «faculty development» to be a synonym for expressions such as «academic development», «learning and teaching development», «education development» and «educational development» the latter being recognized by them as more suitable than «Faculty Development». But the translation is complex also because the referent itself is not fixed and is culturally and historically conditioned. Mary Deane Sorcinelli (2020) identifies an evolution of the construct from the *age of the academic*, referring mainly to practices improving and advancing academic competence in one's discipline through sabbaticals and scholarships for advanced degrees, to the *age of the network* in faculty, administrators, and institutions face increasingly higher challenges regarding individual learning and institutional development.

William Toombs (1975) elaborated comprehensive dimensions of Faculty Development along three axes: professional, curricular, and institutional. The professional dimension involves the academic role, its professionalization, and the need for continuous development. The curricular dimension focuses on teaching improvement through specific programs, emphasizing teaching effectiveness, student learning outcomes, and curriculum contributions to career objectives. The institutional dimension addresses the functioning of academic institutions, balancing academic, public, and managerial interests. Steinert et al. (2007) revisited Toombs' perspective, highlighting Faculty Development as a multifaceted process involving professional, curricular, and institutional aspects, with faculties being complex systems with multiple stakeholders. Faculty Development includes activities and actions that promote the renewal and development of skills and roles for university professors, aligning with student learning objectives (Lampugnani, 2020). It also entails a continuous process aimed at building internal communities (Eib and Miller, 2006; Morelock, Sochacka, and Walther, 2020) and engaging with the external community. Universities play a societal and economic role through knowledge transfer and transformation within their regions, (Moretti et al., 2021; Pee and Vululleh, 2020; Price et al., 2021).

3 THE EXPERIENCE OF LIUC UNIVERSITÀ CATTANEO

In order to answer to the research question – how debate can be fruitfully adopted for supporting Faculty Development in engineering faculties – the experience of LIUC Università Cattaneo is considered. In particular, assuming the categories hereby detailed and developed, we will illustrate two of the main activities carried out by the Engineering Faculty of the Cattaneo University LIUC related to debate adoption. The adopted methodological approach is the case study, an empirical inquiry that investigates a phenomenon within its real-life context. The case study method is not a method of data collection but a comprehensive research strategy to study in-depth a social unit involving multiple data sources such as questionnaires, surveys, in-depth interviews, participant or non-participant observation, and document analysis (Priya, 2021). The exploratory nature of the present case study, conducted between 2020 and 2023, is intended to tackle the research question introduced at the outset of this study, aiming to arrive at a provisional conclusion that remains contextually grounded and receptive to new, particularly more systematic, avenues for further investigation.

The LIUC - Cattaneo University was founded in 1991 by the initiative of the Industrial Union of the Province of Varese, Italy. Committed to the development and dissemination of knowledge and skills useful to businesses and institutions, LIUC offers courses in Business Economics and Organizational Engineering based on the real needs of companies. Since 2020, Cattaneo University LIUC has significantly invested in the development of debate, based on the potential of this methodology for Faculty Development. There have been various implementations and repercussions of this commitment, but for the sake of brevity, we will focus on the systematic adoption of debate in teaching and the *Debating Agenda 2030* tournament.

3.2 The systematic adoption of debate in curricular activities

In its strategic plan for Faculty Development 2021-2025 (Università Cattaneo LIUC, 2020), the Cattaneo - LIUC University has included debate in its engineering degree courses by heading it under 'didactics' to promote both innovative ways of conducting university teaching and transversal skills. Debate has found widespread use in extra-curricular teaching and in disciplinary teaching since 2021. In disciplinary teaching, debate has found use in the teaching of Ethics for Engineers, Technology and Law, Manufacturing Strategy and Systems Theory. To also demonstrate the versatility of this teaching method, debate has taken on different purposes and applications in each of the aforementioned subjects.

To prepare faculty members to organize and manage debate activities within the university and in their courses, several strategies were adopted. In January 2021, a training course on debate and its use was held, promoted by the University's Learning Teaching Hub and aimed at the entire faculty. Subsequently, the institution published a call for a three-year lecturer position to be assigned to a professor specialized in pedagogy with experience in debate methodology. This professional was tasked with developing debate activities and assisting faculty members in introducing debate into lectures. Faculty members interested in using debate were supported in various ways in the implementation of their activities, ranging from complete management of initiatives to targeted support aimed at fostering autonomy in the teaching methodology.

In Ethics for Engineers, aimed at bachelor's degree students, the debate was used to create a concrete context in which to address ethical dilemmas through argumentation and to apply, in debate preparation, some dilemma-solving procedures such as the ethical cycle (Van de Poel and Royakkers, 2007). The aim was therefore not to assess the acquisition of content but to experientially promote the application of content and skills for better learning. Specifically, the debates were conducted during the final four hours of a 24-hour course. Approximately the first half-hour was used to provide a simple and intuitively understandable overview of the phases, tasks, and roles that the students were expected to undertake. The next hour was dedicated to the students' autonomous preparation, divided into teams, for their respective positions. One and a half hours were allocated to the actual debate, and the remaining class time was used by the teacher to provide feedback on the arguments presented, the exchanges that took place, and the course material utilized or overlooked by the teams so as to promote metacognition and further learning. To make the debate more relevant to real-life situations, traditional motions such as "This house believes that medical doctors should be replaced by AI in disease detection and diagnosis" were replaced with cases providing more detailed contexts, such as "Imagine a rural community with limited access to healthcare services due to a shortage of medical professionals. In this scenario, the local clinic decides to implement AI technology for disease detection and diagnosis to improve healthcare outcomes for the residents [...] Would you support the introduction of AI technology?". In these cases, despite the lack of thorough debate preparation, the outcome was consistently appreciated by both the teacher and the students.

In Technology and Law, a course aimed at master's degree students, debates changed their aims over time. The first two years it was used at the end of each content module to consolidate learning but also to assess the students' learning to date. Last academic year, instead of using it at the end of each content module, the debate was employed before each content module. The rationale was to get the students to debate on topics they did not yet know in depth in order to bring out their naive pre-understandings or stereotypes and then to orient the teaching in such a way as to link it to the content emerged in order to relativise it, redefine it, revise it, and deepen and enrich it. Unlike the approach taken in the Ethics for Engineers course, the Technology and Law course provided an initial four-hour training session on debate. This session aimed to introduce students the pedagogical objectives of the method, the structure to be followed in each debate, principles of argumentation and non-verbal communication, and elements of rhetorical disposition to enhance students' understanding of structuring their discourse. Furthermore, for each edition of the course, three debates were conducted with the same group of students.

In the Manufacturing Strategy course aimed at master's degree students, debates were held in the form of a tournament consisting of 6/8 teams per years, each composed of 4 students, on the topics of Smart Factory or System Engineering. As explicitly stated in the course syllabus, debate was utilized to equip students with the ability to assess the advantages and disadvantages of automation choices, thereby enabling them to propose automation options suitable for both technical and human contexts of application and to defend these theses in front of a jury of experts from the corporate world, including general managers. The evaluation of the debate was carried out according to established practices for this type of competition, with a focus on the clarity of the arguments, persuasiveness and the ability to answer questions from the jury, which in this case could intervene and interact with the students. The activities concluded with high appreciation from the teachers, evaluators, and participating students. Finally, the Systems Theory course for master's degree students implemented debate in a teaching innovation game called *Hard Decisions*. The project led students from the faculty of Economics and Management and the faculty of Industrial Engineering to work together to find solutions to a difficult case study through non-traditional teaching methods and content. One instance of dilemma involved a company managing a social media platform, where significant dependency among younger and more vulnerable users was uncovered, was worded, at the end of the whole case, as following: "The Board of Directors must find a synthesis to submit to the approval of the Shareholders'

Assembly, deciding whether to maintain a successful and profitable business by simply adding a disclaimer to Pistagram's "Terms and conditions," or to temporarily close Pistagram and initiate a study to determine if and how the platform can be modified." Initially, teams, each focused on one of the two decisions, deepened their own position in preparation for debating with the opposing side. The second phase consisted of a debate with a simple structure and reduced intervention times per each student (2 minutes each). Through debate students determined which of the two alternatives, or what integration of the two positions, to develop in order to solve the assigned case. The third phase of developing the identified solution led to a final phase, which involved presenting the solution to the ideal Board of Directors, who could pose questions or objections and evaluate the work done. The *Hard Decisions* project aimed to experiment with inquiry-based learning, with an explicit focus on assisting students in developing critical thinking skills in gathering, analyzing, and synthesizing information on complex and controversial issues and their main positions. In contrast to previous didactic uses, debate assumed the role of a decision-making method extensively documented in the general literature (Cf. Ehninger and Brockriede, 2008; Freeley & Steinberg, 2013).

The questionnaire administered to seven faculty members involved in debate activities revealed both diversity and uniqueness in their usage and perspectives. Some instructors utilized debates exclusively within their courses, while others also employed them in extracurricular activities aimed at high school teachers. Nevertheless, all interviewed faculty members confirmed their intention to continue using debates in their activities, as they facilitate the development of presentation and project justification skills more effectively than other methodologies, help students understand legal concepts outside their engineering studies (as in the case of the Technology and Law course), and serve as a valuable strategy for classroom engagement. An interview with the instructor of the Ethics for Engineering course provided additional insights on this aspect: "Debate has helped restore student interaction, especially in the post-pandemic period, when students tended to apply remote work strategies even in in-person group activities, limiting direct exchanges among them. Moreover, in an elective course like mine, it has encouraged student participation, which often was confined to mere physical presence while they engaged in other activities on their laptops." The questionnaire also highlighted another interesting and counterintuitive aspect: The attempt to use debate as a tool to promote autonomous learning of course topics before exams was disastrous. This observation aligns with findings from the Technology and Law course, where debate, initially used as an assessment tool at the end of each module, was later employed as a method to prompt students to expose and reflect on their naïve conceptions and stereotypes before addressing the module content. Another significant result from the questionnaire is that debate prompted reflection and, in some cases, a change in teaching and learning concepts among the faculty. Debate was considered a coherent and excellent method for achieving situated learning; it made clear that instructors cannot take for granted certain argumentative skills they believed to be acquired, and it facilitated the adaptation of curricula not traditionally designed for engineering students. The faculty also perceived an improvement in teaching quality, as debate made the courses more focused on decision-making process objectives where applicable; increased awareness of the fragility of the argumentative processes often developed by students; and promoted the ambition to reach a higher level of competencies. This last aspect was also observed in anonymous teaching evaluation questionnaires administered by the University to assess the teaching quality, and completed by students before registering for exams, which included appreciative comments for an activity capable of developing useful skills and making students engaged, active, and involved in a course that initially did not attract them.

3.3 The experience of the *Debating Agenda 2030* project at Cattaneo University - LIUC

The *Debating Agenda 2030* project is a periodic event characterized by a course and a debate tournament dedicated to Sustainable Development Goals and aimed at all university students in Italy. The proposal of the tournament to all university students in Italy has allowed for the establishment of relationships between groups, student associations, and debate clubs initiated at other universities, but also to establish exchange relationships on the mutual practical applications of debate. These exchanges have been fundamental for reflecting on the project and for adapting the activity to the learning needs of students from different academic backgrounds. Opening the activity to students from other universities, and the focus on debate methodology mentioned, promoted the establishment of a collaboration with different non-profit organizations. The first organization involved was ASDUNI, the *Italian association for the development of learning and teaching in university*, which allowed for the enhancement of the activity at the university level. Focusing on Sustainable Development Goals has instead favoured cross-disciplinary learning, responding to the University's commitments in terms of raising awareness of sustainable development, involving expert faculty members through teaching interventions on the various Goals of the 2030 Agenda, and obtaining the patronage of ASviS, the *Italian Alliance for Sustainable Development* which contributed to the initiative with in-depth materials and publicizing the event.

The tournament preparation course promoted technological integration as it was conducted on the Moodle platform through materials accessible asynchronously and synchronously. The use of the e-learning platform favoured the creation of a repository of interchangeable and combinable materials with other educational activities of the university related to debate and argumentation as, among other examples, the project *Culture and business: debate experiences*, whose aim is to consolidate and expand the skills involved in the debate methodology through the discussion of a complex topic related to business culture. The *Debating Agenda 2030* course, had a duration of approximately one month for each edition. The course was structured into modules that were made available at regular intervals of one week, consisting of a pedagogical module, a regulatory module, an argumentative module, and a communicative module. Additionally, there was a section dedicated to the evaluation of the Debate as students were required to be familiar with the criteria upon which they would be assessed. All this was aimed at introducing students to the skills necessary for conducting a debate – professionalizing skills such as critical thinking, argumentation, public speaking, and teamwork – also involved introducing students to the British Parliamentary debate format, i.e., the protocol of the World Universities Debating Championships (WUDC). This characteristic allowed for collaboration with the SNDI APS, the national debate society, a non-profit organization that promotes debate from primary school to university and contributed with the intervention of some experts to introduce the rules of international tournaments and the management of the tournament. Regarding the collaboration with the University Cattaneo LIUC, the SNDI APS director stated in an interview that partnering with universities is essential, particularly within the Italian educational context where students require specific tools to cultivate skills such as critical thinking and problem-solving, which are often deficient upon graduating from high school. This is crucial not only for the students but also for society at large, as it benefits individuals and future workers.

The hybrid tournament (online selections and final in-person event), on the other hand, aims to create an authentic and interactive learning context on specific themes of Agenda 2030, environmental sustainability, and social responsibility, as well as to serve as a laboratory for exercising the soft skills promoted in the course. One of the characteristics of this methodology is that it involves a panel of judges, composed also of specially qualified faculty, which provides expert formative evaluation of the interventions and interactions carried out by the students. The *Debating Agenda 2030* tournament also takes place periodically on different Sustainable Development Goals in order to ensure the in-depth exploration, from one edition to another, of the various and heterogeneous topics. The various editions of the tournament phase lasted approximately one and a half months, involving both an elimination phase and a final phase where the top four teams from the eliminations competed directly against each other.

4 DISCUSSION AND CONCLUSION

The provisional conclusion of the case study conducted between 2021 and 2024 among a subset of the overall debating activities carried out at the Cattaneo University - LIUC is that debate methodology can contribute to Faculty Development. Debate is not only properly considered among the methods with high potential to innovate university teaching, still often confined to a transmissive didactic model, but it can also allow the creation of educational and didactic contexts that are integrative or complementary to disciplinary courses. Furthermore, as indicated by the questionnaires administered to the involved teachers, the debate has led them to alter their conception of teaching and learning. This process has facilitated the identification of some of their preconceptions and has also driven them towards a more ambitious pedagogy in terms of the cognitive processes activated in students. As a final point, its confrontational and interpersonal features as well as the various dimensions that the debate method manages to intertwine promote institutional development in terms of internal and external community building and relations.

More in depth, the systematic integration of debate into teaching, aimed at fostering innovative teaching approaches and combine the development of transversal skills with technical specialization, has highlighted how the debate methodology can find consistent application across various technical and social disciplines such as ethics, law, industrial engineering, and statistics. This versatility extends beyond its ability to be adopted for any problematic topic, but also encompasses the multitude of functions it can serve, such as addressing dilemmas and case studies, promoting practical application of content and skills, fostering interaction between students and industry professionals, or serving as a decision-making method. Another aspect explored in our investigation is the *Debating Agenda 2030* activity, a themed tournament focusing on the Sustainable Development domain and its instructional implications. This type of activity has facilitated the establishment of connections among student groups, associations, and debate clubs from other universities, as well as collaborative relationships with national professional and social organizations interested in these issues, their social impact, the methodology employed, or educational innovation in universities. Currently, this particular application of debate is catalyzing the creation of a network among various universities sharing the common goal of supporting a sustainability-oriented approach and integrating transversal and technical skills.

The impacts and implications of these activities and approaches clearly highlight both how the debate methodology can positively contribute to Faculty Development and how this can occur. Specifically, it emerges that debate can not only intervene in the professional and curricular dimension, as one might intuitively imagine, and how this happens, but also operates on the institutional dimension of Faculty Development, which pertains to the balancing among academic interests, public interest, and managerial interests within the institution. This overall, institutional convergence around the debate of the faculty as a whole places a greater emphasis on the development of transversal skills of the engineer. Moreover, the systematic adoption of debate in instruction and the *Debating Agenda 2030* tournament are just some of the ways debate has been institutionalized at the Cattaneo University - LIUC, allowing us to consider that our conclusions can be strengthened and expanded. Nevertheless, they enable the integration and opening of new research perspectives in the study of debate and Faculty Development for engineering faculties, which the literature does not seem to consider except in rare cases (Cfr. Crawley et al., 2014; Gabriel et al., 2016).

The research conducted, however, is subject to significative limitations that stem primarily from its methodological approach. While the case study method can indicate how debate can be used to promote Faculty Development, the response to the logically prioritized assertion that debate is effective for Faculty Development is less solid and would require a different method to be rigorously consolidated and evidence-based. Indeed, not only does this type of intervention appear unprecedented in the literature, which led to an exploratory qualitative design when analyzing the teaching quality evaluation questionnaires, but the types of activities carried out, of which this article only summarizes two, were also diverse (didactic use, debate club, debate tournament, etc.). Moreover, the limited sample size observed is due to significant factors that must be considered and articulated regarding the debate methodology. The first factor concerns the substantial amount of instructional hours that debate exercises take away from traditional teaching, which not all educators are willing to sacrifice. The second factor pertains to the complexity and organizational effort required to arrange meetings or tournaments, which takes time away from the teachers' research activities. Finally, there is a prejudice against this methodology, often viewed as a simple game or as promoting relativistic or superficial personal epistemologies (see Anonymous, 2024). Therefore, the conclusions drawn from this investigation may not be considered as endpoints but rather as starting points for further research and the establishment of new research avenues. Another limitation of this study is its failure to encompass the numerous activities in which debate has been applied within the Cattaneo University - LIUC due to their heterogeneity and multitude. Examples include: the university debate club, which brings together engineering and economics students, interacts with other debate clubs by participating in national and international tournaments, and allows for the attainment of an open badge attesting the acquired transversal skills; the adoption for foreign language learning, which spans both disciplinary and extracurricular activities. Indeed, in its faculty development strategic plan, the University Cattaneo - LIUC has in fact included the debate to promote transversal skills and the placement of graduates in the labour market; to use teaching methodologies to develop critical thinking and integrate ethics with technology; to implement the internationalisation of the institution through student exchanges, building relations with foreign universities and participation in projects beyond the academic sphere; to involve the LIUC in the network of national and international debate networks and the enhancement of associations that collaborate with the LIUC itself. And what is most important is that such flexibility in applications seems to be limited only by the creativity and initiative of teachers or administrators.

REFERENCES

Alford, Kenneth L., and John R. Surdu. "Using in-class debates as a teaching tool." In *32nd Annual Frontiers in Education*, vol. 3, pp. S1F-S1F. IEEE, 2002. https://doi.org/10.1109/FIE.2002.1158634

Allen, Mike, Sandra Berkowitz, Steve Hunt, and Allan Louden. "A meta-analysis of the impact of forensics and communication education on critical thinking." *Communication Education* 48, no. 1 (1999): 18-30. https://doi.org/10.1080/03634529909379149

Angeli, Lorenzo, Massimiliano Luca, Chiara Grossi, Francesca Fiore, Andrea Capaccioli, Andrea Guarise, Milena Stoycheva, and Maurizio Marchese. "Prove me wrong! how debating becomes the secret weapon to teach ict students innovation and entrepreneurship." In *2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, pp. 173-180. IEEE, 2020. https://doi.org/10.1109/TALE48869.2020.9368481

Anonymous. "The impact of competitive debate on managing the conflict communication strategies of Italian students." *Argumentation and Advocacy* 51, no. 2 (2014): 123-131. https://doi.org/10.1080/00028533.2014.11821843

Anonymous, "Le epistemologie personali dei partecipanti alle pratiche di Debate." In *Le emergenze nella formazione L'innovazione della ricerca educativa: i drammi del presente e le sue risorse*, edited by Anita Gramigna and Rita Minello, 333-340. Lecce: Pensa MultiMedia, 2024. https://www.pensamultimedia.it/libro/9791255681076

Borgaonkar, Ashish D., Chizhong Wang, Moshe Kam, and Jaskirat Sodhi. "Getting Students to Explore Engineering Ethics through Debate-Style Presentations." Paper presented at 2020 First-Year Engineering Experience, East Lansing, Michigan. 2020. https://doi.org/10.18260/1-2--35765

Borgaonkar, Ashish D., Jaskirat Sodhi, and Chizhong Wang. "Embedding Engineering Ethics in Introductory Engineering Courses using Stand-Alone Learning Modules." Paper presented at Middle Atlantic ASEE Section Spring 2021 Conference. 2021. https://doi.org/10.18260/1-2--36298

Branham, Robert James. *Debate and critical analysis: The harmony of conflict*. Oxfordshire: Routledge, 2013.

Bruschke, Freddi-Jo Eisenberg, “Using Debate to Improve Scientific Reasoning.” In *Using debate in the classroom: encouraging critical thinking, communication, and collaboration*, edited by Davis, Karyl A., M. Leslie Wade Zorwick, James Roland, and Melissa Maxcy Wade, 83-94. New York: Routledge, 2016.

Buluev, I. I., and E. A. Fedorov. “Debate Course for Engineering Students.” In *Коммуникативные аспекты языка и культуры*, pp. 37-39. 2015. https://www.elibrary.ru/item.asp?id=24929241&pf=1https://core.ac.uk/download/pdf/53082329.pdf

Chang, Kyungwon, and M. H. Cho. “Strategy of selecting topics for debate teaching in engineering education.” *Religion* 30, no. 50 (2010): 2016.

Crawley, Edward, Johan Malmqvist, Soren Ostlund, Doris Brodeur, and Kristina Edstrom. *Rethinking engineering education. The CDIO approach*. Switzerland: Springer, 2014.

Ehninger, Douglas, and Wayne Brockriede. *Decision by debate*. New York: IDEA, 2008.

Eib, B. J., and Pam Miller. “Faculty development as community building.” *International Review of Research in Open and Distributed Learning* 7, no. 2 (2006): 1-15. https://doi.org/10.19173/irrodl.v7i2.299

Eunice, Aclan, and Pattawan Jimarkon. “What do you mean Engineering students can’t debate?” 2008. http://dspace.unimap.edu.my/bitstream/handle/123456789/5837/WHAT%20DO%20YOU%20MEAN%20ENGINEERING%20STUDENTS%20CAN%E2%80%99T%20DEBATE.pdf?sequence=1

Fraser, Kym, David Gosling, and Mary Deane Sorcinelli. “Conceptualizing evolving models of educational development.” *New directions for teaching and learning* 2010, no. 122 (2010): 49-58. https://doi.org/10.1002/tl.397

Freeley, Austin J., and David L. Steinberg. *Argumentation and debate*. Boston: Cengage Learning, 2013.

Gabriel, Bárbara, António Andrade-Campos, João Dias-de-Oliveira, Robertt Valente, and Victor Neto. “Open think-tank on engineering education: A forum of “face-to-face “ debate between stakeholders.” In *2016 2nd International Conference of the Portuguese Society for Engineering Education (CISPEE)*, pp. 1-8. IEEE, 2016. https://doi.org/10.1109/CISPEE.2016.7777744

Gravitt, Denise Diana. “Using Debate as an Inductive Learning Technique with Construction Case Studies.” In *2017 ASEE Annual Conference & Exposition*. 2017. https://peer.asee.org/using-debate-as-an-inductive-learning-technique-with-construction-case-studies.pdf

Hamouda, A. M. S., and F. Tarlochan. “Engaging engineering students in active learning and critical thinking through class debates.” *Procedia-Social and Behavioral Sciences* 191 (2015): 990-995. https://doi.org/10.1016/j.sbspro.2015.04.379

Hassan, Firas. "A Student Led Debate about Pros and Cons of CDMA and OFDM." Paper presented at 2014 ASEE NCS Conference, Oakland University, April 2014. https://asee-ncs.org/wp-content/uploads/2021/12/proceedings/2014/Paper%20files/aseencs2014_submission_86.pdf

Heesun, Shin. "Critical Thinking and Debate Education under Non-Face-to-Face Situation-Through Online classes for Freshmen at the Engineering College." *Journal of Engineering Education Research* 24, no. 1 (2021): 34-45. https://doi.org/10.18108/jeer.2021.24.1.34

Holik, Ildikó. "Preparing Engineering Teacher Students for the Challenges of Vocational Training." In *Learning in the Age of Digital and Green Transition. Proceedings of the 25th International Conference on Interactive Collaborative Learning (ICL2022)*, edited by Michael E. Auer, Wolfgang Pachatz and Tiia Rüütmann, 328-337. Switzerland: Springer, 2022.

Jodłowski, Grzegorz S., and Karol Sztekler. "Oxford-style debate as a tool of engineering learning in the teachers practice." In *2017 IEEE Global Engineering Education Conference* (EDUCON), pp. 1868-1870. IEEE, 2017. https://doi.org/10.1109/EDUCON.2017.7943106

Kirkland, Ashleigh, Cornelius Paardekooper, Joshua Flynn, Dylan Cuskelly, Elena Prieto-Rodriguez, William McBride, and Alexander Gregg. "Scalable vivas: Industry authentic assessment to large cohorts through "debate club" tutorials." In *33rd Australasian Association for Engineering Education Conference (AAEE 2022): Future of Engineering Education*, pp. 602-610. Sydney: Australasian Association for Engineering Education (AAEE), a Technical Society of Engineers Australia. 2022.

Klaassen, Renate, M. Van Dijk, R. Hoope, and A. Kamp. "Engineer of the Future–envisioning higher engineering education in 2035." *TU Delft* (2019). https://www.4tu.nl/cee/Publications/engineer-of-the-future.pdf

Lampugnani, Paola Alessia. "Faculty Development. Origini, framework teorico, evoluzioni, traiettorie." In Lotti A., Lampugnani P.A. editors *Faculty Development in Italia. Valorizzazione delle competenze didattiche dei docenti universitari*, 27-40. Genova: GUP, 2020. https://gup.unige.it/sites/gup.unige.it/files/pagine/Faculty_Development_in_Italia_ebook_indicizzato.pdf

Mackay, Isobel, Thomas Miller, and G. H. Benson. "Enhancing student communication skills via debating Engineering Ethics." In *SEFI 2022-50th Annual Conference of the European Society for Engineering Education, Proceedings*, pp. 1340-1348. SEFI, 2022. https://doi.org/10.5821/conference-9788412322262.1207

Mezuk, Briana, Irina Bondarenko, Suzanne Smith, and Eric Tucker. "Impact of participating in a policy debate program on academic achievement: Evidence from the Chicago Urban Debate League." *Educational Research and Reviews* 6, no. 9 (2011): 622.

Morelock, John R., Nicola W. Sochacka, and Joachim Walther. "Building communities of engineering faculty, staff, and students engaged in educational research: The approach of UGA's Engineering Education Transformations Institute." *Journal of Higher Education Theory and Practice* 20, no. 12 (2020).

Nadeu Camprubí, Climent, José B. Mariño Acebal, and Mireia Farrús. "Learning engineering ethics by debate." In Fabregat J, editor. *ICEHVE 2008: International Conference on Ethics and Human Values in Engineering*; 2008 Mar 5-7.

Novikoff, Alex J. *The medieval culture of disputation: Pedagogy, practice, and performance*. Philadelphia: University of Pennsylvania Press, 2013.

Pee S, Vululleh N. "Role of universities in transforming society: challenges and practices." In: Sengupta E, Blesinger P, Mahoney C, editors. *International perspectives on policies, practices and pedagogies for promoting social responsibility in higher education (innovations in higher education teaching and learning)*, vol. 32. Leeds: Emerald Publishing Limited; 2020. p. 67–79. https://doi.org/10.1108/S2055-364120200000032005

Pellicer, Teresa M., and Vicente López-Mateu. "The Academic Debate as a tool to develop soft skills in Civil Engineering Master teaching." In *ICERI2021 Proceedings*, pp. 7324-7332. IATED, 2021. https://doi.org/10.21125/iceri.2021.1644

Potter, David. *Debating in the Colonial Chartered Colleges: An Historical Survey, 1642 to 1900*. New York: Teachers College, 1944.

Price, Elizabeth AC, Rehema M. White, Kate Mori, James Longhurst, Patrick Baughan, Carolyn S. Hayles, Georgina Gough, and Chris Preist. "Supporting the role of universities in leading individual and societal transformation through education for sustainable development." *Discover Sustainability* 2, no. 1 (2021): 49. https://doi.org/10.1007/s43621-021-00058-3

Priya, Arya. "Case study methodology of qualitative research: Key attributes and navigating the conundrums in its application." *Sociological Bulletin* 70, no. 1 (2021): 94-110. https://doi.org/10.1177/0038022920970

Refrigeri, Luca, and Noemi Russo. "Il contributo della pedagogia alla valutazione degli apprendimenti attraverso il Debate." *RicercAzione*. Forthcoming

Rodriguez-Dono, Alfonso, and Antoni Hernández-Fernández. "Fostering Sustainability and Critical Thinking through Debate—A Case Study." *Sustainability* 13, no. 11 (2021): 6397. https://doi.org/10.3390/su13116397

Rogers, Jack E., Nicole PM Freeman, and Arthur R. Rennels. "Where are they now (?): Two decades of longitudinal outcome assessment data linking positive student, graduate student, career and life trajectory decisions to participation in intercollegiate competitive debate." *National Forensic Journal* 35, no. 1 (2017): 5.

Schmidt, Taly. "DEBATE. " *ASEE Prism* 27, no. 8 (2018): 40-43.

Scholte, Samantha, Eleftheria Vasileiadou, and Arthur C. Petersen. "Opening up the societal debate on climate engineering: how newspaper frames are changing." *Journal of integrative environmental sciences* 10, no. 1 (2013): 1-16. https://doi.org/10.1080/1943815X.2012.759593

Sidorenko T. V., Rybushkina S. V. “Debates as a mean to develop meta-subject competencies of technical students in learning foreign languages.” *Novosibirsk State Pedagogical University Bulletin*, 2014, vol. 4, no. 6, pp. 7–21. http://dx.doi.org/10.15293/2226-3365.1406.01

Snider, Alfred, and Maxwell Schnurer. *Many sides: Debate Across the Curriculum*. New York: IDEA, 2002.

Sorcinelli, Mary Deane. “Fostering 21st century teaching and learning: new models for faculty professional development.” In Lotti A., Lampugnani P.A. editors *Faculty Development in Italia. Valorizzazione delle competenze didattiche dei docenti universitari*, 19-25. Genova: GUP, 2020. https://gup.unige.it/sites/gup.unige.it/files/pagine/Faculty_Development_in_Italia_ebook_indicizzato.pdf

Steinert, Yvonne, Richard L. Cruess, Sylvia R. Cruess, J. Donald Boudreau, and Abraham Fuks. “Faculty development as an instrument of change: a case study on teaching professionalism.” *Academic medicine* 82, no. 11 (2007): 1057-1064. https://doi.org/10.1097/01.ACM.0000285346.87708.67

Takanokura, Masato, and Shigeo Hayashi. “A Debate Exercise for Practical Education of Engineering Ethics.” *Journal of JSEE* 55, no. 5 (2007): 40-47. https://doi.org/10.4307/jsee.55.5_40

Takanokura, Masato, and Shigeo Hayashi. “Educational effects of practical education using a debate exercise on engineering ethics.” *Journal of JSEE* 56, no. 2 (2008): 8-13. https://doi.org/10.4307/jsee.56.2_8

Toombs, William. “A three-dimensional view of faculty development.” *The Journal of Higher Education* 46, no. 6 (1975): 701-717. https://doi.org/10.1080/00221546.1975.11778670

Università Cattaneo - LIUC. “Piano strategico 2021-25”. 15 December 2020. https://www.liuc.it/wp-content/uploads/Piano_strategico_2021-25.pdf

University College London, *Innovations in Engineering Education Inspiring & Preparing Our Engineers for the 21st Century*, (2019). https://www.ucl.ac.uk/centre-for-engineering-education/sites/centre-for-engineering-education/files/ucl_cee_lrf_report_0.pdf

Van de Poel, Ibo, and Lamber Royakkers. "The ethical cycle." *Journal of Business Ethics* 71 (2007): 1-13. https://doi.org/10.1007/s10551-006-9121-6

Winberg, Christine, Mike Bramhall, David Greenfield, Patrick Johnson, Peter Rowlett, Oliver Lewis, Jeff Waldock, and Karin Wolff. "Developing employability in engineering education: a systematic review of the literature." *European Journal of Engineering Education* 45, no. 2 (2020): 165-180. https://doi.org/10.1080/03043797.2018.1534086

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ABSTRACT

Being one of the visions of the European University Alliance ENHANCE, the Massive Open Online Course (MOOC) “Responsible Innovators of Tomorrow” was developed by the Chair of Gender and Diversity in Engineering (GDI) at RWTH Aachen University to drive responsible social transformation. The MOOC integrates the expertise of various European experts and contexts to offer students an interdisciplinary and holistic perspective on current topics in Responsible Research and Innovation and Science and Technology Studies. Intended for mandatory integration in all Bachelor curricula of the ten ENHANCE universities, the MOOC is one step towards a broad introduction to Future Skills in technical study programs. This practice paper describes the process of development and implementation as well as our experiences with conceptualizing and implementing the MOOC at the European level to guide future similar projects.

1 INTRODUCTION

Given the global challenges addressed, for example, in the Sustainable Development Goals (SDGs), engineers as drivers of much-needed innovations must be enabled to fulfill their responsibilities towards the environment, economy, and society (Tassone et al. 2018; Owens 2017; Crawley et al. 2007). As the addressed challenges are 'wicked problems' that arise at the intersection of societal, environmental, and economic factors, engineers can only use their innovative potential if they can conceptualize this complexity holistically (United Nations 2017).

Thereby, universities play a central role as drivers of innovation (Owens 2017) by teaching relevant skills such as problem-solving, collaborative work, or critical thinking (Thomas 2009; Puente et al. 2021). Due to the complex and interrelated nature of the addressed challenges, universities can contribute to training responsible innovators of tomorrow by fostering inter- and transdisciplinary education and cooperation, which is cited as a key factor of success when addressing such challenges (United Nations 2017). Engineering education therefore should include technical skills as well as social and ecological future skills (Stifterverband and McKinsey 2021) which are in line with the EU framework “Industry 5.0, a transformative vision for Europe” (Renda et al. 2021) and the “Responsible Research and Innovation” (RRI) framework (Schomberg 2013).

Given the need for inclusive and sustainable research and education, the RRI Hub (RWTH Aachen University 2022), anchored at the Chair of Gender and Diversity in Engineering at RWTH Aachen University, developed the Massive Open Online Course (MOOC) “Responsible Innovators of Tomorrow” (edX 2024b) in the context of the European ENHANCE Alliance (ENHANCE Alliance 2024b) of ten leading technical universities in Europe. The course aims to provide students with the necessary knowledge and skills to act as responsible innovators. The MOOC was published in April 2023 and has since been accessible to students from all ENHANCE universities and the general public –intended to be anchored as a compulsory course in all Bachelor’s degree programs at ENHANCE universities.

In this practice paper, we describe our experiences and learnings from designing and implementing a European MOOC across ten technical universities. We report on conceptual and structural challenges and make recommendations for establishing a European MOOC.

1.1 European Integration within the ENHANCE University Alliance

The European ENHANCE Alliance was founded in 2020 and is co-funded by the European Union (European Commission 2024b) to create an innovative European university where students are empowered to reflect on European values, including democracy, equality, and respect for human rights. With ten leading European Universities of Technology as members, ENHANCE envisions “to drive responsible social transformation” and “turning global challenges into opportunities” (ENHANCE Alliance 2024a). Since November 2022, the following ten universities are part of the alliance: Chalmers Tekniska Högskola AB, Eidgenössische Technische Hochschule Zürich, Politechnika Gdańska, Norges Teknisk-Naturvitenskapelige Universitet, Politecnico di Milano, Rheinisch-Westfälische Technische Hochschule Aachen, Technische Universität Berlin, Technische Universiteit Delft, Universitat Politècnica de València, Politechnika Warszawska (ENHANCE Alliance 2024c).

ENHANCE focuses on three pilot topics: Digitalization and Artificial Intelligence (AI), Sustainable Cities and Communities, and Climate Action, all of which are among society's most pressing challenges. To address these, the alliance seeks to innovate in the domain of higher education by encouraging inter- and transdisciplinary collaboration, engagement, and empowerment of students and academic staff. In particular, it seeks to create mobility, collaboration, and learning opportunities among all university members.

Within the ENHANCE alliance, students shall work with society and industry to understand the complexities of science, technology, society, and environmental interconnections at a European level to “help build a joint European sphere of knowledge” (ENHANCE Alliance 2024a). Our MOOC addresses this in two ways: First, it is supposed to be made eligible for all students from the ten European technical universities: It shall be anchored in all Bachelor curricula from all ten ENHANCE universities as a mandatory course. Second, to map current challenges and different realities of European countries and regions, the MOOC’s contents were designed by experts from the ENHANCE universities. Up to now, 33 videos have been recorded from Rheinisch-Westfälische Technische Hochschule Aachen, Technische Universität Berlin, Chalmers Tekniska Högskola AB, Politecnico di Milano, Universitat Politècnica de València, and Technische Universiteit Delft.

1.2 Holistic Learning Through MOOCs

MOOCs represent a pivotal component in advancing digital education and skill development as they offer accessible, flexible, and (often) interdisciplinary learning opportunities, aligning with the goals of SDG 4, while promoting digital inclusion and fostering lifelong learning (Sosa-Díaz and Fernández-Sánchez 2020; Voudoukis and Pagiatakis 2022; Patru and Balaji 2016). Further, they provide individuals with the chance to acquire digital skills, engage in innovative learning experiences, and adapt to evolving demands in the digital economy (Alraimi, Zo, and Ciganek 2015). Moreover, MOOC platforms contribute to democratizing education by breaking down geographical barriers and offering diverse learning pathways tailored to individual needs (Sosa-Díaz and Fernández-Sánchez 2020; UNESCO 2023). Accordingly, by integrating MOOCs into educational strategies, educators and learners can use these resources to enhance digital competencies, promote collaborative problem-solving, and prepare for the challenges and opportunities of the digital age.

The European Commission's Digital Action Plan 2021-2027 (European Commission 2024a) addresses the learning foundations for navigating this increasingly digital world. By emphasizing digital skills and inclusion, it recognizes the importance of fostering digital literacy and proficiency as essential competencies for student agency and transformational skills. Through initiatives promoting interdisciplinary thinking and developing critical problem-solving skills, the Digital Action Plan contributes to shaping a future-ready workforce capable of thriving in the digital age.

This is particularly in line with the OECD's vision for holistic learning. The OECD Learning Compass 2030 (OECD 2019) guides education systems and stakeholders worldwide to promote holistic and future-oriented education. Its transformative endeavor identifies necessary elements of knowledge, skills, attitudes, and values that students need to actively participate in shaping a positive future as responsible innovators of tomorrow. For this, it names various elements such as student agency, transformation competencies, learning foundations, knowledge, skills, attitudes, and values, as well as the anticipation-action-reflection cycle. This shall enable learners to develop responsible and purposeful personalities who can continuously develop and positively influence their environment by critically analyzing and evaluating alternatives from an ethical point of view (OECD 2019).

2 THE MOOC "RESPONSIBLE INNOVATORS OF TOMORROW"

A holistic learning concept is crucial to recognize the multidimensional nature of education (Mahmoudi et al. 2012; Miller 2000; Miseliunaite, Kliziene, and Cibulskas 2022). It acknowledges that learning goes beyond acquiring facts and figures, encompassing the development of critical thinking skills, emotional intelligence, and a sense of responsibility (Mahmoudi et al. 2012). By integrating various subjects, perspectives, and skills, a holistic approach prepares students to navigate the complexities of the modern world. It fosters interdisciplinary thinking, problem-solving abilities, and empathy – essential qualities for success in both personal and professional spheres. Moreover, a holistic learning approach cultivates lifelong learners who are adaptable, creative, and capable of thriving in diverse environments (OECD 2019). Furthermore, holistic learning can address the diverse needs and aspirations of learners in the digital age and integrate visions of Industry 4.0 to bridge the gap between Industry and Education (Koul and Nayar 2021).

Therefore, the content of our MOOC is structured according to the OECD Learning Compass 2030 (OECD 2019) to offer a didactically future-oriented teaching and learning concept. To achieve the necessary knowledge, skills, and attitudes, the Learning Compass proposes a so-called anticipation, action, and reflection cycle (AAR cycle) to foster the development of transformational competencies that enable learners to adapt to change, think creatively, and actively contribute to shaping the future. The cycle is an iterative learning process in which students continuously improve their thinking, act responsibly, and contribute to collective well-being through anticipation, action, and reflection. In the first phase, *anticipation*, learners consider how their actions today may affect the future. To do so, learners try to anticipate short and long-term consequences of actions, to understand their own and others' intentions, and to broaden their own and others' perspectives. In the *action* phase, learners develop the will and ability to direct their actions towards general well-being. Actions in the action phase can relate to research, taking responsibility, creating new values, or implementing change. These actions can be individual, joint, or collective. In the *reflection* stage, learners improve their thinking, leading to better advocacy for their well-being and the well-being of society and the environment. In this phase, learners train their thinking, which leads to a deeper understanding and better actions in terms of well-being. As a result, learners gain awareness of the possibility of shaping their future actions – and a sense of direction, which in turn promotes agency development.

We designed the MOOC with respect to these three phases in accordance with the three ENHANCE pilot topics: Digitalization and AI, Climate Action, and Sustainable Cities and Communities. The resulting structure is depicted in Figure 1.

Fig. 1. Content of the MOOC structured according to the OECD Learning Compass

To train students to be responsible innovators of tomorrow, they must be enabled to identify wicked problems and develop solutions. For this purpose, they must have fundamental knowledge of topics addressing future skills such as RRI, ethics and gender, and diversity competencies. With this knowledge, students can learn how to respond to the questions and challenges of the second phase in an action-oriented manner based on the ENHANCE pilot topics. Thus, sustainable and social innovation, social responsibility, digitalization, and AI are addressed in the action phase. This is followed by a reflection phase in which the students, guided by the SDGs, reflect on today's challenges and possible action strategies.

Every module comprises video lectures, scientific texts, and additional material like web links or journal articles implemented in a platform-based e-learning environment (edX). The course is designed for a nine-week program with a learning effort of eight hours per week plus an additional 18 hours for final examination preparation. After completing the course, the students should know the Sustainable Development Goals, define different dimensions of sustainability, and understand the relation of their field to sustainable development. Further, they shall understand the relevance of interdisciplinary work and the importance of considering gender and diversity perspectives in research and innovation. They understand the connection between sustainability and their personal and social responsibility as future innovators. In addition, they can explain the concept of RRI, the relationship between technical and social innovation, and their importance in solving global challenges. They can evaluate ethical aspects within their specialization and feel confident dealing with (digital) challenges. A weekly quiz supplements every week's learning by reflecting on the learned content. After completing the whole course, a final exam is aimed at assessing the learning outcomes of the whole course.

3 EXPERIENCES AND RECOMMENDATIONS

This section elaborates on our experiences and lessons learned when planning, designing, and implementing a European MOOC in collaboration with different technical universities to inspire similar future projects.

1) *The MOOC-Concept – Communication and Coordination at European Level*

As part of the conceptualization of our European MOOC, we developed a novel democratic, participatory, and agile teaching concept in line with the ENHANCE network's goal of strengthening European values. Careful planning was required to establish a teaching concept that addresses global challenges related to the SDGs and allows scientists from all universities in the network to participate, supporting the collaborative European education of responsible innovators of tomorrow. Extensive analysis and conversation were required to achieve consistent knowledge without redundancy or alienation of students at any of the member universities. This involved considering different levels of cultural and social influences, too. We have invited academics from all Alliance universities to participate in producing learning content in line with the idea of participatory democratization. This has required efforts in coordination and communication across national and linguistic boundaries. In addition, a uniform design had to be created, implemented, and synchronized with various national or university designs. Despite being a challenge, this allowed for establishing a shared European level of knowledge.

2) *Agile Learning for European Students*

To cater to varying levels of knowledge and promote skill development, we have provided general introductory videos and the option to create additional videos. These videos can cover more specialized topics or showcase scientists' research. This approach opens up a common European horizon, allowing students to learn together at a shared level. The responses of ENHANCE colleagues were positive, and there was great interest in participating in the MOOC. Due to the time constraints of production in the various countries, we decided to finalize the first version and will add more contributions in the second round. Overall, the MOOC already contains videos from almost all alliance universities. Thanks to the agile concept and the possibility of adding additional videos to edX at any time, it is also possible to keep expanding the MOOC.

In terms of the teaching format's agility, one challenge during the course design was to transfer the teaching and learning concept of the OECD Learning Compass into the digital teaching format of a MOOC. In particular, mapping the action phase was a challenge to realize in a solely online format. In future runs, practical supplementations such as project weeks and summer or winter schools are desirable and have been tested in a pilot project at RWTH Aachen University in March 2023.

3) Digital Implementation and Recognition

Further, there were challenges during the implementation. For example, identifying a standardized platform that allows democratic participation for students from all universities has proven to be a central challenge. The primary difficulty stems from the fact that universities use different software applications to implement their digital teaching and learning content. Unfortunately, this has resulted in the absence of a uniform European network in the digital space, which would allow for seamless integration of students without any barriers. Further, the absence of a European software application that is independent of universities, adheres to European data protection regulations, and meets the technical requirements of a MOOC, has made it even more challenging to select a suitable platform. Ultimately, we opted to utilize edX (edX 2024a), an online teaching and learning platform established by Harvard University in 2012. This decision was made due to the absence of European alternatives and the platform's familiarity and accessibility. On the one hand, the MOOC's availability to a worldwide audience is advantageous. On the other hand, its integration into the ENHANCE network is only secondary. Furthermore, there is a conflict or obstacle to the participation of Alliance students due to the anchoring on edX. This is because acquiring a certificate of participation on edX is subject to a fee, which stands in the way of the planned curricular and obligatory embedding in the Alliance universities' bachelor programs and democratized participation in the offer. A voucher system has remedied this, making the certificates virtually free for students. However, the distribution of the vouchers requires a considerable amount of bureaucracy. These difficulties clearly show that establishing and strengthening European software applications must be promoted more strongly if European learning is to be made possible in a contemporary way.

4 SUMMARY

In this practice paper, we presented our concept of the European MOOC "Responsible Innovators of Tomorrow" developed within the ENHANCE Alliance, which aims to educate future responsible innovators in Europe. We reported on conceptual and structural opportunities and challenges and derived recommendations for establishing a MOOC at the European level. We hope to inspire similar projects in the future and guide their practical realization. Although bearing many challenges, the national and international feedback of colleagues shows that it is a promising and future-oriented format that is one step towards raising awareness regarding the social responsibility of engineers on an international level that overcomes disciplinary as well as national barriers and supports the development of a holistic introduction to future skills on the European level.

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REFERENCES

Alraimi, Khaled M., Hangjung Zo, and Andrew P. Ciganek. 2015. "Understanding the MOOCs Continuance: The Role of Openness and Reputation." *Computers & Education* 80:28–38. https://doi.org/10.1016/j.compedu.2014.08.006.

Crawley, Edward F., Johan Malmqvist, Sören Östlund, and Doris R. Brodeur. 2007. *The CDIO Approach to Engineering Education: The CDIO Approach.* 1. Aufl. s.l. Springer-Verlag. http://gbv.eblib.com/patron/FullRecord.aspx?p=372880.

edX. 2024a. "EdX: Fuel Your Ambition." Accessed March 26, 2024. https://www.edx.org/.

edX. 2024b. "RWTHx: Responsible Innovators of Tomorrow." Accessed March 26, 2024. https://www.edx.org/learn/innovation/rwth-aachen-university-responsible-innovators-of-tomorrow.

ENHANCE Alliance. 2024a. "About Us." Accessed March 26, 2024. https://enhanceuniversity.eu/about-us/.

ENHANCE Alliance. 2024b. "ENHANCE Alliance – the European Universities of Technology Alliance." Accessed March 26, 2024. https://enhanceuniversity.eu/.

ENHANCE Alliance. 2024c. "University Partners." Accessed March 26, 2024. https://enhanceuniversity.eu/partners/.

European Commission. 2024a. "European Education Area - Quality Education and Training for All: Digital Education Action Plan (2021-2027)." Accessed March 26, 2024. https://education.ec.europa.eu/focus-topics/digital-education/action-plan.

European Commission. 2024b. "European Education Area - Quality Education and Training for All: European Universities Initiative." Accessed March 26, 2024. https://education.ec.europa.eu/education-levels/higher-education/european-universities-initiative.

Koul, Surabhi, and Burna Nayar. 2021. "The Holistic Learning Educational Ecosystem: A Classroom 4.0 Perspective." *Higher Education Quarterly* 75 (1): 98–112. https://doi.org/10.1111/hequ.12271.

Mahmoudi, Sirous, Ebrahim Jafari, Hasan Ali Nasrabadi, and Mohmmd Javad Liaghatdar. 2012. "Holistic Education: An Approach for 21 Century." *IES* 5 (3). https://doi.org/10.5539/ies.v5n3p178.

Miller, Ron. 2000. "Beyond Reductionism: The Emerging Holistic Paradigm in Education." *The Humanistic Psychologist* 28 (1-3): 382–93. https://doi.org/10.1080/08873267.2000.9977003.

Miseliunaite, Brigita, Irina Kliziene, and Gintautas Cibulskas. 2022. "Can Holistic Education Solve the World's Problems: A Systematic Literature Review." *Sustainability* 14 (15): 9737. https://doi.org/10.3390/su14159737.

OECD. 2019. “The OECD Learning Compass 2030.” Accessed August 20, 2021. http://www.oecd.org/education/2030-project/teaching-and-learning/learning/learning-compass-2030/.

Owens, Taya Louise. 2017. “Higher Education in the Sustainable Development Goals Framework.” *Euro J of Education* 52 (4): 414–20. https://doi.org/10.1111/ejed.12237.

Patru, Mariana, and Venkataraman Balaji. 2016. *Making Sense of MOOCS: A Guide for Policy Makers in Developing Countries. Commonwealth of Learning:* UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000245122.

Puente, Cristina, María Eugenia Fabra, Cindy Mason, Cristina Puente-Rueda, Maria Ana Sáenz-Nuño, and Ramiro Viñuales. 2021. “Role of the Universities as Drivers of Social Innovation.” *Sustainability* 13 (24). https://doi.org/10.3390/su132413727.

Renda, Andrea, Sylvia Schwaag Serger, Daria Tataj, Andrew Morlet, Darja Isaksson, Francisca Martins, Montserrat Mir Roca et al. 2021. *Industry 5.0, a Transformative Vision for Europe: Governing Systemic Transformations Towards a Sustainable Industry.* ESIR Policy Brief No. 3. Luxembourg: Publications Office of the European Union.

RWTH Aachen University. 2022. “Responsible Research and Innovation (RRI) Hub Der RWTH Aachen.” Accessed March 26, 2024. https://www.hub.rwth-aachen.de/.

Schomberg, René von. 2013. *A Vision of Responsible Research and Innovation.* Responsible Innovation: John Wiley & Sons, Ltd.

Sosa-Díaz, María José, and María Rosa Fernández-Sánchez. 2020. “Massive Open Online Courses (MOOC) Within the Framework of International Developmental Cooperation as a Strategy to Achieve Sustainable Development Goals.” *Sustainability* 12 (23): 10187. https://doi.org/10.3390/su122310187.

Stifterverband, and McKinsey. 2021. “Future Skills.” https://www.stifterverband.org/medien/future-skills-2021.

Tassone, Valentina C., Catherine O’Mahony, Emma McKenna, Hansje J. Eppink, and Arjen E. J. Wals. 2018. “(Re-)Designing Higher Education Curricula in Times of Systemic Dysfunction: A Responsible Research and Innovation Perspective.” *High Educ* 76 (2): 337–52. https://doi.org/10.1007/s10734-017-0211-4.

Thomas, Ian. 2009. “Critical Thinking, Transformative Learning, Sustainable Education, and Problem-Based Learning in Universities.” *Journal of Transformative Education* 7 (3): 245–64. https://doi.org/10.1177/1541344610385753.

UNESCO. 2023. “Technology in Education: A Tool on Whose Terms? - 2023 GEM Report.” Accessed March 21, 2024. https://gem-report-2023.unesco.org/technology-in-education/.

United Nations. 2017. “Guidelines on Sustainability Science in Research and Education: 2017/SC/SHS/1.”.

Voudoukis, Nikolaos, and Gerasimos Pagiatakis. 2022. “Massive Open Online Courses (MOOCs): Practices, Trends, and Challenges for the Higher Education.” *EJEDU* 3 (3): 288–95. https://doi.org/10.24018/ejedu.2022.3.3.365.

TOWARDS RESPONSIBLE AI - COMPETENCIES FOR ENGINEERS: AN EXPLORATIVE LITERATURE REVIEW ON EXISTING FRAMEWORKS

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ABSTRACT

The rapid evolution of artificial intelligence (AI) underscores the critical necessity for engineers to comprehend their responsibilities in AI use and development. This imperative requires equipping engineers with the requisite skills and knowledge to address societal challenges while ensuring that AI technologies are harnessed for societal benefit and mitigating potential risks. To support educators and course developers in identifying relevant competencies, the Responsible AI Competencies for Engineers (RAICE) framework is currently being developed collaboratively among educators, engineers, mathematicians, sociologists, and ethicists. This practice paper reports a work-in-progress based on our first explorations. In particular, we focus on Responsible AI (RAI), connected competencies, and their importance within the engineering domain. This paper answers how competencies of RAI are addressed in current frameworks for AI and ethics in general and for engineers. We report preliminary results from existing Responsible AI and engineering ethics frameworks and outline our research approach toward defining a competence framework that can guide engineering educators in developing novel learning experiences on Responsible AI and integrate these into their programs and courses.

1 MOTIVATION

Engineers today have access to powerful tools such as machine learning systems, data analytics, and advanced computational models that can analyze large datasets and simulate complex systems: For example, these capabilities facilitate the dedicated design of sustainable infrastructure, optimize resource utilization, and develop adaptive solutions for global challenges (Huang, Li, and Fu 2019; Abolhasani and Brown 2023; Tang, Liu, and Pan 2022; Yetilmezsoy, Ozkaya, and Cakmakci 2011)

Besides developing systems with good goals in mind, engineers must also consider the social and ecological effects of their work: With the ability to shape technology and society comes the responsibility to ensure that technologies are developed, deployed, and utilized in ways that benefit society while minimizing potential harms (Lemke et al. 2023). AI has the potential to create new systemic risks, for example, by affecting ecological sustainability (Galaz et al. 2021), reinforcing stereotypes, introducing biases, and having unintended negative effects on marginalized groups (Barocas, Hardt, and Narayanan 2023).

Since risk management is an integral aspect of the work of engineers and in particular when AI is involved, engaging with the field of Responsible AI (RAI) is therefore not just a moral imperative but also a pragmatic necessity for engineers (Blake et al. 2021). As delineated by Drage, McInerney, and Browne (2024), the accountability for artificial intelligence (AI) is primarily attributed to engineers and the stakeholders associated with their endeavors. It is incumbent upon the participating engineers to be incentivized to assume responsibility not only during dynamic assignments but also during routine maintenance activities. Only additional awareness of individual and structural barriers allows for responsibility to be taken (Dignum 2019).

Higher education institutions are imperative for value development among engineers (Yortsos 2021). Thus, engineering educators must understand the underlying competencies engineers must acquire during their study programs to build, deploy, and use AI responsibly. At the same time, engineering educators are often not direct experts in AI systems and ethics, making it challenging to oversee this broad and dynamic field and identify the relevant competencies to teach in their domain-specific courses (Schleiss et al. 2023).

To address this gap and to support educators in (higher) engineering education with related competence development, we are currently developing the Responsible AI Competencies for Engineers (RAICE) framework in a collaborative effort among educators, engineers, mathematicians, sociologists, and ethicists. The framework aims to identify relevant competencies to demonstrate to course developers and educators what aspects are relevant in educating their respective engineering students. This paper reports the preliminary results of categorizing and analyzing foundational work in the literature. In particular, it answers how RAI competencies are addressed in current frameworks for AI and ethics in general and for engineers.

To do so, we mapped out competence frameworks for general AI competencies, AI competencies for engineers, responsible competencies, and responsible AI competencies. A recent systematic review of AI literacy constructs found that almost all frameworks highlight ethical components (Almatrafi, Johri, and Lee 2024). In this work, we propose to add nuances to this construct in the context of AI by applying the differentiation into Ethical sensitivity or awareness; Ethical judgment, decision-making, and imagination; Ethical courage, confidence, or commitment proposed by Hess and Fore (2018). Moreover, our work builds the foundation for further analysis and definition of RAI competencies for engineers.

In the following section, we introduce the background and related work, discuss our research approach and present preliminary results of the explorative literature analysis. We conclude by discussing the results and outlining future work.

2 BACKGROUND AND RELATED WORK

Acknowledging that AI systems are always embedded in socio-technical systems, we refer to the notion of Responsible AI as “the fact that decisions and actions taken by intelligent autonomous systems have consequences that can be seen as being of an ethical nature” (Dignum 2019, 48). This requires ethical reasoning from people involved in developing, deploying, and using AI (Prem 2023). Therefore, the notion of RAI is closely linked to Ethical AI (EAI) – terms that are often discussed within the same vein or used interchangeably (Tahaei et al. 2023; Galaz et al. 2021; Gkontra et al. 2023). To bring these aspects of RAI into practice, guidelines hint at the importance of considering both technical and social perspectives (Prem 2023; Hagendorff 2020). This indicates that understanding both is relevant for both responsible development of and usage of AI.

Many engineering curricula and competence frameworks already consider general foundations of responsible conduct for engineers (Malmqvist, Edström, and Rosén 2020). This includes, for example, the integration of the Sustainable Development Goals (UNESCO 2023) or the emphasis on human-centered approaches in the emerging concept of Industry 5.0 (European Commission. Directorate General for Research and Innovation 2021a, 2021b) as well as the integration of the Responsible Research and Innovation concept (Owen, Schomberg, and Macnaghten 2021) in academia (Berg-Postweiler, Decker, and Leicht-Scholten 2024). At the same time, pedagogical strategies, learning goals, and assessment approaches of societal considerations in engineering education often lack consensus (Hess and Fore 2018).

Next to considering responsible conduct in engineering curricula, proper comprehension of AI-related responsibility issues requires corresponding technical literacy. This requires a shift in engineering education (Bühler, Jelinek, and Nübel 2022) towards integrating more advanced STEM knowledge as well as digital and AI competencies (Guile and Mitchell 2022), including data, technological, and human literacy (McDonald et al. 2022) as well as literacy on ethicality, responsibility, and social aspects (Schleiss et al. 2022; Bosen et al. 2023). While the importance of RAI and EAI is acknowledged in general competence frameworks for AI, it is mostly seen as an external position aside from other principles (Laupichler et al. 2022).

We conclude that there seems to be a shared understanding of the necessity for competencies for engineers to engage responsibly in their field. However, RAI often remains detached from practical implementation, highlighting the need for cohesive frameworks to guide engineering education. Existing accreditations acknowledge the relevance of these skills (Malmqvist, Edström, and Rosén 2020) and pilot studies with engineering students do so as well (Decker et al. forthcoming), but further efforts are required to develop a structured approach for scientifically grounded education in Responsible AI.

3 METHODOLOGY

The RAICE framework is developed in three steps (see Figure 1). First, we undergo a competency mapping of existing frameworks, which we present in detail in this paper. Second, we will derive the initial constructs of RAICE. Third, we will validate the framework in use with educators and translate RAICE constructs into educational offers.

Figure 1. Overall methodological approach in developing the RAICE framework

This study focuses on step 1 and aims to map and categorize existing competence and literacy frameworks as a basis for deriving the RAICE framework and motivating its relevance. Considering the target audience of a learning experience, it is essential to consider the context in which the knowledge has to be applied (Domínguez Figaredo and Stoyanovich 2023). In the long term, the RAICE framework aims to teach engineers to be well-educated users and system owners of AI (Domínguez Figaredo and Stoyanovich 2023). To this end, this paper includes an explorative literature analysis based on four categories of related frameworks: frameworks on 1) AI competencies in general, 2) AI competencies for engineers, 3) responsible competencies for engineers, and 4) responsible AI competencies.

For our analysis, we followed a recent differentiation of AI literacy constructs in aspects of know & understand, use & apply, evaluate, create, and navigate ethically (Almatrafi, Johri, and Lee 2024). This differentiation builds upon the idea of mapping AI literacy constructs to Bloom's taxonomy of learning (Ng et al. 2021b). To add more nuance to the ethical perspective, we followed the differentiation by Hess and Fore (2018) into categories of Ethical sensitivity or awareness, Ethical judgment, decision-making, or imagination, Ethical courage, confidence, or commitment. This categorization allows for better education of responsible understanding and behavior. We employed a qualitative content analysis of frameworks, mapping them to the relevant literacy constructs. Moreover, we described how frameworks address each category.

Overall, the data collection and analysis presented in this paper allow for a first explorative understanding of the landscape of frameworks that can work as a foundation for building and establishing a thorough intersectional framework.

4 PRELIMINARY RESULTS

In the following, we describe the preliminary results of the explorative literature analysis. For each framework, in Table 1, we report the target topic and target group and map the used constructs to the competence constructs of Almatrafi, Johri, and Lee (2024) and Hess and Fore (2018).

Recognize. Recognizing AI refers to the idea of non-professionals knowing which technologies inherit AI and which do not (Almatrafi, Johri, and Lee 2024). This is in line with basic knowledge of defining AI in general (Long and Magerko 2020)In our review, we found that all frameworks that focus on AI literacy include the skills that allow for the recognition of AI. On the contrary, literacy frameworks on responsible and ethical conduct in technical domains did not include the perspective of recognizing the technology behind AI.

Know and Understand. Knowledge and understanding of AI is defined by Almatrafi, Johri, and Lee (2024) as a combination of knowledge of concepts and practices that go from data collection and processing to AI process and output. Similar to the construct of recognition, knowledge and understanding of the technology is recognized in the general and technical competence frameworks but not in the ethical frameworks of our review.

Use and Apply. Based on the knowledge from previous steps, the usage and application of AI refers to the ability to interact with the wide range of applications that fall under the term AI and use them to achieve objectives and goals (Almatrafi, Johri, and Lee 2024; Ng et al. 2021a). Thus, it is generally about the ability to apply knowledge in different scenarios and contexts (Ng et al. 2021a). Moreover, Knoth et al. (2024) add to this that these contexts affect how to assess these skills. Again, general and technical frameworks include this aspect of being able to use and apply, while the ones considered with general responsibility and ethicality mostly do not.

Evaluate. Evaluating AI requires both knowledge of AI and skills with AI, so application contexts, processes, and outcomes can be critically analyzed. Following Wang, Rau, and Yuan (2023) or Almatrafi, Johri, and Lee (2024), this especially requires technical understanding. We found that only a set of frameworks considered these critical evaluation skills. Especially wider critical and technical frameworks (Ng et al. 2021b; Ng et al. 2021a) as well as some ethical frameworks (Bogina et al. 2022) do consider this aspect. Moreover, this construct seems to include classical aspects of professional responsibility (Tenório and Romeike 2023) and is thereby closely related to other more diversified ethical constructs.

Table 1. Mapping frameworks to constructs (R: Recognize, K: Know & Understand, U: Use & Apply, V: Evaluate, C: Create, ES Ethical sensitivity or awareness, EJ: Ethical judgment, decision-making, or imagination, EC: Ethical courage, confidence, or commitment)

Framework	Target Topic	Target Group	Responsible AI Competency Constructs							
			Technical Competencies					Responsibility Competencies		
			R	K	U	V	C	ES	EJ	EC
Knoth et al. (2024)	AI literacy	General Public	X	X	X	X	X	X	X	X
Long and Magerko (2020)	AI Literacy	General Public	X	X		X		X		
Heyder and Posegga (2021)	AI Literacy	Workforce	X	X		X		X		
Ng et al. (2021b)	AI Literacy	General public	X	X	X	X	X	X		
Tenório and Romeike (2023)	Responsible AI literacy	Non-computer Science Students	X	X	X	X		X	X	
Moreno, Decker, and Leicht-Scholten (2024)	Engineering Literacy	Engineering students	X	X	X		X	X		

Lurie and Mark (2016)	Software engineering ethics	Software Engineers				X		X	X	
Barakat (2015)	Engineering ethics	Engineering students						X	X	X
Romero-Yesa et al. (2022)	Engineering ethics	Engineering students						X	X	
Bogina et al. (2022)	AI Ethics	Software and AI Stakeholder				X	X	X		

Create. Almatrafi, Johri, and Lee (2024) recognize the complexity of the construct as not correlating with other AI literacy constructs (Carolus et al. 2023). Still, they see it as relevant so that skills in designing, coding, and releasing AI systems are integrated within the literacy framework. Certain large frameworks (such as Knoth et al. 2024) also include the ability to create AI systems even though the notion of AI literacy often only addresses non-professionals and base competencies (Ng et al. 2021a). Nevertheless, this skill seems relevant to take over decision-making roles in ethical AI contexts (Domínguez Figaredo and Stoyanovich 2023).

We found ethical constructs within AI literacy frameworks to be broad. Thus, when using Almatrafi, Johri, and Lee (2024) as guidance for analysis, we propose that their construct of *Navigate Ethically* can be split into the three following constructs from Hess and Fore (2018).

Ethical sensitivity or awareness. This (sub-)construct aims to increase students' recognition of ethically problematic situations and sensitivity to ethical issues they may face (Hess and Fore 2018). Across our analysis, all frameworks included this awareness of ethical issues. It was by knowledge of the ethical principles of fairness, accountability, and transparency, as in Bogina et al. (2022), or the identification of more general opportunities and risks held by AI (Long and Magerko 2020).

Ethical judgment, decision-making, or imagination. Following Hess and Fore (2018), this construct focuses on acting ethically and reasoning about ethics, e.g. by understanding and discussing ethical theory or codes of ethics or applying technical knowledge responsibly. In the context of the analyzed frameworks, only a subset referred to aspects of ethical judgment or decision-making like "Apply procedures when developing AI tools that can mitigate ethical problems" in Tenório and Romeike (2023).

Ethical courage, confidence, or commitment. According to Hess and Fore (2018), this construct targets the underlying attitudes and values by aiming to develop a commitment to ethical principles or motivation to act ethically. They also identified that this construct is only prevalent in less than 30% of their analyzed articles. As an example, we mention Barakat (2015) who considers this confidence in regard to engineering ethics. For AI ethics, Knoth et al. (2024) shortly mention the construct in their analysis without further elaboration.

5 Discussion and Conclusion

Responsibility is an important aspect of engineering education. With the rapid advancement of AI, it becomes even more important to teach engineers their responsibility in using and developing AI. By empowering educators, we aim to increase awareness of the importance of Responsible AI in the context of engineering and build the foundational educational offerings to ensure that engineers are equipped with the right tools to act responsibly with AI.

Our analysis also demonstrates the ongoing discussion among educators and authors of frameworks along the question of seeing ethical competencies in AI as integrative to all or as a separate construct (Ng et al. 2021b; Knoth et al. 2024). While on one side, the separation of the construct allows individual consideration, it leaves aside the multifaceted nature of responsibility competencies (Hess and Fore 2018).

5.1 Practical Implications

This paper highlights that while most frameworks include ethical components, the notion lacks nuance and detail, making it difficult for educators to address it in course situations. As outlined in the overall research approach, this preliminary analysis builds the foundation for a systematic definition of relevant Responsible AI competencies for engineers.

Hess and Fore (2018) found that only a few educational measures for ethical engineering include ethical courage, confidence, or commitment. In the context of this analysis of RAI frameworks, we can add that frameworks also often do not address the differentiation of ethical judgment, decision-making, imagination, courage, confidence, or commitment. Accordingly, Dutta, Mishra, and Budhwar (2022) find that ethics is considered important but often stays on a broad level or is even ignored in business competence models due to challenges in ideation, conceptualization, and implementation. Additionally, even though a technical understanding is needed (Prem 2023), many ethical frameworks take these skills as prerequisites without putting them into context. This underlines the need and importance for more consideration of educators in terms of what and how to teach about AI, especially with a focus on building practical ethical behavior and a strong ethical disposition in students.

5.2 Limitations and Outlook

In its current stage, the work has certain limitations. First, the work presented in this paper focuses on the foundational work based on an explorative literature analysis. Thus, the framework is not yet in its final version nor validated in practice with educators. For further validation, we will first derive the RAICE constructs and validate them in an interactive workshop for educators and engineering education instructors interested in education for responsibility and teaching about RAI in the context of their domain. Moreover, future work will include different roles engineers take when interacting with AI to add more nuance to the competencies and ethical challenges. We also plan to decrease the depth by considering competencies as a combination of knowledge, skills, and attitudes. Furthermore, future work will include mapping further (accreditation) frameworks such as CDIO 2.0, EUR-ACE, ABET or BCS.

In the long run, the RAICE framework aims to support educators in understanding relevant competence dimensions of Responsible AI and provide them with the tools to develop and integrate teaching about Responsible AI in their courses. In this context, it will be especially interesting to see differences in the disciplinary communities and international perspectives.

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REFERENCES

Abolhasani, Milad, and Keith A. Brown. 2023. "Role of AI in Experimental Materials Science." *MRS Bulletin* 48 (2): 134–41. https://doi.org/10.1557/s43577-023-00482-y.

Almatrafi, Omaima, Aditya Johri, and Hyuna Lee. 2024. "A Systematic Review of AI Literacy Conceptualization, Constructs, and Implementation and Assessment Efforts (2019–2023)." *Computers and Education Open* 6:100173. https://doi.org/10.1016/j.caeo.2024.100173.

Barakat, Nael. 2015. "Engineering Ethics and Professionalism Education for a Global Practice." In *Engineering Leaders Conference 2014 on Engineering Education*: Hamad bin Khalifa University Press (HBKU Press).

Barocas, Solon, Moritz Hardt, and Arvind Narayanan. 2023. *Fairness and Machine Learning: Limitations and Opportunities.* Cambridge, Massachusetts, London, England: The MIT Press.

Berg-Postweiler, Julia, Marie Decker, and Carmen Leicht-Scholten. 2024. "Academia as a Key Factor in Fostering Responsible Research and Innovation with and for Society: The Case of the RRI Hub at RWTH Aachen University." In *Transformation Towards Sustainability: A Novel Interdisciplinary Framework from RWTH Aachen University*, edited by Peter Letmathe, Christine Roll, Almut Balleer, Stefan Böschen, Wolfgang Breuer, Agnes Förster, Gabriele Gramelsberger et al. 1st ed. 2024, 399–424. Cham: Springer International Publishing; Imprint Springer. https://link.springer.com/chapter/10.1007/978-3-031-54700-3_15.

Blake, Robert W., Robins Mathew, Abraham George, and Nikolaos Papakostas. 2021. "Impact of Artificial Intelligence on Engineering: Past, Present and Future." *Procedia CIRP* 104:1728–33. https://doi.org/10.1016/j.procir.2021.11.291.

Bogina, Veronika, Alan Hartman, Tsvi Kuflik, and Avital Shulner-Tal. 2022. "Educating Software and AI Stakeholders About Algorithmic Fairness, Accountability, Transparency and Ethics.” *Int J Artif Intell Educ* 32 (3): 808–33. https://doi.org/10.1007/s40593-021-00248-0.

Bosen, Jennifer, Sebastian Bernhard, Evamaria Fauster, Marie Decker, Miriam Lämmerhirt, and Carmen Leicht-Scholten. 2023. “Engineering Society: The Role of Intersectional Gender and Diversity Studies for a Sustainable Transformation on the Case of Interdisciplinary Engineering Education.”.

Bühler, Michael Max, Thorsten Jelinek, and Konrad Nübel. 2022. “Training and Preparing Tomorrow’s Workforce for the Fourth Industrial Revolution.” *Education Sciences* 12 (11): 782. https://doi.org/10.3390/educsci12110782.

Carolus, Astrid, Martin J. Koch, Samantha Straka, Marc Erich Latoschik, and Carolin Wienrich. 2023. “MAILS - Meta AI Literacy Scale: Development and Testing of an AI Literacy Questionnaire Based on Well-Founded Competency Models and Psychological Change- and Meta-Competencies.” *Computers in Human Behavior: Artificial Humans* 1 (2): 100014. https://doi.org/10.1016/j.chbah.2023.100014.

Decker, Marie, Sarah Gail Moreno, Ben Schultz, and Carmen Leicht-Scholten. forthcoming. “AI in Engineering : Why Is Teaching Social Components of Technology Relevant to Engineering Students?”.

Dignum, Virginia. 2019. *Responsible Artificial Intelligence.* Cham: Springer International Publishing.

Domínguez Figaredo, Daniel, and Julia Stoyanovich. 2023. “Responsible AI Literacy: A Stakeholder-First Approach.” *Big Data & Society* 10 (2). https://doi.org/10.1177/20539517231219958.

Drage, Eleanor, Kerry McInerney, and Jude Browne. 2024. “Engineers on Responsibility: Feminist Approaches to Who’s Responsible for Ethical AI.” *Ethics Inf Technol* 26 (1). https://doi.org/10.1007/s10676-023-09739-1.

Dutta, Debolina, Sushanta Kumar Mishra, and Pawan Budhwar. 2022. “Ethics in Competency Models: A Framework Towards Developing Ethical Behaviour in Organisations.” *IIMB Management Review* 34 (3): 208–27. https://doi.org/10.1016/j.iimb.2022.10.002.

European Commission. Directorate General for Research and Innovation. 2021a. *Industry 5.0, a Transformative Vision for Europe: Governing Systemic Transformations Towards a Sustainable Industry:* Publications Office.

European Commission. Directorate General for Research and Innovation. 2021b. *Industry 5.0: Towards a Sustainable, Human Centric and Resilient European Industry:* Publications Office.

Galaz, Victor, Miguel A. Centeno, Peter W. Callahan, Amar Causevic, Thayer Patterson, Irina Brass, Seth Baum et al. 2021. “Artificial Intelligence, Systemic Risks, and Sustainability.” *Technology in Society* 67:101741. https://doi.org/10.1016/j.techsoc.2021.101741.

Gkontra, Polyxeni, Gianluca Quaglio, Anna Tselioudis Garmendia, and Karim Lekadir. 2023. “Challenges of Machine Learning and AI (What Is Next?), Responsible and Ethical AI.” In *Clinical Applications of Artificial Intelligence in Real-World Data*, edited by Folkert W. Asselbergs, Spiros Denaxas, Daniel L.

Oberski, and Jason H. Moore. 1st ed. 2023, 263–85. Cham: Springer International Publishing; Imprint Springer.

Guile, D., and J. Mitchell. 2022. “Fusion Skills for Engineers Working in Industry 5.0.” In *Proceedings of the 8th International Symposium for Engineering Education*.

Hagendorff, Thilo. 2020. “The Ethics of AI Ethics: An Evaluation of Guidelines.” *Minds & Machines* 30 (1): 99–120. https://doi.org/10.1007/s11023-020-09517-8.

Hess, Justin L., and Grant Fore. 2018. “A Systematic Literature Review of US Engineering Ethics Interventions.” *Sci Eng Ethics* 24 (2): 551–83. https://doi.org/10.1007/s11948-017-9910-6.

Heyder, Teresa, and Oliver Posegga. 2021. “Extending the Foundations of AI Literacy.” In *ICIS 2021 Proceedings: Building Sustainability and Resilience with IS: A Call for Action.* 9 vols. Austin, Texas. https://www.researchgate.net/profile/teresa-hammerschmidt/publication/357511112_extending_the_foundations_of_ai_literacy_research-in-progress/links/643cdd67a08d9a67a4a2ec92/extending-the-foundations-of-ai-literacy-research-in-progress.pdf.

Huang, Youqin, Jiayong Li, and Jiyang Fu. 2019. “Review on Application of Artificial Intelligence in Civil Engineering.” *Computer Modeling in Engineering & Sciences* 121 (3): 845–75. https://doi.org/10.32604/cmes.2019.07653.

Knoth, Nils, Marie Decker, Matthias Carl Laupichler, Marc Pinski, Nils Buchholtz, Katharina Bata, and Ben Schultz. 2024. “Developing a Holistic AI Literacy Assessment Matrix – Bridging Generic, Domain-Specific, and Ethical Competencies.” *Computers and Education Open* 6:100177. https://doi.org/10.1016/j.caeo.2024.100177.

Laupichler, Matthias Carl, Alexandra Aster, Jana Schirch, and Tobias Raupach. 2022. “Artificial Intelligence Literacy in Higher and Adult Education: A Scoping Literature Review.” *Computers and Education: Artificial Intelligence* 3:100101. https://doi.org/10.1016/j.caeai.2022.100101.

Lemke, Clara, Ann-Kristen Winkens, Marie Decker, Inanma Elif, and Carmen Leicht, eds. 2023. *Development in Students' Perceptions of Sustainability and Responsibility as Relevant Aspects of the Role of Engineers*. European Society for Engineering Education (SEFI).

Long, Duri, and Brian Magerko. 2020. “What Is AI Literacy? Competencies and Design Considerations.” In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. New York, NY, USA: ACM.

Lurie, Yotam, and Shlomo Mark. 2016. “Professional Ethics of Software Engineers: An Ethical Framework.” *Sci Eng Ethics* 22 (2): 417–34. https://doi.org/10.1007/s11948-015-9665-x.

Malmqvist, J., K. Edström, and A. Rosén. 2020. “CDIO Standards 3.0 - Updates to the Core CDIO Standards.” In *Proceedings of the 16th International CDIO Conference*.

McDonald, Nora, Adegboyega Akinsiku, Jonathan Hunter-Cevera, Maria Sanchez, Kerrie Kephart, Mark Berczynski, and Helena M. Mentis. 2022. “Responsible

Computing: A Longitudinal Study of a Peer-Led Ethics Learning Framework.” *ACM Trans. Comput. Educ.* 22 (4): 1–21. https://doi.org/10.1145/3469130.

Moreno, Sarah Gail, Marie Decker, and Carmen Leicht-Scholten. 2024. “Implementing AI Ethics Education: Engineering Competencies for Sustainable Societal Impact.” In *Proceedings of the 20th International CDIO Conference*. Tunis.

Ng, Davy Tsz Kit, Jac Ka Lok Leung, Kai Wah Samuel Chu, and Maggie Shen Qiao. 2021a. “AI Literacy: Definition, Teaching, Evaluation and Ethical Issues.” *Proceedings of the Association for Information Science and Technology* 58 (1): 504–9. https://doi.org/10.1002/pra2.487.

Ng, Davy Tsz Kit, Jac Ka Lok Leung, Samuel Kai Wah Chu, and Maggie Shen Qiao. 2021b. “Conceptualizing AI Literacy: An Exploratory Review.” *Computers and Education: Artificial Intelligence* 2:100041. https://doi.org/10.1016/j.caeai.2021.100041.

Owen, Richard, René von Schomberg, and Phil Macnaghten. 2021. “An Unfinished Journey? Reflections on a Decade of Responsible Research and Innovation.” *Journal of Responsible Innovation* 8 (2): 217–33. https://doi.org/10.1080/23299460.2021.1948789.

Prem, Erich. 2023. “From Ethical AI Frameworks to Tools: A Review of Approaches.” *AI Ethics* 3 (3): 699–716. https://doi.org/10.1007/s43681-023-00258-9.

Romero-Yesa, Susana, Olatz Ukar-Arrien, Galo Bilbao-Alberdi, Pedro Manuel Sasia Santos, Diego Casado-Mansilla, and Andoni Eguiluz-Moran. 2022. “Tecnoetica: Inclusion and Assessment of the Ethical Competence in Engineering Final Degree Projects.” *IEEE R. Iberoamericana Tecnologias Aprendizaje* 17 (1): 41–47. https://doi.org/10.1109/RITA.2022.3149777.

Schleiss, Johannes, Michelle Bieber, Anke Manukjan, Lars Kellner, and Sebastian Stober. 2022. “An Interdisciplinary Competence Profile for AI in Engineering.” *Artificial Intelligence (AI) and Education* 13 (10): 978. https://doi.org/10.5821/conference-9788412322262.1288.

Schleiss, Johannes, Matthias Carl Laupichler, Tobias Raupach, and Sebastian Stober. 2023. “AI Course Design Planning Framework: Developing Domain-Specific AI Education Courses.” *Education Sciences* 13 (9): 954. https://doi.org/10.3390/educsci13090954.

Tahaei, Mohammad, Marios Constantinides, Daniele Quercia, and Michael Muller. 2023. “A Systematic Literature Review of Human-Centered, Ethical, and Responsible AI.” http://arxiv.org/pdf/2302.05284.

Tang, Jun, Gang Liu, and Qingtao Pan. 2022. “Review on Artificial Intelligence Techniques for Improving Representative Air Traffic Management Capability.” *J. of Syst. Eng. Electron.* 33 (5): 1123–34. https://doi.org/10.23919/jsee.2022.000109.

Tenório, Kamilla, and Ralf Romeike. 2023. “AI Competencies for Non-Computer Science Students in Undergraduate Education: Towards a Competency Framework.” In *Proceedings of the 23rd Koli Calling International Conference on Computing Education Research*. New York, NY, USA: ACM.

UNESCO. 2023. “Global Education Monitoring Report 2023: Technology in Education - a Tool on Whose Terms?”.

Wang, Bingcheng, Pei-Luen Patrick Rau, and Tianyi Yuan. 2023. “Measuring User Competence in Using Artificial Intelligence: Validity and Reliability of Artificial Intelligence Literacy Scale.” *Behaviour & Information Technology* 42 (9): 1324–37. https://doi.org/10.1080/0144929X.2022.2072768.

Yetilmezsoy, Kaan, Bestamin Ozkaya, and Mehmet Cakmakci. 2011. “Artificial Intelligence-Based Prediction Models for Environmental Engineering.” *NNW* 21 (3): 193–218. https://doi.org/10.14311/nnw.2011.21.012.

Yortsos, Yannis C. 2021. “The Grand Challenges Scholars Program 12 Years Later: A New Vision.” In *2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC)*, 23–28: IEEE.

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Rewarding Responsibility: Constructing a Responsible Artificial Intelligence Competition for Future Engineers

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ABSTRACT

In Fall 2023, we developed an experiment that would enable two different sectors to participate in a responsible artificial intelligence (RAI) competition for engineering students. MathWorks® and FİGES collaborated with a Science Technology and

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Society (STS) instructor on this effort. As part of the STS class at Bilkent University, engineering students applied responsible innovation (RI) theory to their case studies on artificial intelligence (AI) innovation sites. As industry players and policy makers have been grappling with the ethical aspects of AI in recent years, this is a key time for engineering students to become aware of the need to innovate for RAI. Through a short questionnaire, we found that students who took part in the Fall 2023 RAI competition are aware of the need for technical solutions to ethical and social aspects, including transparency, discrimination, privacy and the inclusion of stakeholder values. We also found that some engineering students were motivated to learn about RAI through the competition, perhaps partly because the initiative was supported by industry. Although the RAI competition started with STS students, FİGES plans to progressively expand the competition to other engineering courses at Bilkent University and beyond. RAI competitions can help motivate future engineers to begin imagining solutions for responsible AI.

1 INTRODUCTION

1.1 The Emergence of Responsible Artificial Intelligence

Responsible Artificial Intelligence (RAI) is a concept that has been emerging alongside artificial intelligence developments. Recent RAI developments signal a need to pay attention to responsibility practices in AI at an early stage in engineering education. It is also inevitable that engineers will need to prepare for RAI, as funding mechanisms, such as Responsible AI UK, are starting to emerge (UK Research and Innovation, 2024). Through interacting with industry on responsibility practices during their undergraduate training, engineering students can gain an understanding of the need to consider social values at an earlier stage in their development.

In recent years, the Asilomar conference on AI, the Partnership on AI and the Montreal Declaration on Responsible AI all addressed ethical concerns around AI. The Asilomar conference on AI produced a set of principles that were quite broad in nature and advocated that innovators consider transparency, safety, sharing benefits, steering clear of an AI arms race and producing technologies that have been aligned according to human values (Stilgoe and Maynard, 2017; Future of Life, 2017). The Partnership on AI (PAI), began in Berlin and led to similar goals, which look toward safe, transparent, fair and accountable AI (Heer, 2018). In 2018, the Montreal Declaration on Responsible AI held that humans should hold responsibility for critical decisions (Morandín-Ahuerma, 2023).

The debate around AI ethics and the need for regulation certainly deepened after Geoffrey Hinton, who is well known for his contributions to neural networks and deep learning, reacted to the arrival of ChatGPT by sounding the alarm about potential risks (Metz, 2023). In response, policy makers have moved quickly to address the potential problems that may arise. Arguably, the EU is leading these efforts, as European Parliament endorsed the Artificial Intelligence Act on March 13th, 2024. This milestone is set to regulate according to the level of risk and will be regulated according to discrimination, transparency, privacy and explainability (Gibney, 2024). Also, the UK has implemented the AI Safety Institute (AISI) to test AI tools for safety and will collaborate with other countries and several AI companies on this effort (Milmo, 2024). In addition to testing, an international advisory committee on AI will be established to assess emerging AI tools (Milmo and Stacey, 2023). In this context, industry will need to respond to the call to develop RAI solutions (Li et al., 2023). Engineering educators will also need to contribute to this effort.

1.2 The Responsible Artificial Intelligence Competition

In September 2023, MathWorks, FİGES and a Science Technology and Society (STS) instructor at Bilkent University partnered on a competition for responsible artificial intelligence.[2] Over 100 engineering students enrolled in the STS course participated in the RAI competition. The student projects all focused on one specific company or university laboratory involved in AI innovations and asked questions about risks, stakeholder inclusion and solutions that came up in the innovation process. Engineering students from the same class in previous semesters also used responsible innovation approaches to examine innovation sites and discovered that innovators encountered value conflicts, implemented sustainability practices and made responsible adjustments during the innovation process (Downey, 2023). However, for the 2023 RAI competition, the students found innovators that were developing algorithms, machine learning technologies and big data tools. The students asked questions that were intended to help them understand how innovators handled and responded to various risk issues, including discrimination, privacy, inadequate consent practices and explainability. The students also considered how users and other stakeholders were included in the innovation process and assessed how innovators solved relevant social concerns with technical solutions.

The RAI Competition was integrated in the STS course with the goal of inspiring students to challenge themselves within a dynamic and competitive framework. All the students were organized in groups of different sizes and tasked to interview three innovators from one relevant research or innovation site about the role of RI and AI in current industrial workflows. The students were asked to research technical developments, the associated social and ethical values and consider the opportunities for novel technical alternatives. After the instructor identified seven finalists, then the jury for the RAI competition identified two groups that received RAI awards for their work and they presented their work in an online setting. The jury members were not attached to the innovation sites in which the students conducted interviews.

In addition to one of the authors of this paper, the members of the jury were chosen from various companies that are amongst the AI leaders in the local and global market (Science Technology and Society 2024; also see the Acknowledgements section below). To guarantee an equal and neutral grading, the jury used a metric of assessment that was created by the instructor. In addition to assessing writing and creativity (20 marks), these metrics included the following: inclusion of RAI principles (30 marks), attention to key stakeholders (10 marks), focus on relevant risk issues (10 marks) and the identification of RAI solutions (30 marks). The “Outstanding Responsible AI Award” was given to the group with the highest rating and the “Responsible AI Innovation Award” was given to an additional group (Science Technology and Society 2024). The winners of both awards received a personal certification signed by both MathWorks and FİGES. A Responsible AI Competition event was organized at the end of the course and held online. The final event lasted

[2] The RAI competition was conceived during SEFI 2023 conference in Dublin as follow-up from the panel discussion: “Which engineering is needed for AI?.”

for one hour and included a 30-minute presentation on “Responsible AI: Navigating the Importance of Responsible Innovation”, which was given by Akhil Gopinath, an Artificial Intelligence Liaison at MathWorks and presentations from the students (Science Technology and Society, 2024).

2 RESPONSIBLE INNOVATION: THEORY AND PRACTICE

2.1 Engineering Formation, Broadening Problem Definition and RI

STS offers a number of valuable resources for helping engineering students to include social aspects in the innovation process and this can have an impact on the formation of engineers. As Downey notes, engineering students can benefit from going beyond dominant engineering practices, which focus on analytical problem solving, to engaging with “alternative images of engineering work” (Downey, 2009, 67). The alternative approaches go beyond defining problems in narrow quantitative terms, which may emphasize efficiency and economy, through including social aspects at the problem definition stage of the innovation process. Downey suggests that this approach can have an impact on engineering formation: “Key potential benefits from increased attention to problem definition in engineering formation include . . . producing active mobilizers of support for perspectives that take account of other perspectives” (Downey, 2008, 452). Feenberg has also suggested that engineers may prioritize instrumental values during the innovation process, as they are often shaped by the ‘unreflected projections of the engineering culture in which they are socialized” (Feenberg, 2002, 98). These observations both support the idea that students should be introduced to alternative innovation methods and approaches, such as responsible innovation (RI), during their training years. RI theory can help to provide methods and approaches for broadening problem definition at an early stage in the innovation processes.

Alternative innovation paths include social knowledge, which may be included through, for example, consulting stakeholders and making technical adjustments to social concerns. By introducing students to RI, they learn about the importance of identifying social risk issues at an early stage in the innovation process and they also realize that there are implications for tangible technical solutions. RI projects have been used in the STS course for several years at Bilkent University and they provide students with an opportunity to consult companies on their responsibility practices. The projects can help students to notice that social knowledge is routinely considered during the research and innovation context by innovators to varying degrees. Through conducting the RI assessments, students also have the opportunity to realize that social values, which may be aligned with concerns from a range of stakeholders, can lead to technical alternatives. For the 2023 RAI competition project, students used a Value Sensitive Design (VSD) approach. VSD has received attention as an approach for RI practitioners, although it has much earlier roots (Friedman, 1996). The methods include identifying values, addressing mitigation strategies and developing technical measures to respond to various values and risk concerns. van de Poel’s work in the area of values and design helps engineering students to understand how various values, including human well-being, justice, safety, health, and sustainability may be addressed during the course of the innovation process (van de Poel, 2015).

The key goal for our exercise is to demonstrate that collaborative activities, which cross social and technical boundaries, can help all of the participants begin to imagine alternative pathways for the technology. In this case, the key participants are the students, educational technology representatives, the innovators that participated in student interviews and an STS instructor. Boundary-crossing collaborations may be called “critical participations” (Downey, 2009) or “experiments in participation” (Downey and Zuiderent-Jerak, 2016, 239).The very act of engaging with social values may help students and innovators to reflect on emerging technical solutions for the ethical problems associated with AI. For example, MathWorks and FİGES are engaging in the social dimension of innovation through reading and reviewing the student RAI papers. We suggest that students and innovators gain an understanding of relevant AI social values through this experience.

2.2 Building Technical Solutions to RAI Problems

In addition to supporting research and teaching, MathWorks and FİGES have consistently been involved in academic innovation, so they are extremely well positioned to collaborate with universities on RAI projects. Within this context, the university-industry collaboration presented in this paper is designed to prepare Turkish engineering students for what it is an increasingly recognized standard in the world: the responsible development of AI. Elevating their awareness towards AI ethics and equipping them with critical thinking skills are imperative steps for their preparation toward upcoming challenges.

MathWorks, and FİGES are interested in engaging students in proactive learning, including RAI, through interacting with AI industry players. The objective is to motivate next generations to stay informed on latest developments in AI ethics while participating in discussions with their peers and with industries where RAI is already a key priority. This conversation becomes particularly resonant within the ecosystem of the MathWorks platform, where engineers and scientists have the opportunity of using low-code, hence accessible to everyone, AI solutions in connection with their field of expertise.

RAI and responsible innovation approaches in general, align with MathWorks’ technical solutions in terms of safety, security, transparency and explainability. The MathWorks website hosts many public and open access examples and tutorials that promote a responsible use of AI capabilities (see for example, MathWorks Inc., 2021; MathWorks Inc., 2023). Moreover, with ethical values in mind, technical adjustments have been made to enhance explainability and interpretability of deep neural networks. Many other techniques, aligned with current state of the art discussion, will be considered in the software development: compliance with global standards/policies, systematic identification of bias and discrimination, and the integration of ethical decision-making frameworks.

3 CONSULTING STUDENTS ON THEIR EXPERIENCE WITH THE RAI COMPETITION

3.1 RAI Competition Questionnaire for Students

On January 17 2024, 108 students were invited to participate in the RAI competition survey. Unfortunately, we were not able to survey the students directly after the competition, as it was essential to receive ethics approval from Bilkent University and this was not possible until after the STS course had finished and the students were no longer in the class. For this reason, we did not send the follow up questionnaire until a month after the competition had taken place and this may have had an impact on the response rate, which was about 18%. As we only had a limited response rate and many of the students did not respond to the optional open-ended questions, this study does have limitations. However, the findings offer some insight into student views of the RAI competition.

In the questionnaire, we asked students to check a form related to social risks, stakeholder engagements and responsible solutions that they discovered during their interviews with the companies and labs. They were also given an optional opportunity to elaborate on their choice. As some students responded to the open-ended questions, we were able to collect some interesting qualitative data, which we report on in the section below. Just over half of the survey participants reported that their innovation sites were medium to large companies, whereas nearly 40% indicated that they consulted start-ups on the responsibility practices and just over 10% of those surveyed conducted their studies with university labs focused on AI. The survey respondents indicated that they conducted their research interviews at innovation sites that developed AI tools for use in communications, transportation, education, healthcare, aerospace, defense, entertainment, generative AI and object recognition.

3.2 Student Views of Values and Ethical Solutions

The results suggest that students became familiar with responsibility practices in artificial intelligence. The students indicated that they uncovered different types of values through their RAI study. All students checked privacy, three quarters of the students indicated that they found that they uncovered transparency concerns, nearly 70% checked bias, and almost half of the students indicated that they had identified discrimination in their RAI assessments. One student indicated that regulations and ethical values were also a key focus for innovators. The majority of students (84.1%) indicated that innovators included stakeholder feedback in their innovation practices. Although some students suggested that this was an ordinary part of the innovation process, several students clarified that users played a special role in innovation practices and were able to describe how this information was used in innovation practices (see Table 1).

Students were also aware of the different types of technical solutions to social concerns that innovators may apply in artificial intelligence. For example, about three quarters of the respondents indicated that they had identified "privacy by design" solutions that were employed by their innovation sites. For example, the award winning projects included information on how innovators implemented privacy solutions by blurring images and anonymization practices (Science Technology and Society, 2024). Over 60% found that their company considered consent practices in their research. One instance of this is that students found that innovators received consent from parents before using an application for use in a kindergarten environment (Science Technology and Society, 2024). Slightly over 25% discovered that there were some "transparency by design" procedures are in place. Only 2 students suggested that there were not any additional responsibility practices beyond the inclusion of stakeholder values.

Table 1. Student Views on Stakeholder and User Inclusion in the Innovation Process

Role of Users	Student Views
Users identified as key stakeholders	"The company takes feedbacks from pilots, who are the users of the technology" "Users are the largest stakeholders for the company and the company does innovate according to feedback surveys." "Expert opinion is also considered when implementing the design"
Approaches for including users in the innovation process	"They make multiple meetings with the stakeholders and note their feedback to make their product both useful and beneficial." "They gather . . . with customers regularly to get their feedbacks and be responsive to those comments." "They keep doing tests according to users' feedback criteria" "An agile project approach is implemented."

Although most of the survey participants (84%) indicated that they agreed with the innovation site's RAI solutions, two students did not. One student elaborated on how the RAI solutions could be implemented better through the development of appropriate regulation: "Searching for and adapting international RI practices in the defense industry could be a great start." Although some had only a satisfactory experience, others emphasized that the competition helped to motivate them by stating that the competition "was very motivating" or made them "eager to work" on the project. Others noted that they became more familiar with ethical aspects of AI. For example, one student indicated that the experience provided information on "the ethical and stakeholder sides of the engineering process" and another suggested that it helped students to "become more aware of ethical aspects surrounding AI." These views suggest that including RAI activities in engineering education can help to reinforce the importance of attending to social values during the innovation process.

3.3 General Experience with the RAI Competition

Through the questionnaire, we learned about how to improve the competition in the future and we already implemented these aspects in the 2024 RAI competition (Science Technology and Society, 2024). One student indicated that they would like to have a longer competition, which could involve an opportunity to present their work directly to the jury: "I would like to be able to meet with the jury as well in a face to face environment." Other students indicated that they would like to receive more information about how they were assessed: "Maybe we could have learned about the project feedbacks but we only learned about our ranking." We will continue to improve on these aspects in future competitions by having face to face meetings and clarifying the evaluation process.

However, students also indicated that the competition helped to motivate them to learn about RAI practices in industry. For example, one student emphasized that the RAI competition provided new insights into the role of responsibility: "It was a very interesting journey that opened up a whole new world for me . . . this competition showed me that [RI] is . . . necessary." Other students were motivated by industry playing a key role in the event: "It was a great experience . . . this competition opportunity with MathWorks and FİGES was very important for every engineering student." By including industry members in RAI activities, it may help students to see the relevance of responsibility practices in their engineering training.

4 SUMMARY AND ACKNOWLEDGEMENTS

4.1 Improving Awareness of RAI in Engineering Education

Through the "critical participation" experiment described in this paper, the authors learned a great deal about implementing an RAI competition (Downey, 2009). This type of activity has the potential to help students and innovators start to imagine alternative innovation paths. Collaborative efforts that highlight social knowledge are increasingly important to include in engineering training, especially in the area of artificial intelligence. The applied fieldwork project provided an opportunity for students to focus on the role of responsible AI development in their future career. Some students indicated that the RAI competition helped to motivate them to learn about responsibility practices. For example, they discovered that innovators integrate privacy, explainability, discrimination and other key ethical aspects into technical developments. The RAI working group, through this manuscript, hopes to collect feedback and ignite constructive discussions to improve on the RAI competition outcomes. Based on the experience gained from the industry-university RAI collaboration at Bilkent University, the authors are working to create a blueprint for a student competition that can be expanded to other universities, beginning with a national contest in Türkiye. The next steps are to progressively expand the RAI competition to other engineering course of studies at Bilkent University. Afterwards, leveraging the solid partnerships of MathWorks and FİGES with other universities in Türkiye, the basis for a country-wide competition can be established. The RAI competition is not only vital for raising awareness among students about AI ethics but also serves to engage other industries in Türkiye in meaningful discourse on the subject. It has the potential to be a catalyst for establishing a community that bridges industry and academia, with a shared focus on responsible innovation.

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REFERENCES

Downey, Gary Lee. "The Engineering Cultures Syllabus as Formation Narrative: Critical Participation in Engineering Education through Problem Definition," University of St. Thomas Law Journal 5, no. 2 (Winter 2008): 428-456. https://heinonline.org/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/usthomlj5&section=23

Downey, Gary Lee. "What is engineering studies for? Dominant practices and scalable scholarship." *Engineering Studies* 1, no. 1 (2009): 55-76. https://doi.org/10.1080/19378620902786499

Downey, Gary Lee and Teun Zuiderent-Jerak. "Making and doing: Engagement and reflexive learning in STS." In *Handbook of science and technology studies,* edited by Ulrike Felt, Rayvon Fouché, Clark A. Miller, and Laurel Smith-Doerr, 223-250. Cambridge: MIT, 2016.

Downey, Robin Ann. "Discovering Sustainability Practices In Research and Innovation Sites." Paper presented at SEFI: Engineering Education for Sustainability, Dublin, September 12, 2023. https:// doi.org/10.21427/A4WQ-5M48.

Feenberg, Andrew. *Transforming technology: A critical theory revisited*. Oxford University Press, 2002. https://doi.org/10.1093/oso/9780195146158.002.0001

Friedman, Batya. "Value-Sensitive Design." *Interactions* 3, no. 6 (1996): 16-23. https://doi/pdf/10.1145/242485.242493

Future of Life Institute. “Asilomar AI Principles.” Last Modified August 11, 2017. https://futureoflife.org/open-letter/ai-principles/

Gibney, Elizabeth. "What the EU's tough AI law means for research and ChatGPT." *Nature* 626 (February 16, 2024): 938-939. https://doi.org/10.1038/d41586-024-00497-8

Heer, Jeffrey. "The partnership on AI." *AI Matters* 4, no. 3 (2018): 25-26. https://doi.org/10.1145/3284751.3284760

Li, Wenda, Tan Yigitcanlar, Alireza Nili, and Will Browne. "Tech Giants’ Responsible Innovation and Technology Strategy: An International Policy Review." Smart Cities 6, no. 6 (2023): 3454-3492. https://doi.org/10.3390/smartcities6060153

MathWorks Inc. “Responsible AI Hackathon.” Last Modified February 25, 2023. https://la.mathworks.com/academia/student-competitions/responsible-ai-hackathon.html

MathWorks Inc. “Building a Responsible AI Pipeline.” Last Modified October 5, 2021. https://www.mathworks.com/videos/building-a-responsible-ai-pipeline-1633579165223.html

Metz. Cade. “The ‘Godfather of AI’ Leaves Google and Warns of Danger Ahead” *New York Times*. May 1, 2023. https://www.nytimes.com/2023/05/01/technology/ai-google-chatbot-engineer-quits-hinton.htm

Milmo, Dan. “UK’s AI Safety Institute ‘needs to set standards rather than do testing” *The Guardian*, February 11, 2024. https://www.theguardian.com/technology/2024/feb/11/ai-safety-institute-needs-to-set-standards-rather-than-do-testing

Milmo, Dan and Kiran Stacy. “Tech Firms to Allow Vetting of AI Tools, as Musk Warns all Human Jobs Threatened.” *The Guardian*, November 3, 2023. https://www.theguardian.com/technology/2023/nov/02/top-tech-firms-to-let-governments-vet-ai-tools-sunak-says-at-safety-summit

Morandín-Ahuerma, Fabio. "Montreal Declaration for Responsible AI: 10 Principles and 59 Recommendations." OSF Preprints. September 20, 2023. https://doi.org/10.31219/osf.io/sj2z5

Science Technology and Society. “Responsible Artificial Intelligence Awards.” Last Modified May 15, 2024. http://ge301.bilkent.edu.tr/activities/responsible-artificial-intelligence-competition/

Stilgoe, Jack and Maynard, Andrew. “It’s time for some messy, democratic discussions about the future of AI.” *The Guardian*, February 1, 2017,

https://www.theguardian.com/science/political-science/2017/feb/01/ai-artificial-intelligence-its-time-for-some-messy-democratic-discussions-about-the-future

UK Research and Innovation. “Responsible AI UK Funding Calls.” Last Modified April 15, 2024. https://rai.ac.uk/funding/

van de Poel, Ibo. "Design for values in engineering." In *Handbook of Ethics, Values,and Technological Design: Sources, Theory, Values and Application Domains*, edited by Jeroen Van den Hoven, Pieter E. Vermaas, and Ibo Van de Poel, 667- 690.Springer Science+Business Media, 2015. https://doi.org/10.1007/978-94-007-6970-0_25

MENTORING MATURE STUDENTS: EXPLORING PEER MENTOR EXPERIENCES AT A PRE-UNIVERSITY ENGINEERING PROGRAMME

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ABSTRACT

Many positive outcomes have been associated with peer transition mentoring at university, there is however limited research on the influence of the mentor-mentee relationship when both sides are mature students. This project investigates how the mentor-mentee relationship influences the development of the mentors' professional skills, such as empathy and interpersonal communication by exploring the experience of engineering peer mentors with mature students in a preparatory engineering programme at a UK university.

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Through semi-structured interviews and thematic analysis, the study aims to deepen insights into mentor-mentee dynamics and learning outcomes, providing guidance for future mentoring initiatives and student support strategies and highlighting the areas where further training of the mentors may be required.

Outcomes indicate that mentors benefited from improvements in their professional skills and some even developed friendships with their mentees. They were surprised by how the experience positively affected them, highlighting the reciprocal nature of mentoring relationships. At the same time, they also reported cases of breakdown of trust and feelings of isolation.

The findings of this inquiry carry implications for the future development of mature student mentoring initiatives, particularly concerning mentor recruitment and preparation. The ongoing project aims to expand our understanding of mentoring in engineering education, especially with traditionally marginalised groups of students and mentors.

1 INTRODUCTION

1.1 Background

The benefits of peer mentoring are well documented, especially for traditionally marginalised student groups (Atkins et al, 2020), (Dennehy & Dasgupta, 2017).

Research on peer mentoring and the mentor–mentee relationship includes qualitative studies exploring the peer mentors' experiences with their mentees. These studies have shown that peer mentors gain significant benefits in their interpersonal skills, such as communication, listening, and assertion (Holt and Lopez, 2014).

This study is looking at a pre-sessional peer mentoring initiative that ran at the authors' institution, a British research-intensive, highly selective, large, multidisciplinary university in 2023-2024. The initiative supported mature students who were admitted to a general engineering preparatory programme that aimed to provide access to a range of engineering degree options to students that do not fulfil the usual entry requirements for engineering, including mature students.

In the UK a mature student is someone who is over 21 years old at the start of their Undergraduate degree. In the 2022-23 academic year only 12 students out of the over 900 newly enrolled in the first year of this institution's Faculty of Engineering programmes were classified as mature students. However, the preparatory programme attracted a high proportion of older applicants and eight of this first cohort of 20 students were mature students. The mature students who participated in this programme ranged in age from 22-49.

According to the Office for Students, the UK's independent regulator for higher education, mature undergraduate students are more likely to come from traditionally marginalised or underserved backgrounds (ethnic minorities, people with disabilities, first generation students etc.), (OfS, 2020). They are also more likely to drop out of their course than younger students (84% as opposed to 94% continuation in 2017-18). Therefore, it is recommended that mature students receive enhanced support during their transition to higher education, in foundation years and the first year of study (OfS, 2020). Several Higher Education providers offer support specifically tailored to mature students (LondonMet, 2022) and the value of prearrival transition schemes is well documented (Lefever and Ahmed, 2015), (Morgan, 2012).

For this reason, and in line with practice at other higher education providers, a mentoring programme was established specifically for mature students, to help them ease into return to study. This was in addition to support offered to the cohort as a whole. The activities planned followed recommendations from other HE institutions (Lefever and Ahmed, 2015), (Exeter, nd), (Morgan, 2012).

The study aims to validate existing research and uncover findings regarding the experiences of mentors of mature students. and especially which aspects of the mentor- mentee relationship require the most support and training.

While university mentorship schemes can provide valuable support to both students and mentors, their successful implementation requires continuous planning and communication (Fishman, 2021). A study conducted in Australia examined the effectiveness of a peer-assisted program specifically for mature Health Science students. Mentors reported positive experiences, expressing personal satisfaction from aiding mentees and simultaneously developing their own leadership skills (Hryciw et al, 2013). Minor (2007) further supports the view that mentors develop leadership skills as they have to solve the problems and challenges that mentees encounter. Mentors also enhance their own study skills, ultimately leading to the improvement of self-esteem and confidence (Drew et al, 2000). Holden (2006) attributed the benefit to mentors to self-reflection and internalisation of their own experiences. Consequently, past literature shows the significant benefits of peer mentoring programs for mentors.

However, mentors also report poor communication with mentees (Gunn et al, 2016) or indicate that mentoring is unexpectedly demanding (Heirdsfield et al, 2008). Numerous studies also highlight issues in peer mentoring programmes, particularly with mature students. These include cultural differences and unclear mentoring information (Chester et al, 2012; Golding and O'Beirne, 2003). Despite these limitation and challenges, mentors' personal capacity may further improve in the process between tackling challenges and self-regulation (Heirdsfield et al, 2008).

2 METHODOLOGY

2.1 Scheme setup

This research is work in progress and builds on an earlier pilot study on transition mentoring (Economides *et al*, 2022). The earlier study examined transition mentors' perceptions of the transition mentoring scheme of the institution. Following the pilot study, a new mentoring scheme was developed specifically for the engineering foundation programme students and was implemented in the 2023-2024 academic year. Here we are presenting the findings of this work in relation to the experience of the mentors who participated in the initiative for mature students. A separate study of the experience of the mature students is under way. A review of the scheme will then be conducted, with a view of implementing changes for the next academic year. A summary of the activities of the project in 2023-2024 are given in Table 1.

Table 1: Timeline of the project activities

Dates	**Activity**

July- August 2023	Recruit student mentors and research assistants
July- August 2023	Invite offer holders to fill in survey/ gather information on expectations and concerns
September 2023	Pre-sessional mentoring sessions (online or face to face) up to three sessions per student
October- December 2023	Mentor meetings
December 2023	End of term survey
January 2024	Collect data on student performance
February-March 2024	Mentor meetings (optional)
April 2024	Individual interviews, qualitative analysis
May 2024	Mentor meetings (optional)
June 2024	New cycle for 2024 offer holders begins
September 2024	Follow up survey/ interviews on expectations for Year 1
December 2024	Interviews and progress check

In August 2023 six students were recruited and trained as mentors. Since the programme of study for which they were recruited was presented for the first time it was not possible to find previous attendees who could act as mentors, so with the help of the Mature Student Society and the Society of First Generation Students, mentors from across the university were recruited, with a preference for students of STEM subjects.

The criteria used for recruitment included knowledge of DEI issues, previous mentoring experience, experience of being an older student and willingness to support other students. The mentors ranged in age from 23-50 and had all studied for an undergraduate qualification as mature students, either at this or another university. Most of them were active in the institution’s Mature Student Society.

The mentors attended paid training, where an emphasis was placed on active listening skills and where they had the opportunity to reflect on their own experiences and expectations. The training also included guidance on how to navigate potential problems and provided a model for topics of discussion. It was explained to mentors that mature students have different concerns than the average 18-year-old student, for example: family obligations, concerns about returning to education, concerns about the future or about having made the right choice by going to university (OfS, 2020).

Mentors were then matched to mentees of a similar age, gender and, wherever possible, similar degree subjects, as it has been shown that such pairings lead to improved rapport and better outcomes (Blake-Beard et al, 2011). The mentees were introduced to their mentors in early September and had three meetings with them before the start of the academic year. The meetings were held online and were followed by a “meet your mentor” session during university induction week. Mentors and mentees were given vouchers that could be used around the university cafeterias, so they could get to know each other in a casual setting.

Mentors were also asked to fill in a form after every mentoring session where they described the activities carried out, topics discussed and any concerns. A member of academic staff with relevant experience acted as a point of contact in case of problems and had meetings with mentors who wanted to discuss their work.

From the start of the academic year the mentors continued working with their mentees on a regular basis for the first term and it was recommended that they have a "catch up meeting" in the second and third term. Mentors and mentees could arrange for more meetings if they wanted to.

2.2 Data collection

The study received ethical approval from the institution. All participants were over 21 years old at the time of the study and provided informed consent. Participants were informed that their names would be pseudonymised and their true identities known only to three researchers. They were also advised that they could retract any information shared, ensuring it would be excluded from the analysis.

The primary method of data collection was semi-structured interviews, which were then transcribed by the interviewers and coded using an inductive thematic analysis. A structured interview protocol was designed to guide the discussions, featuring a range of questions and follow-up prompts to facilitate the conversational flow of each interview (Jacob and Furgerson, 2012).

At the end of the programme, the semi-structured interviews were carried out by student research associates. This intended to narrow the gap between the mentors and the interviewers in the hope that mentors would be reflective, open and critical of their experience. The research questions intended to capture the learning, personal development and thoughts on potential growth of the mentors.

Of the eligible participants two chose not to participate, citing a lack of interest, reducing the number of interviews to four. These four participants were mentoring at the time eight mature students.

Each transcript was subsequently reviewed by the researchers and finalised. All recordings were then deleted.

Thematic analysis was used to help identify common experiences and to help identify best practice. Thematic analysis is used to recognise and interpret patterns or themes, frequently leading to new insights and comprehension (Boyatzis, 1998).

3 RESULTS

Some positive case studies were observed early on in the scheme, especially with students over 25. For example, an older mature student was feeling overwhelmed by the documentation required by the Admissions Office in order to process enrolment. The mentor went above the expectations of the role, to help the student reconsider. The mentor also helped the mentee with organising a language test and offered ongoing support until the start of teaching. Another mentor arranged a tour of a biomedical lab for some mentees and discussed future job opportunities with them.

However, there was also a rift between a mentor and a mentee that led to the mentee no longer participating in the scheme and some other mentors described their relationship as just “professional”.

Most mentors felt that they developed a range of professional skills, with communication being the most common skill developed, followed by empathy and listening. Other benefits of participation included insights into their own education path and personal growth.

Two key themes emerged from the study: the value of the mentor-mentee relationship and the professional skills that mentors developed from their mentoring experience.

3.1 Value of the mentor-mentee relationship

Findings relating to the mentor- mentee relationship are discussed in terms of two subthemes: Role perception and rrewards, respect and friendship

Role Perception and Rewards: All participants believed that the mentoring process can bring personal rewards to mentors, such as satisfaction. One participant noted, *“…mentoring is simply about facilitating the development of your mentees”.* Others expressed similar beliefs:

- *“We are trying to equip them [mentees] with the right tools and strategies that will support their idea of success”*
- *“I hope that my mentees will not have to go through so many iterations of mistakes or struggles [as I had]”*
- *“The reason I participated is that I wanted really to give them help and advice as a mature student myself”*.
- *“The role of a mentor is to provide an outside listening ear, a sounding board, but also access to networks and opportunities […] that might not be available through other routes”*.

One mentor said: *“I'm not seeking out something to put on a CV. I'm not seeking out something to use in my future career”.* This mentor joined the program to support mature students making major life changes. Additionally, they were motivated by a desire to support women entering the field of engineering.

Personal growth was also cited as a reward of the role:

- *“[It gave me] more of an opportunity to support myself with my observation of other people's personal experiences”*
- *“I wasn't expecting it would help me think about how I approach my own studies”*
- *“I will definitely use this during my graduate scheme when I graduate”*
- *“I didn't go into it expecting to learn […] So, the fact that I've got something out of it as well is an absolute plus”*

Respect and friendship: Some mentors felt sharing their personal experience increased openness from mentees, resulting in more fluid interactions and respect.

- "*After one or two meetings, I feel like I and my mentees, developed [a relationship] for us to be comfortable talking to each other about more personal stuff*".
- *"I think there was a lot of mutual respect. There was an openness to share the experience of mentoring. It was very friendly."*
- *"But I feel like the mature mentor relationship was just totally different really. It was more personal".*

However, some mentors described their relationship as a professional exchange, making it inappropriate to form friendships: *"I would say my relationship with my mentees was just professional. We set up a meeting time. We talk about the problems, I give them my advice, and answer any questions they have and it's just formal communication".* One participant wanted the relationship to extend to friendship, but the mentees did not reciprocate: *"I was hoping we could be more of friends […] and kind of possibly hang out or talk more often. But from the way it was at the end of the day, I'm still called a mentor".* In this situation, meetings could become forced *"After a certain number of meetings, the conversation dies […] They don't need you anymore. So, the meeting that you have feels forced and it ends up finishing quite sooner"*.

One mentor described a relationship that broke down, *"There was unfortunately a loss of trust and there was an imbalance in terms of [what] we could achieve."* The dissimilarity of mentor-mentee backgrounds was also noted in this interview, in terms of fulfilling mentee academic needs: *"It would be interesting to know from them, particularly the one that it did not work out whether it mattered to her, that I wasn't from the same department."*

The experiences of the mentors seem to align with Golding and O'Beirne's (2008) findings when mentors and mentees engage in discussions or pass down knowledge, although some mentors described their relationships as formal. The relationships that remained formal appear to align with Heirdfield et al (2008) and will require further investigation in the future.

3.2 Professional skills development

Findings relating to the mentors' skills development are discussed in terms of the following subthemes: Communication, Active Listening, Organisational skills and Empathy.

The findings indicate that most mentors felt that they developed a range of professional skills, with improved communication skills and active listening being the most noticeable intangible assets gained through mentoring.

Communication: Mentors adapted their communication approaches to suit the characteristics of mentees. This approach includes giving positive feedback and reinforcement:

- *"I learned how I can phrase advice without sounding a bit patronising or a bit bossy"*
- *"Eventually what I ended up learning is really communication skills".*

Active Listening: The interviews highlighted improvements in the mentors' ability to actively listen:

- *“…in terms of specific skills, I have worked hard at active listening, and I think I've gotten better at active listening.”*
- *“I don't particularly do anything other than encourage active listening. I've not noticed any development in soft skills”.*
- *I felt more a bit like a therapist, I would say, which is something I never really done before because I'm an engineer”.*

This skill fostered two-way discussions, making interactions more engaging, as one participant said: *“You don't want to be the one who's always doing the talking, and for them to be sitting there as a chore waiting for you to finish so they can hang up. Just try to listen more and ask questions.”*

Empathy: Empathy was discussed by participants. This skill can relate to active listening and to the diverse backgrounds and issues, both academic and non-academic, that each mentee faces.

- *“[I have been] developing this empathy by really listening and trying to really relate to what they are feeling and what they've been through.”*
- *“Most of them came from a hardship background and it was mostly us talking about it and me relating [coming from a similar background], how I ended up at uni, and that was the foundation for all of the communication we had”.*

Organisational skills: Mentors also mentioned organisational skills, particularly in keeping track of their respective mentees with different characteristics, as one mentor described, *“…keeping track of three different people with three different lives, and three different hobbies, that was quite tricky to manage…”*.

Several professional skills appear to align with previous research. For instance, communication skills, as noted by Hryciw et al. (2013), were frequently mentioned by mentors based on their experiences. Additionally, participants reported variations in mentees' characteristics, which required them to accommodate different needs and personalities, thereby enhancing their organisational skills (Calder, 2024). Insights gained from mentors, who were able to develop empathy, indicate that this specific skill can be cultivated due to the diverse backgrounds of mature mentees (Beltman and Schaeben, 2012).

3.3 Discussion

This qualitative study sought to understand how mentors of mature students in one university in England experience mentoring. Results generally agree with the findings of Marshall et al (2021).

In order to enhance understanding of the mentor experience, Social Exchange Theory (SET) (Molm, 2006) has been applied to analyse the themes, looking at the rewards and costs for mentors. It can be seen from the themes that peer mentors gain rewards such as personal satisfaction from helping others succeed. They also receive respect and the potential development of friendships within the mentoring group.

Costs and Risks: Mentors invest time and effort in mentoring. There may be emotional costs if the relationship with the mentee is dysfunctional. Or they may feel isolated if they cannot get support from other mentees. Understanding the costs and risks can help us put in place structures that will enhance the mentoring scheme by minimising costs and maximising rewards.

One key aspect that could be improved in the further mentoring process is mentor-mentee matching, including academic background. This aspect could potentially lead to a more mutually respectful relationship and enjoyment, as explained by Gattis et al. (2017).

Our recruitment drive for mentors stressed the altruistic nature of mentoring, but the development of professional skills and personal rewards could be highlighted in future mentor recruitment drives.

The interviews highlighted the need for more support from the university or for managing expectations. While some students were keen to become friends with their mentor, many were content with a close but formal relationship and any mentor training must include information on coping with the disappointment of mentor-mentee lack of rapport and even loss of trust.

A common aspiration among mentors was to foster communication with other mentors to share experiences, common issues and possible solutions, *“It might have been interesting, after the first term, to host a mentoring lunch so that the mentors could get together and talk about it. I mean not to break any confidentiality, but to just discuss what the issues were that had come up and how they had addressed those issues.”*

It would be of interest to be able to investigate further the breakdown of trust that occurred with one mentee. At the time of writing, neither the mentor nor the mentee were able to comment further, therefore it is difficult to draw clear conclusions, but it appears that this is in line with the findings of Heirdsfield et al (2008) regarding mentor- mentee relationship forming. In future the academic contact could be checking how mentors and mentees interact regularly, in addition to the students being reminded that they can get in touch with them and ask them to mediate or mitigate conflicts.

The next phase of this project will include matching of mentors and mentees by subject topic, mentor information exchange sessions and monitoring from the researchers to ensure improved management of expectations.

4 SUMMARY AND ACKNOWLEDGEMENTS

This study underscores the importance of considering the perspectives of peer mentors when designing and implementing a mentoring programme.

Further work needs to be carried out to compare the mature student peer mentorship scheme with a standard-age mentoring scheme, to see how the age and maturity of the participants makes any difference in the effectiveness of the mentoring and the experience of the mentors. We already know that the concerns of mature students are not the same as those of younger students, so once the scheme is fully implemented in future years, better comparisons will be possible.

REFERENCES

Atkins, K., B. M. Dougan, M. S. Dromgold-Sermen, et al. “Looking at Myself in the Future: How Mentoring Shapes Scientific Identity for STEM Students from Underrepresented Groups.” *International Journal of STEM Education* 7, no. 42 (2020). https://doi.org/10.1186/s40594-020-00242-3.

Beltman, S., and M Schaeben. "Institution-Wide Peer Mentoring: Benefits for Mentors." *The International Journal of the First Year in Higher Education* 3, no. 2 (2012): 33–44.

Blake-Beard, S., M. L. Bayne, F. J. Crosby, and C. B. Muller. "Matching by Race and Gender in Mentoring Relationships: Keeping Our Eyes on the Prize." *Journal of Social Issues* 67, no. 3 (September 1, 2011): 622–43. https://doi.org/10.1111/j.1540-4560.2011.01717.x.

Boyatzis, R. E. *Transforming Qualitative Information: Thematic Analysis and Code Development*. Thousand Oaks, CA: Sage, 1998.

Calder, A. "Peer Interaction in the Transition Process." *JANZSSA: Journal of the Australian and New Zealand Student Services Association* 12, no. 1 (2004): 4–16.

Chester, A., L.J. Burton, S. Xenos, and K. Elgar. "Peer Mentoring: Supporting Successful Transition for First Year Undergraduate Psychology Students." *Australian Journal of Psychology* 65, no. 1 (March 1, 2013): 30–37. https://doi.org/10.1111/ajpy.12006.

Dennehy, T. C., and N. Dasgupta. "Female Peer Mentors Early in College Increase Women's Positive Academic Experiences and Retention in Engineering." *Proceedings of the National Academy of Sciences* 114, no. 23 (May 22, 2017): 5964–69. https://doi.org/10.1073/pnas.1613117114.

Drew, N., L. Pike, J. Pooley, A. Young, and L. Breen. "School of Psychology Peer Mentoring Pilot Programme." In *4th Pacific Rim Conference: First Year in Higher Education*, July 2000. https://unistars.org/past_papers/papers/PooleyPaper.doc

Economides, S. B., B. Gou, K. Noskova, Y. Dai, and A. Preston. "Students Designing For Students: A Peer Mentorship Toolkit For A Cross-Campus, EDI, Engineering Transition Scheme." In *Proceedings of the 50th Annual Conference of the European Society for Engineering Education*, 1927-1932. SEFI. https://doi.org/10.5821/conference-9788412322262.1381.

Exeter, University of. "Transition Support and Enhanced Induction Programme." Transition support | Widening participation student support | University of Exeter. Accessed March 12, 2024. https://www.exeter.ac.uk/students/wp-support/transition-support/

Fishman, J. A. "Mentorship in Academic Medicine: Competitive Advantage While Reducing Burnout?" *Health Sciences Review* 1 (2021): 100004. https://doi.org/10.1016/j.hsr.2021.100004.

Gattis, C., B. Hill, and A. Lachowsky. "A Successful Engineering Peer Mentoring Program." In *2007 Annual Conference & Exposition*, 12-133. 2007. 10.18260/1-2--2293

Golding, G., and N. Coveney O'Beirne. "The Mature Student Peer Mentoring Experience." In *Proceedings of the EFYE 2008*, 80.

Gunn, F., S.H. Lee, and M. Steed. "Student Perceptions of Benefits and Challenges of Peer Mentoring Programs: Divergent Perspectives from Mentors and Mentees." *Marketing Education Review* 27, no. 1 (December 16, 2016): 15–26. https://doi.org/10.1080/10528008.2016.1255560.

Harmon, B. "A Qualitative Study of the Learning Processes and Outcomes Associated With Students Who Serve as Peer Mentors." *Journal of The First-Year Experience & Students in Transition* 18, no. 2 (2006): 53-82.

Holt, L. J., and M. J. Lopez. "Characteristics and Correlates of Supportive Peer Mentoring: A Mixed Methods Study." *Mentoring & Tutoring: Partnership in Learning* 22, no. 5 (2014): 415–32. https://doi.org/10.1080/13611267.2014.983326.

Hryciw, D.H., K. Tangalakis, B. Supple, and G. Best. "Evaluation of a Peer Mentoring Program for a Mature Cohort of First-Year Undergraduate Paramedic Students." *Advances in Physiology Education* 37, no. 1 (March 2013): 80–84. https://doi.org/10.1152/advan.00129.2012.

Heirdsfield, A.M., S. Walker, K. Walsh, and L. Wilss. "Peer Mentoring for First-Year Teacher Education Students: The Mentors' Experience." *Mentoring & Tutoring: Partnership in Learning* 16, no. 2 (May 2008): 109–24. https://doi.org/10.1080/13611260801916135.

Jacob, S. A., and S. P. Furgerson. "Writing Interview Protocols and Conducting Interviews: Tips for Students New to the Field of Qualitative Research." *The Qualitative Report* 17, no. 2 (2012): 1-10.

Lefever, R., and U. Ahmed. "Understanding the Value of a Pre-Arrival Transition Summer School for Mature Students." AMOSSHE, August 2015. https://www.amosshe.org.uk/resources/Documents/AMOSSHE_Insight_Understanding_the_value_of_a_pre-arrival_summer_school.pdf.

London Metropolitan University. "The Preparation Mentoring Programme." London Metropolitan University, 2022. https://www.londonmet.ac.uk/about/school-programmes-and-outreach/the-preparation-mentoring-programme/.

Marshall, M., J. Dobbs-Oates, T. Kunberger, and J. Greene. "The Peer Mentor Experience: Benefits and Challenges in Undergraduate Programs." *Mentoring & Tutoring: Partnership in Learning* 29, no. 1 (2021): 89–109. https://doi.org/10.1080/13611267.2021.1899587.

Morgan, M. *Improving the Student Experience: A Practical Guide for Universities and Colleges.* London: Routledge, 2012

Minor, F. D. "Building Effective Peer Mentor Programs." *Learning Communities & Educational Reform*, 2007. http://sites.evergreen.edu/nsilc2016/wp-content/uploads/sites/153/2016/07/Minor-Effective-Peer-Mentors.pdf.

Molm, Linda D.. "Chapter 2 The Social Exchange Framework" In *Contemporary Social Psychological Theories* edited by Peter J. Burke, 24-45. Redwood City: Stanford University Press, 2006. https://doi.org/10.1515/9780804768047-004

Office for Students. "Mature Students." Office for Students, July 27, 2020. https://www.officeforstudents.org.uk/advice-and-guidance/promoting-equal-opportunities/effective-practice/mature-students/.

ON STUDENTS' FUTURE READINESS REGARDING SUSTAINABLE DEVELOPMENT

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ABSTRACT

According to the Swedish Higher Education Act, Higher Education Institutions in Sweden must relate to Sustainable Development (SD), which also means that elements of SD must be given in courses and study programs within Swedish universities. Seen from a perspective of SD, the Higher Education Institutions should give students a preparation to contribute to the society at large, partly based on their profession, and partly through ethical, sensible, and responsible actions. Elements of

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examination can be measured, and this especially applies to elements that are particularly linked to the specific subject given by the universities and taken by the students. What is more difficult to assess, however, is how well this affects the student's future desired skills in influencing the surrounding society in a meaningful way. This contribution aims to investigate what happens afterwards. That is, these studies focus on questions regarding how well the alumni have absorbed teaching elements regarding SD, and how they find themselves being future ready based on their previous studies.

1 INTRODUCTION

According to the Swedish Higher Education Act[2], Swedish universities must adhere to Sustainable Development (SD). In order to see that this has been followed, the Swedish Higher Education Authority[3] given a mandate in 2016 (Finnveden, et al. 2020) to evaluate this obligation via a thematic survey. Unfortunately, this survey showed that a majority of the Swedish universities did not meet the obligations concerning SD in a satisfactory manner (Finnveden, et al. 2020). Thus, the universities were requested to make significant changes, including, by highlighting SD in education. Especially, it was recommended that SD should be based on the United Nations' Agenda 2030[4], and its 17 Sustainable Development Goals (SDGs)

1.1 On Initiatives taken at Kristianstad University

Kristianstad University (HKR), Sweden, which is the home university of the authors of this contribution, was among the universities that needed to make improvements regarding SD. Several initiatives were taken at different levels of the organization. A preliminary investigation was performed to share experiences concerning how SD was approached in different disciplinary areas of the university (Argento, et al. 2020). Moreover, a higher education pedagogical (HEP) course, *Teaching for SD*, for the educators at HKR was initiated to guide and support those educators in their relation to SD and their implementation of SD into their teaching practices (Persson, Einarson and Melén 2023).

Fig. 1. A Process to Achieve Student SD Literacy

Fig. 1 illustrates the context of the HEP course, and where (Persson, Einarson and Melén 2023) addresses that course as a part of a 4-step process towards SD literacy amongst the students. The steps of Fig. 1 are further outlined as follows:

1. To meet the above-mentioned thematic evaluation, an initiative was taken to investigate the circumstances regarding SD within HKR, and where a report among other things proposed the HEP course.
2. The HEP course is designed and announced as available to take to all educators at HKR.
3. The HEP course is implemented and given to the educators. Moreover, a study is conducted to inform about the outcomes of the course in terms of

[2] UHR, The Swedish Higher Education Act (1992:1434) 2023
[3] The Swedish Higher Education Authority. 2024. https://english.uka.se/
[4] United Nations – Department of Economic and Social Affairs. 2022. https://sdgs.un.org/2030agenda

teaching practices, course/program syllabuses, and examination elements at the educators' side.

4. It is identified that to give a full picture of the efforts, there is a need for an investigation on the outcome of the students' readiness to contribute to society from a SD perspective.

Here, the leftmost arrow of Fig. 1 represents the demands put on the universities regarding SD. The rightmost arrow represents the possible impact the students/alumni have on society from a perspective of SD.

1.2 On Initiatives taken at the Dept. of Computer Science at HKR

Several initiatives have been taken at the Dept. of Computer Science, at HKR to live up to demands regarding SD in education. For instance, a one-year master program in Computer Science, open for international students, was developed to especially emphasize SD (Einarson, SEFI 2023). The structure of that program reflects on one hand, technical content, and on the other hand elements especially reflecting concepts of SD. Moreover, projects and thesis work aim to integrating skills in Computer Science-based techniques with practice in consequences on a sustainable society. Thus, students should be prepared to be ready to have positive impact on society through their core profession, and added to this, with a maturity to look at the world from the lens of ethically based actions.

Moreover, (Klonowska, Teljega and Einarson, SEFI 2023) outline of a bachelor study program in Computer Science, and where concepts of SD have been added to elements of courses of that program. The paper illuminates on how such a SD track has been built into that 3-year program, and how that track includes a progression over the study years. Here, (Klonowska, Teljega and Einarson, SEFI 2023) show how the concepts of SD were integrated with practice in Computer Science based activities, such as, programming and system building and cooperation, to introduce the students into an appropriate context. Furthermore, (Klonowska, Teljega and Einarson, SEFI 2023) reflected on students' attitudes towards SD within their study program. A survey showed that while SD was not seen as a significant subject to develop programming skills, it was still considered important that software developers were introduced to aspects of sustainability and ethical issues.

1.3 On Evaluating Future Readiness for SD

It is claimed that higher education contributes to the development of individuals, social involvement, and critical thinking (Regeringskansliet[5]) and furthermore that the higher education institutions shall ensure that the knowledge and expertise found at the higher education institution bring benefit to society (UHR, The Swedish Higher Education Act (1992:1434) 2023). This section has addressed several attempts that motivate that HKR and Computer Science at HKR live up to such benefits. The higher education institutions have the responsibility for the future readiness of the students. Courses and study programs contain the necessary elements of practice, and examinations should furthermore serve as guarantees that the students have achieved a satisfactory level of skills.

Still, as pointed out by the discussions from Fig. 1, and further elaborated on in (Persson, Einarson and Melén 2023), how well the former students, that is, the

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[5] Regeringskansliet (Swedish Government Office). n.d. https://www.regeringen.se/regeringens-politik/hogskola-forskning-och-rymd

alumni, benefit to society is out of the borders of the university. Still, it may be essential to have an understanding of the effects of the educational system. The work of (Persson, Einarson and Melén 2023), points out a need for a larger study across the disciplinary borders to achieve such experiences. However, this contribution will address a rather narrowed down approach and restrict such a study to former students of Computer Science at HKR and limited to former bachelor students. The focus of this contribution lies in answering a question regarding how the former students have adopted their previous studies concerning SD, and how those have contributed to their working situation regarding SD.

1.4 Related work

The Higher Education Ordinance[6] is the framework in Sweden that generally describes the learning objectives that must apply within the Swedish universities. However, the relationship to SD is explained rather weakly and does not provide clear guidance for the syllabus of the university courses. In contrast to this, the global framework and network CDIO (cdio.org) for engineering educations can be mentioned. CDIO provides, e.g., a syllabus with several learning outcomes reflecting on engineering impact on SD, and furthermore guides faculties regarding approaches towards SD through the, so called, CDIO Standards. CDIO has, moreover, inspired to several works, such as, (Chea., Lim, and Chao 2022) and (Adlemo 2023), where SD is shown to be integrated in different educational contexts from CDIO perspectives. CDIO has also provided sources of inspiration at levels of alumni. For instance, (Kovacs 2022) claims that “Alumni studies are often overlooked in engineering education research, despite holding great potential for improving engineering programmes and creating the links that are missed when it comes to university-workplace transitions”. The authors illuminate on a survey where it is shown that in contrary to disciplinary skills, skills regarding ethics and sustainability amongst the alumni were considered weaker. Such results certainly may serve well as feedback to universities for improvements concerning students’ ‘soft skills’.

Furthermore, (Boone, Bromaghim, and Kapuscinsk 2023) especially elaborates on concepts, such as, Green Jobs, or Sustainability Careers, especially with a focus on environmental challenges in work life. The authors propose a set of skills (in much aligned with skills suggested by CDIO), that are desired for careers based on sustainability challenges. An interesting viewpoint of that contribution is the main perspective on skills for job, rather than for university courses. This approach is also discussed by (Salovaara 2022). Here, the author emphasizes that quite much research can be found regarding sustainability elements in education, while the qualitative results of such educational efforts have been less carefully investigated.

In the context of this contribution, it is shown that initiatives for SD in education have been made, but that there is a lack of sufficient studies of the effect on the work-operational context. Such studies may not only show how well-prepared students are but can also provide valuable feedback on the preparatory learning elements.

[6] The Swedish Higher Education Ordinance (1993:100). November 6, 2023. https://www.uhr.se/en/start/laws-and-regulations/Laws-and-regulations/The-Higher-Education-Ordinance/Annex-2/

2 METHODOLOGY

2.1 Context and Participants

In 2020, the Student Center at HKR has initiated its first general alumni survey, aimed at all HKR alumni. The objective was to gather information to improve the quality of the programs. The survey questions were tailored to primarily investigate the students' establishment on the labor market and whether they believe that their skills and abilities meet the program objectives. Since then, an alumni survey has been conducted every year, where new questions with new orientations are added. This study specifically targets the personal development aspect of the alumni from the Software Development program, encompassing the following questions:

Q1: Has the education contributed to increased **self-awareness**?

Q2: Has the education given you a better understanding of your **social relationships**?

Q3: Has the education made you aware of various **societal challenges**?

Q4: Has the education contributed to **increased societal engagement and responsibility**?

In the spring of 2024, questions were designed with a focus on personal and professional growth of our alumni (Software Development) in the light of the principles of SD they acquired during their education. A specific interested addressed the understanding on how their education had influenced their attitudes and actions towards sustainability in different aspects of their lives.

The survey of this study has addressed the following **10 questions**:

1. In your **profession**, how do you see that you took advantage of the teaching/learning elements regarding sustainable development that you received from your education?
2. How has education in sustainable development benefited you on a more **personal** level?
3. Against the background of the knowledge you gained from the education concerning sustainable development, how ready do you feel to face future adaptations based on a *sustainable development **mindset***, **professionally**?
4. Against the background of the knowledge you gained from the education concerning sustainable development, how ready do you feel to face future adaptations based on *sustainable development **mindset***, **personally**?
5. In the context of risks and innovations, how much do you see that *sustainable development **needs*** to be considered?
6. How do you acquire knowledge about which sustainability **goals** (SDGs) are relevant to you (**personally**) and your **professional** life?
7. What sources of information or strategies do you use to identify and understand the sustainability goals that best align with your **professional** activities?
8. Can you share specific methods or resources you have used to stay informed about relevant sustainability goals and how these affect your work and professional life?
9. What initiatives or projects have you been involved in that promote sustainability? What challenges have you encountered?

10. Do you have any comments / reflections?

As can be seen, the above points concern the professional approach to SD of the alumni, as well as the personal. Reasons to this are based on the roles of the universities to educate for the needs of the industry and society at large, and to build a basis for social contributions through social involvement and critical thinking.

2.2 Data collection and analysis

The data were collected from two sources, the alumni surveys administrated by the Student Centre from 2021 - 2023, and the alumni survey conducted in Spring 2024, administrated by the authors of this paper.

The response rates for the alumni surveys from Student Centre varied across the years: in 2021, there were 16 responses, accounting for 27% of the total number of examined students between 2016-2018; in 2022, there were 9 responses, representing 32% of the examined students of the year 2019; and in 2023, there were 26 responses, making up 55% of the examined students of the year 2020. Overall, there were 51 responses out of 210, indicating a response rate of approximately 24%. These surveys were mostly based on quantitative data analysis and Microsoft Excel tool were used for visualizing the results.

For the 2024 survey, 15 out 210 respondents participated, accounting for 7% of the total. This survey was based on gathering qualitative data and Microsoft Forms tool was used. Here, for the answers, we experimented with the NVivo[7] tool. Unfortunately, it did not yield satisfactory results for our intended purpose because we were interested not only in finding common patterns but also in individual responses to understand how alumni applied their knowledge of Sustainable Development in their personal and professional lives. Therefore, a detailed analysis of each answer was conducted. It is worth mentioning that in a similar study (Bohm, et al. 2023), the authors mentioned difficulties of using the tool in analyzing the survey based on qualitative data.

3 Results and Analysis

3.1 Alumni survey 2021 – 2023 – questions focused on Personal development

The questions related to personal development were classified on a scale from 0 to 4. The result is presented in Figure 2.

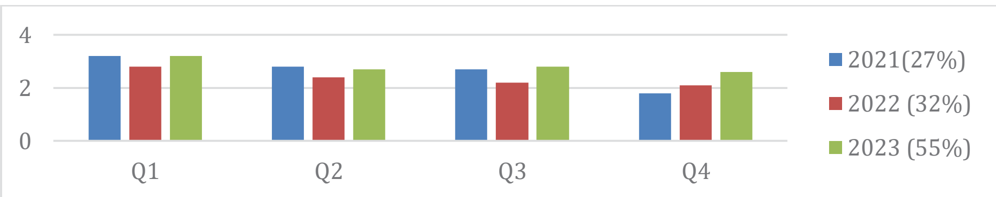

Fig 2. Result of the Personal development - from survey from 2021 - 2023

The alumni responses for questions Q1 – Q3 show relatively little variation across different study periods. A slight increase is in the last question ("increased societal engagement and responsibility"). This suggests that our efforts in collaborative and

[7] NVivo - Lumivero. n.d. https://lumivero.com/products/nvivo/.

diverse project during last years (Klonowska, Teljega and Frisk, SEFI 2023) yielded increased positive results. It also confirms that besides subject knowledge, social contacts, and collaborative project during the education, play a crucial role. This aspect is particularly significant in professions like software development.

3.2 Alumni survey 2024 – questions focused on SDG

Questions 1 to 10 and the corresponding answers were grouped in such a way that 1 to 5 report gradual agreement. The answers to questions 6 to 9 are rather of the 'either or' type, while finally question 10 concerns a pure comment on the question.

Concerning questions 1 to 5. The answers partly corresponded to a scale from 'no agreement at all', to 'meaningful', with 'potentially meaningful' in between. In addition to this, there were answers related to purely technical aspects, where this may be seen as a misunderstanding of the questions regarding sustainability being more about technical sustainability and maintainable software, rather than about SD according to Agenda 2030.

Table 1 shows the distribution of the answers where **T** stands for Technically held answer, **N** stands for No agreement, **P** stands for Potential agreement, and **M** stands for Meaningful. The rows in the table corresponds to *questions 1 to 5*. The content is then exemplified with excerpts from the answers, and where examples on answers are indexed according to **[Row,Column]**.

Table 1. Distribution of answers to questions 1 to 5

	T	N	P	M
1	7	3	2	3
2	2	4	2	7
3	1	3	3	8
4	1	2	2	10
5	3	2	2	8

Generally, the **N** column include leaving out answers, or answers of type ‘No’, ‘Nothing’, or ‘Not applicable’. While being anonymous, the survey still shows that it is in much the same persons that are behind the answers of that column (there is a similar correlation also regarding the other columns). Certainly, there is nothing right or wrong in this, it is just that SD actually have less meaning to some than to others.

One of the respondents seems to have advanced to Master Studies, where SD seems to be significant for that Master study program. Thus, that person completely responds to the **M** column. Below are exemplified some of the responses that Table 1 represents:

- **[1,T]**: In my profession, I learned many different techniques and the process of learning new programming languages from scratch. Today as a consultant for a big company, I can use these elements to adaptively learn new techniques necessary to provide customers the help they need.
- **[1,T]**: Writing tests and having technical dept in mind.

- **[1,P]**: Difficult to say. My studies gave me strong academic skills that are probably very useful in research, while they are not 1 to 1 transferable to software development. Sadly, there are usually not specific recipes on how to do professional software development in a sustainable way, and things like that need to be found out by experience.
- **[1,M]**: While sustainable development was not an integral part of my day-to-day work, the education I received has positively influenced my decision-making process, allowing me to consider sustainability aspects in my professional activities.
- **[2,T]**: Opened eyes for testing and ci\cd.
- **[2,P]**: I try to be more cautious about energy consumption and device usages.
- **[2,M]**: A lot. I became a bit more focused towards the future and the betterment of humanity.
- **[3,P]**: Well I never tested my knowledge so the question not applicable (Feel like not ready)
- **[3,M]**: I think that, given my continuation in academia, SDGs will be an omnipresent factor so I feel pretty well equipped to develop professionally with them in mind.
- **[4,P]**: Don't know, medium level most likely.
- **[4,M]**: Quite ready. Since the SDG's were talked about, I always looked for real life adaptation and to see what I can do.
- **[5,M]**: When it comes to risks and innovations, sustainability is important for several reasons, viability, resilience to risks, environmental implications, and resource efficiency among others.
- **[5,M]**: A lot. The thought is that everything we do has consequences. Better to aim for the positive consequences

Concerning 6 to 9. These questions reflect aspects such as how to acquire information about SD, and experiences around working with SD professionally. The answers can be grouped into Negative and Positive respectively, where Negative generally means that the respondents do not have SD in mind at all, and Positive stands for examining SD and having SD as a perspective in their work.

Table 2 shows the distribution of the responses where **N** stands for Negative response (not contributing) and **P** stands for Positive response (contributing). The rows answer *questions 6 to 9*. Examples of answers are given, and where these are indexed according to **[Row,Column]**.

Table 2. Distribution of answers to questions 7 to 9

	N	P
6	5	10
7	6	9
8	6	9
9	6	9

The almost complete similarity between the values for each row in Table 2 correlates broadly with how the respondents have answered. Although it is not a complete match, it is almost the same groups of respondents behind column **N** and column **P** respectively. There is thus a clarity in how SD has significance in general for the people involved in the survey. Examples of responses are included below:

- **[6,N]**: Apart from common sense, there is no real other way. SDGs are defined as admirational goals (utopian in some cases) and they are politically focused. These things have little to no power in engineering.
- **[7,P]**: To identify and understand the sustainability goals that align with my professional activities, I rely on my workplace's plans and initiatives, as well as additional information from various online resources. These tools help me stay aligned with sustainable practices within my field.
- **[8,N]**: Yes, ignore them completely and use common and experience. The organisation that I work at has it's own goals that are freely available for every employee.
- **[9,P]**: I did the paperwork for a construction company to gain a few ISO certifications that were related to sustainability.

Concerning question 10. There were 8 out of 15 responses concerning further comments or reflections, still, only 3 of those were actually contributing to the question. Examples:

- Learning and applying sustainable development principles has been enriching both professionally and personally. It's inspiring to see how even small changes can contribute to a bigger impact on our planet's health.
- I work as a consultant for a large Ehealth company and am not doing any development, so the questions are not currently relevant unfortunately.
- It would be more useful to focus on sustainable development in terms of business practices instead of learning about it in abstract as defined by UN. Reframing sustainable development as scalable, affordable, maintainable and accessible software would be more beneficial in the long term, would allow it to include software specific goals. It would also provide a channel for the real world, practical applications and examples which would help students understand and internalize the concepts. Reduced inequality means nothing on its own, having accessibility support means reaching more users which results in higher profits. Economic growth means nothing, but prioritizing long term success over short term gain is a good business practice. I could go on and on, but I think I'll end here.

4 SUMMARY AND ACKNOWLEDGEMENTS

As pointed out by, e.g., (Kovacs 2022) and (Salovaara 2022), there is a lack of research on study outcomes in the context beyond the university studies. This contribution approaches alumni skills with respect to SD literacy, according to the fourth step of Fig. 1. That step corresponds to the main research question of this paper, and more precisely, investigations regarding the level of readiness of alumni with respect to SD, on a professional basis as well as personally, and this as an effect universities' educational elements. The study behind this contribution has a focus on alumni from the Computer Science dept. of the home university of the authors. Still, the mentioned fourth step of Fig. 1, corresponds to more full-scaled studies concerning several disciplinary programs, and hopefully, this contribution may be a starting point of such. Such studies may also open for reflections on differences in alumni's attitudes towards SD with respect to disciplinary background.

To begin with, the investigations of this contribution have shown that there is a general awareness of SD amongst the alumni. Moreover, it can be seen that SD has no major role in their professional practice. This can certainly be considered natural as the programming profession itself does not directly relate to SD. It is rather at a level of project management and product development where SD can be seen as significant. The alumni behind this study have mostly not reached such levels, and thus cannot see SD as essential to their work, beyond common sense reflections. The low response rate may possibly also reflect this, a case only can be answered by future surveys.

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5 REFERENCES

Adlemo A., “A Framework for a Sustainability Transition of two Engineering Master’s Courses”, “*Proceedings of the 19th International CDIO Conference”*, 67-83, NTNU, Norway, 2023

Argento, D., Einarson D., Mårtensson L., Persson C., Wendin K., and Westergren A.. "Integrating sustainability in higher education: a Swedish case”,." *International Journal of Sustainability in Higher Education",* 21, no. 6, 1131-1150, 2020

Bohm, N.L., Klaassen R.G., and Bueren E.M. v, and den Brok P.. "*Between Flexibility and Relativism: How Students Deal with Uncertainty in Sustainability Challenges*.", "*European Society for Engineering Education,. SEFI*", 212 - 221, 2023.

Boone C., Bromaghim E., and Kapuscinski A.., "*Sustainability Careers*", "*Annual Review of Environment and Resources*", Vol. 48:589-613, 2023, doi.org/10.1146/annurev-environ-120920-105353

Chea S., Lim L., and Chao Y., "*CDIO for Education for Sustainable Development using Common Core Curriculum*", "*Proceedings of the 18th International Conference*", Reykjavik, Iceland, 2022.

Einarson, D. "*On A Computer Science Master Program For Sustainable Development*". "*European Society for Engineering Education.*",. Dublin, Irland:, 2023.

Einarson, D., Fredrik F., Klonowska K.,. "*Work-Based Learning in Computer Science Education: Opportunities and Limitations*", "*18th CDIO International Conference".* Reykjavík, Iceland: CDIO, 2022.

Finnveden, G., et al. "*Evaluation of integration of sustainable development in higher education in Sweden*." *International Journal of Sustainability in Higher Education* ", 21, no. 4, 685-698, 2020.

Klonowska, K., Teljega M., and Einarson D., "*A three-year academic track towards literacy in Sustainable Development: - A Computer Science Study Program Case*." "*European Society for Engineering Education: Engineering Education for Sustainability",.* Dublin, Ireland, 2023.

Klonowska Kamilla, Teljega M., Fredrik F., "*Engaging Students Through Innovation in Computer Science Education*" *,* "*European Society for Engineering Education: Engineering Education for Sustainabilit*y". Dublin, Irland:, 2023.

Kovacs H., ICapdevila I., and Jermann P., Lermigeaux-Sarrade I., "*From University to Work: Alumni Viewpoints*", "*Proceedings of the 18th International CDIO Conference*," Reykjavik University, Iceland, 2022

Persson, C., Einarson D., Melén M.. "*Educating the educators to be a driving force in higher education towards sustainable development*.", "*International Journal of Sustainability in Higher Education*", 24, no. 9, 197-212, 2023.

Salovaara, J., "Sustainability Alumni at Work—Interviews on Educated Sustainability Professionalism", "*MIDP Sustainability*", 14(22), 14774; 2022, https://doi.org/10.3390/su142214774

TEACHING TECHNOLOGY AND POLITICS:
FROM A LESS DESIRABLE TO A PREFERRED DIGITAL NATION

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Conference Key Areas: *Teaching social and human science to engineering and science students | Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing*
Keywords: *Civic Tools - Responsible Engineering – Sustainable Future – Digital Society - Democracy*

It is hard to imagine a "different" Internet, but the character of the Internet as we experience it today is,
in fact, contingent on key decisions made in the past... – David D. Clark (Clark 2016)

ABSTRACT

Digital nations are embedded in a globally connected civilization largely supported by centralized technology mostly designed with an exported ideology. Our aim is to transform education to enable the conditions for regional innovation and sustainability. Engineering curriculums have a tendency to disassociate technology from politics, despite that responsible engineering requires an interdisciplinary perspective. The EPFL computer science bachelor course *CS-234* has been offering a broad but hands-on introduction to technologies for human self-organization since 2019 once per year. Unique in its own, this course blends political and computer science while creating a coherent and interdisciplinary narrative for the younger generation, i.e., connecting the dots between the evolution of governance, historical roots of democracy and design choices in state-of-the-art technologies for organization. Whereas democracy is not a technology in the conventional sense of hardware and digital software, it can be thought of as a form of social technology that structures how societies operate and make decisions. We argue that education

cannot disengage technology from politics. Educational programs that blend technology and politics may enable a path for responsible engineering the digital infrastructures that will take us from a less desirable to a preferred digital nation. We share our experience with the course CS-234 and suggest improvements based on teaching experiences and students' feedback. We believe that an interdisciplinary and evolving curriculum can help addressing some of the complex challenges that future engineers will have to face. Yet, many questions remain unanswered.

1. Introduction

The work of scientists, engineers, and other technological innovators has brought about transformative improvements for society by revolutionizing communication, information access, business innovation, and scientific progress. Consequently, many aspects of our life and work are becoming digital, and governed by algorithms and networked systems. The term digital nation has emerged as a common way to describe countries in which digital technology is integrated into all aspects of the country's social, economic, and political systems.

In digital nations, urban and rural citizens, government, academia, and the industry use technology to interact with each other generating value that should benefit everyone. However, the realization of these benefits greatly depends on the design of the digital infrastructures that support society. The architecture design can foster or hinder accountable association, economic growth, and fair competition. To illustrate, personalized content on streaming content and social media enhances user engagement and improves user experience since recommendations are aligned with user's interests. On the other hand, algorithms for personalized recommendations can increase polarization and promote the generation of echo chambers. From the perspective of democratic governance, the diversity of technological solutions weakens governmental capacity to control information flows, while, at the same time, increases decentralization and, with that, the opportunities for local governments to connect better with their citizens (OECD 2019). Given the existing challenges and risks of technologies for democratic societies, it becomes indispensable to deliberate on our approach to technological development. A relevant question for responsible engineering is: **How do we design or choose technologies that take us from a less desirable to a preferred situation?**

A modern engineer curriculum includes ethical and social responsibility, emerging technologies, academic literature, and other resources to equip future engineers amid the complex landscape of digital infrastructure. Without a solid foundation, the youth risk being misled by the very technologies meant to empower them, repeating historical mistakes. Thus, the modern curriculum benefits from educational experiences that build a space to raise questions about technology. Why did Usenet fail (Hauben 1995)? Why the Web creator wants to decentralized the web again (Hardy 2016)? What does "redecentralization" mean? Knowing how to answer the previous questions makes the difference between students who understand a power law graph from those students who understand the political powers shaping technological architectures and networks.

Integrating an evolving curriculum that balances technical skills with an understanding of technology's broader societal implications is essential for steering towards a more inclusive and equitable future. This type of education is key to ensuring engineers can thoughtfully address the challenges posed by digital advancements and contribute to a preferred societal trajectory.

Science, technology, engineering, and mathematics (STEM) assemble careers that prepare students with a solid foundation in computer science, along with problem-solving, critical thinking, and technical skills. It is hard to conceive that students can elaborate a well-founded narrative about technology with a traditional technical curriculum because technology is heavily entrenched in our social, cultural, and political behaviors. A caveat is the current disassociation between a rigorous technology education from other topics like for example political science, which are typically studied within the frame of a liberal arts curriculum.

This paper discusses why teaching decentralized technologies and self-organization brings value to STEM careers and helps developing competences for responsible engineering. In section 2, we analyze the relevance of decentralized technologies for the young generation by making the connection between some of our reading assignments with the current activism summarized with the “decentralized the web” motto. Taking the web as an example, we provide historical context on how the web evolved from a decentralized environment favoring freedom of expression and privacy towards client-server architectures that focus mostly on scalability and performance. In section 3, we argue that education cannot disengage technology from politics and discuss how to address teaching gaps, providing as an example the EPFL’s bachelor course for computer science CS-234, which blends both disciplines. Finally, we share expertise to improve the course design with multiple suggestions based on the lecturer’s last semester teaching experience.

2. Relevance of Decentralized Technologies For Democratic societies

In this section, we revisit the foundational principles of the open internet and web, providing context to grasp the evolution of technology over recent decades, as well as to recognize the challenges and their implications for democratic societies.

2.1 The strong feelings associated with decentralization and freedom

Vint Cerf and Bob Kahn, the architects behind the TCP/IP protocol suite—the foundation of the Internet—imbued their creation with a profound sense of openness and interoperability, anticipating its organic growth. The Internet, alongside Usenet and similar networks, fostered a bottom-up design, sparking a revitalization of society (Hauben 1995). In a prescient paper (Licklider and Taylor 1968), Licklider and Taylor depicted the Net as an intricate web of interconnected networks, where individuals, hardware, and software seamlessly unite to exchange computational and human resources. Their vision placed a premium on human interaction and the creative aspects of communication. They envisioned collaborative endeavors that would possess a regenerative essence—unrestricted communication, swift responsiveness, and interactive multi-access computer systems—and "open-endedness."

Recently, the web decentralization argument is enjoying a revival both as a grassroots movement and in academic environments. As the founders of redecentralization.org stated, the values tied up with the culture of an open net and web are freedom, autonomy, collaboration, and experimentation (Bolychevsky 2018). In 2015, Brewster Kahle, the founder of the Internet Archive, initiated a call for a "decentralized web" (DWeb), to put it in other words, a web that looks more like how initial pioneers like Tim Berners-Lee envisioned it (Clark 2014) (Quentin 2016). In 2016, the movement officially started at the Internet Archive, in a start-studded summit event, in which I participated together with Web architects, activist, engineers, archivist, scholars, journalists and other stakeholders to explore the technologies required to build the decentralized web. The DWeb movement raises awareness of the centralization that tech giants brought to cyberspace. Aiming at decentralizing the web, the DWeb wants to encode freedom of expression, privacy, and universal access to all knowledge.

The Web3 is a contemporary burgeoning movement that overlaps to some extent with DWeb, but its origins are traced back to blockchain technologies, cryptocurrencies, and NFTs (Tiffany 2022) (Korpal and Scott 2022). Many people use Web3 and DWeb interchangeably, and even academic researchers are not always aware of the differences in meanings carried by each movement. Both communities care about user self-determination and being in control of data (Tiffany 2022). A distinctive characteristic of the DWeb is its blockchain agnosticism. In addition, the DWeb may include technologies such as community-owned mesh networks (Panayotis et al., 2008) to build own private intranets without relying on a last-mile communication provider. The industry also exhibits a trend to democratization, decentralization, and moving to the edge with offers like IoT-based 5G mesh networks (Petterson et al. 2019) and emerging Web3 topics like decentralized physical infrastructure networks (DePIN). For others, the term Web3 is associated with hype about getting rich in pyramid schemes, and therefore, it receives more scrutiny (Weaver 2021).

Decentralization is not a cure-all, but many consider it is a valid answer to the growing concern about the extreme centralization observed in information communication technologies (ICT). The decentralization trend suggests a general expectation of a more equal Internet and more flexible technologies (open and interoperable). Particularly, peer-to-peer (p2p) technologies not only offer more resilience due to a distributed network, they raise emotions and a unique culture (Agre 2003).

The strong relationship between engineering and politics is rarely acknowledged in engineering courses. Some students, however, welcome opportunities to understand the politics that have shaped design decisions and want to learn skills that will prepare them to address or at least reduce societal challenges. This is at least justified on the enthusiasm raised by these subjects in one-to-one discussions with our students.

2.2. Contrasting the end-to-end argument and centralization

Decades ago, peer-to-peer (p2p) networks were often perceived as unreliable due to inadequate node availability, bandwidth, and other limitations. The consensus has gradually shifted towards the belief that a reliable network is essential for applications to function effectively. A notable counterargument stems from the end-to-end argument (Saltzer et al. 1984), advocating for a clear separation of responsibilities in which lower-level systems or layers should not be burdened with the expectation of providing flawless reliability. The Ethereum network can be seen as a modern system that embraces this argument. Decentralized applications (dApps) are implemented as smart contracts (Szabo 1997) that operate regardless of individual node reliability.

The tension between the end-to-end argument and centralization is at the core of many debates in technology and network policy. Advocates of the end-to-end principle argue that decentralization can lead to more resilient, user-empowered systems that are less prone to censorship and can innovate more freely. Meanwhile, centralized systems often prioritize control, which can lead to efficiencies and easier governance but may also stifle innovation and put privacy at risk.

The strong investment and development in datacenters and the cloud, the consolidation of small internet service providers (ISP) into large ISPs continued to exacerbate centralization, especially in the last two decades. Gradually, academic fellows lost their interest on decentralized p2p networks in part due to the scalability and other promises of datacenter's environments built with distributed systems and centralized governance. Many p2p systems were discontinued for various reasons, sometimes facing legal actions from the media industry and others facing business, network, and management complexities. In the end of 2010, the International Conference on Peer-to-Peer Systems (IPTPS) Workshop, a top venue for research on peer-to-peer systems, was discontinued apparently due to lack of interest (Baochun et al. 2012). With hindsight, such decision ignored that home bandwidth had a 3000-fold increase during the 1988-2011 period and that the Bitcoin network (Nakamoto 2008) started a new page in the history of p2p based systems in 2009.

In essence, the end-to-end argument promotes a vision that empowers end users and developers, fostering an environment of innovation and resilience by distributing functions and responsibilities. Centralization, while offering certain efficiencies and control, can counteract these benefits by concentrating power and potentially inhibiting the organic growth and adaptability that decentralized, end-to-end systems can offer.

2.3. The pervasive client-server architecture and centralization

The Andrew File System (AFS), a distributed file system originating in 1980 from Carnegie Mellon University, played a foundational role in shaping subsequent progress in distributed computing. Expanding on AFS's influence, its successor, Coda, significantly impacted the mobile computing domain. The chief architect of Coda underscored a comprehensive approach, emphasizing scalability, performance, operational feasibility, and security (Satyanarayanan 1992). Notably, Coda's architectural philosophy championed the concept of physical separation between clients and servers, a pivotal principle for realizing scalability, coupled with a security posture predicated on entrusting the fewest possible entities rather than relying on the security of a large number of clients. This asymmetrical client/server architecture pattern is also embedded in the World Wide Web (Berners-Lee 1996).

The trend towards security, efficiency and scalability has led engineering innovations that make human activity more productive and safer. Accordingly, STEM careers give priority to subjects that build competences for designing secure, efficient, and scalable systems, i.e., large-scale systems that respond quickly with a minimal resource consumption and can grow to handle larger workloads effectively.

3. ADDRESSING TEACHING GAPS

The skills taught in STEM careers are crucial not only for increasing students' future employability but also for enabling the industry to recruit from a pool of skilled engineers. Nevertheless, there is an urgent need to further enhance capacity building in responsible engineering and bridge technological gaps in digital nations.

3.1. Teaching technology and politics

We propose a sincere discourse about technology, one that incorporates system thinking and cross-fertilization of at least three disciplines: computer science, political science, and economics. This interdisciplinary approach is essential for our democratic institutions, which inherently blend elements of centralization and decentralization in designs that support both individual and collective goals. As our dependence on ICT increases, it becomes increasingly important to develop a critical thinking mindset to assess how digital infrastructures and technologies respect and serve society's constituents. One pertinent work in the realm of political science is Robert Dahl’s book (Dahl 2008). CS-234 students have to read some of his book chapters to learn Dahl’s criteria for democracy: effective participation, voting equality, enlightened understanding, control of the agenda, and inclusion. This is crucial not only for securing a democratic and sustainable future but also for addressing the micropolitics of everyday online life. Political scientists have raised concerns about how these dynamics, particularly those experienced in Californian-designed software, jeopardize accountable association (Schneider 2023).

To build feasible solutions, the efficiency and scalability arguments and some degree of governance centralization are reasonable engineering principles. But these principles fall short if there is not a solid system thinking framework that protects society from the potential damage that hyper-scalable technologies can directly or indirectly cause to people. Notably, the digital infrastructure colonizing our everyday life is built with an exported "California ideology" as if the scalable Californian apps understand the billions of the world and will come to liberate us from the physical tyranny of our democratic institutions and donate us a utopian apolitical digital space.

3.2. Case study: The course CS-234

Fig. 1 – Topics studied in the course CS-234 and its corresponding week. Additionally, week 1 introduces the course and week 14 is dedicated to a recap session

"It's difficult to imagine a world without Computer Science – it's anchored in all of our society's infrastructures."[1] Accordingly, the CS-234 course examines many of those infrastructures, particularly delving into voting technologies, online public forums, participatory systems, scientific peer-review, and digital money. By bringing this content to the curriculum, future engineers learn about civic tools and get prepared to deal with digital society challenges. Students learn how to explore technologies available for societal self-organization, expound key challenges and risks in using these technologies and discuss social implications of digital communication. The lectures incorporate elements considered in digital democracy: identity, economic inclusion, information flow, and democratic deliberation and choice (Bryan 2021).

This course involves a substantial amount of reading background materials, both technical and non-technical and from a variety of disciplines including computer science, social science, political science, and law. The lectures are heavily discussion-oriented requiring from both sides, lecturer and students, to deal effectively with the uncertainties of the discussion dynamics. It implements teaching engineering innovations such as project-based learning (PBL) and a flavor of a flipped classroom.

The intensive reading workload relies on the student's capacity to filter and prioritize content in their self-study hours. Students expressed feeling overwhelmed by the workload. Some students think the lecture should spend more time analyzing assigned readings. A related problem is that having this course in the third semester of a bachelor degree might present more challenges, primarily due to the lack of foundational knowledge required to fully grasp these subjects. For example, one of the assigned readings for week 6 is about "The DAO" attack. The lecture associated with this topic covers several key elements: it introduces blockchain transactions and smart contracts, explains the vulnerabilities that led to the specific attack, and discusses cryptocurrencies. Additionally, it details how smart contracts are employed to crowdsource funds and establish decentralized autonomous organizations (DAOs). The remaining time to discuss the specifics of the assigned paper reading is short.

Another encountered difficulty is the lack of a class reference book to help students finding connections between the taught subjects. The fragility of the course method is that interesting discussions require high class attendance and engagement. However, political theories and discussions about societal impacts are seen as less relevant to the student's career goal. Many students preferred to skip attendance and study along for the exam than coming to the class for having discussions with their peers.

A weekly lecture of two hours duration is limited for discussing in-depth all the topics and related technologies studied in the course (see Fig. 1). For example, the lecture dedicated to The DAO attack introduces Bitcoin and Ethereum blockchains to explain smart contracts and cryptocurrencies which are critical for the attack. To delve into the sustainability of blockchain designs we would need at least to dedicate another lecture to explain the different consensus mechanisms used in blockchains. Consensus mechanisms are studied in more advanced blockchain courses offered by master degrees. A possibly solution would be to increase the number of lecture

[1] As stated in one of the institutional EPFL webpages about the bachelor of computer science.

hours per week to have more flexibility for teaching other topics relevant to responsible engineering.

Teaching this course shall be an evolving experience to include sustainability, and emerging topics like AI with its ethical implications. The current course format also requires changes to be more resilient against environments that might alienate interdisciplinarity. At least, the course would benefit with the enrollment of more mature students at the final stage of the studies.

Additionally, we suggest reviewing the number of credits assigned for this course. Currently, CS-234 gives 5 ETCS and requires lecturing 2 hours per week. Increasing the number of credits will justify adding more lecture hours per week. We suggest change the number of credits from 5 to 8 ETCS without adding more reading workload. To put it in context, this is equivalent to the number of credits given for the course CS-358 “Making Intelligent Things”, which is another interdisciplinary course in the bachelor program. For students, the additional credits would provide a fair incentive for more robust learning and dedication to CS-234 projects. For the lecturer, the additional time would relax the time constrains for in-depth explorations of each subject.

Finally, the students have to work on a group project during various weeks with the goal of collecting solving problem for the campus community. Students have to (1) gather information about the problem, (2) propose an initial potential solution to the problem, (3) engage in discussions over both theirs’ and other teams’ proposals, (4) refine their proposal by incorporating feedback received from other groups, (5) present their final proposals, and (6) participate in an approval voting over all the proposed solutions. The assignment provides some problem suggestions such as lecture room’s capacity, housing cost, lack of internships for bachelor students, etc. Since the cases repeat every semester without a structure it is difficult to improve the assignment. Students complain about the excessive amount of feedback during the debate although handling the feedback is part of the learning activity. Besides, the lecturer finds difficult to connect this exercise with the reading assignments and lecture topics. The topics seem disconnected given the excessive freedom for suggesting problems. This assignment could improve by implementing the case study method. It is possible to create rich educational experience with crafted case studies that can be reused in various semesters. Considering the various technological transformations taking place in the campus, this course can contribute to reflect on past or ongoing transformations through the student’s perspective. The methodology would provide more incentives to prepare and debate cases in class. While the current assignment design requires that students learn to concentrate on what is relevant and ignore the noise, the case study method is a proved methodology to achieve learning outcomes efficiently.

Two well-known examples of this methodology are the Harvard Case Study and the ETH case study developed at the Department of Environmental Sciences at the Swiss Federal Institute of Technology (ETH) in Zurich (Steiner, Laws 2006). The last one requires students to investigate the problem with real-world stakeholders. Closer to the ETH case study, our students also gather information from campus to deepen the debate on certain issues. However, a single ETH case study lasts a semester with 18 hours class a week and is for advanced students in their ninth semester. To implement this method in our course, more thinking needs to be done to craft use cases that work with the limited resources of our course.

4. SUMMARY AND ACKNOWLEDGEMENTS

Future engineers will benefit from a deeper understanding of the implications of technologies. Teaching technology and politics is a reasonable interdisciplinary step towards the education of more responsible engineers. Digital nations need technologies and infrastructure that help individuals to connect, create, and improve their collective decision-making without causing harm.

We also think that more research needs to be done to better understand the risks of decoupling politics from technology. This separation may contribute to polarization, censorship, monopoly, surveillance, and other forms of authoritarianism or abuse.

To conclude, closing the distance between science and liberal arts by teaching technology and politics to bachelor students is a worthy experience that we recommend to expand outside the engineering curriculum, i.e., to political science students.

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REFERENCES

Agre, Philip E. "P2p and the promise of internet equality." Communications of the ACM 46, no. 2, pp. 39-42, 2003.

Antoniadis, Panayotis, Benedicte Le Grand, Anna Satsiou, Leandros Tassiulas, Rui L. Aguiar, João Paulo Barraca, and Susana Sargento. "Community building over neighborhood wireless mesh networks." *IEEE Technology and Society Magazine* 27, no. 1 (2008): 48-56

Berners-Lee, Tim. "WWW: Past, present, and future." Computer 29, no. 10 (1996): 69-77.

Bolychevsky, Irina. "There's more to decentralisation than blockchains and bitcoin" 2018 Accessed: August 26, 2023 https://redecentralize.org/blog/2018/08/18/theres-more-to-decentralisation-than-blockchains-and-bitcoin.html

Clark, David D. "The contingent internet." *Daedalus* 145, no. 1 (2016): 9-17.

Clark, Liat. "Tim Berners-Lee: we need to re-decentralise the web." Wired, 2014.

Dahl, Robert A. "Democracy and its Critics." Yale university press, 2008.

Ford, Bryan. "Technologizing Democracy or Democratizing Technology? A Layered-Architecture Perspective on Potentials and Challenges." Digital technology and democratic theory/edited by Lucy Bernholz (2021): 274.

Hardy, Quentin. "The Web's Creator Looks to Reinvent It." The NeNew York Times Jun-2016. https://www.nytimes.com/2016/06/08/technology/the-webs-creator-looks-to-reinvent-it.html Accessed: March 29, 2024

Hauben, Michael. "The net and netizens: the impact the net has on people's lives." (1995)

Korpal, Gaurish, and Drew Scott. "Decentralization and web3 technologies." 2022.

Larry Peterson, Tom Anderson, Sachin Katti, Nick McKeown, Guru Parulkar, Jennifer Rexford, Mahadev Satyanarayanan, Oguz Sunay, and Amin Vahdat. 2019. Democratizing the Network Edge. SIGCOMM Comput. Commun. Rev. 49, 2 (April 2019), 31–36. https://doi.org/10.1145/3336937.3336942

Li, Baochun, Yuan Feng, and Bo Li. "Rise and fall of the peer-to-peer empire." *Tsinghua science and technology* 17.1 (2012): 1-16.

J.C.R. Licklider and Robert W. Taylor, "The Computer as a Communication Device," reprinted in "In Memoriam: J.C.R. Licklider 1915-1990," Digital Research Center, August 7, 1990; originally published in Science and Technology, April, 1968.

Nakamoto, Satoshi. (2008). Bitcoin: A peer-to-peer electronic cash system.

OECD (2019), Making Decentralisation Work: A Handbook for Policy-Makers, OECD Multi-level Governance Studies, OECD Publishing, Paris, https://doi.org/10.1787/g2g9faa7-en.

Saltzer, Jerome H., David P. Reed, and David D. Clark. "End-to-end arguments in system design." ACM Transactions on Computer Systems (TOCS) 2, no. 4, pp. 277-288, 1984.

Satyanarayanan, Mahadev. "The influence of scale on distributed file system design." IEEE Transactions on Software Engineering 18, no. 1 (1992): 1-9.

Schneider, Nathan. Afterlives of the Californian Ideology| Homesteading on a Superhighway: The Californian Ideology and Everyday Politics. International Journal of Communication, [S.l.], v. 17, p. 17, jun. 2023. ISSN 1932-8036. Available at: https://ijoc.org/index.php/ijoc/article/view/19342. Date accessed: 28 Aug. 2023.

Steiner, G., and D. Laws. "How appropriate are two established concepts from higher education for solving complex real-world problems? A comparison of the Harvard and the ETH case study approach." *International Journal of Sustainability in Higher Education* 7.3 (2006): 322-340.

Szabo, Nick. 1997. “Formalizing and Securing Relationships on Public Networks”. *First Monday* 2 (9). https://doi.org/10.5210/fm.v2i9.548.

Tiffany, Kaitlyn. "The Battle for the Soul of the Web." The Atlantic, Oct-2022. Accessed: August 27, 2023

Weaver, Nicholas. "The Web3 Fraud." 2021.

Delivering Round-the-Clock Study Support in Mathematics Courses to Engineering Students Using Discord: An Experience Report

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Keywords*: Discord, online tutoring, pear learning, round-the-clock help, mathematics education for engineering students*

ABSTRACT

In this paper, the authors aim to share insights gained from a pilot project on self-studies in mathematics courses for engineering students. We propose an innovative approach to tackle the challenges faced by engineering students, including managing academic workload, stress, and time constraints, namely we re-design a

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Discord platform as a dynamic resource where students can partake in discussions, request guidance on course material, join study groups, and obtain personalized assistance from experienced assistants. This independent resource is not integrated into any specific curriculum and it is available to all engineering students belonging to our university that are in need of help for their mathematics courses, This approach has demonstrated a significant positive impact on engineering education by enhancing student engagement, reducing isolation, and improving academic performance. The findings highlight the potential for teaching assistants to facilitate effective learning experiences through interactions on the user-friendly and freely accessible Discord platform.

1 INTRODUCTION

1.1 Background

The transition from high school mathematics to university mathematics is a widely acknowledged challenge internationally. This shift from being a high school student to a university student entails assuming greater responsibility for one's studies, including planning and managing one's academic workload. With larger student cohorts and less direct teacher interaction, students must adapt their learning habits and organizational skills, which significantly affects their academic performance (Jablonka et al. 2017). Self-study is a fundamental aspect of university education, yet many new students struggle to navigate this independently and find effective study techniques (Turan et al., 2022). The university learning environment differs markedly from that of high school, emphasizing the importance of students becoming self-reliant learners. University teaching often lacks the personal support students may have experienced in high school, contributing to feelings of isolation when facing academic challenges (Vinerean et al., 2023). Moreover, research indicates that the transition from secondary to tertiary education, particularly in mathematics-related subjects, is more challenging, leading to higher dropout rates compared to other fields of study. The downside of heightened autonomy is the cognitive overload experienced by learners. Studies indicate that students frequently struggle to work independently (Winsløw & Grønbæk, 2013). Additionally, the vast amount of information available on the Internet can overwhelm students cognitively (cf. Scheiter & Gerjets, 2007, pp. 291–292). Consequently, the importance of striking a balance between required autonomy and provided support has grown in recent years. Teachers must be cognizant of this situation and equipped to address it effectively (Vinerean, 2022).

1.2 Using Discord platform to offer round-the-clock study support in mathematics to engineering students

In the pursuit of academic excellence and the quest to overcome the daily challenges faced by engineering students, from balancing studies to managing stress and time constraints, a novel initiative has been launched. This pilot project, centred on a Discord server, aims to provide round-the-clock study support to engineering students. It is important to note that this service is not integrated into any specific curriculum. Instead, it is an independent resource available to all engineering students at our university seeking assistance with mathematics during the whole period of their studies.

Discord[2] is a communication platform designed primarily for gamers, but it has expanded to cater to various communities beyond gaming as well (Goes*er, 2022;* Lauricella et al., 2022). It offers text, voice, and video chat capabilities, allowing users to communicate with each other in real-time. Discord is primarily free to use. Users can create an account, join and/or create their own server, participate in text and voice chats, and use most of the platform's basic features with no charge. One of the key advantages of Discord is the ability to create servers, which serve as dedicated spaces for groups to gather and communicate. Within these servers, users can create multiple channels, both text and voice, tailored to specific topics or activities, enabling structured and organized conversations which are easy to manage (Soeiro et al., 2023; Farah & Eagle, 2021).

We redesign the Discord platform to facilitate peer-to-peer learning and mentorship, connecting students with experienced peers who have successfully navigated the mathematics courses. This dynamic resource enables students to engage in discussions, seek guidance on course content, participate in study groups, and receive personalized assistance from knowledgeable assistants during the specific courses and after that too. Such an approach aligns with findings by (Owston & York, 2018) who reported that students in blended learning courses with significant online components experienced higher satisfaction and performed better academically. This suggests that flexible and accessible educational support can indeed empower students to deepen their understanding and tackle challenging aspects of their curriculum effectively.

Moreover, the concept of “round-the-clock help” is a direct response to these unpredictable and demanding needs. The round-the-clock availability of the Discord server is crucial not only for academic pursuits but also for mental health, as it reduces the stress and anxiety associated with challenging coursework by providing a continuous outlet and support network. The importance of flexibility in learning environments, as highlighted by (Turan et al., 2022), indicates that perceived flexibility in time and content management can significantly positively affect students’ behavioural engagement and academic performance.

1.3 Related Work

Several studies have explored the use of Discord as an educational tool in various contexts, providing valuable insights into its effectiveness and implementation strategies. Bridson et al. (2022) describe their experience using Discord to provide round-the-clock help to software engineering students inside a specific course. They highlight the platform's capacity to facilitate continuous support and foster a community of learners, which aligns with the goals of our initiative for engineering students. Soeiro, David, and Neves (2023) implemented Discord in a university STEM learning environment, focusing on collective learning and engagement. Their study emphasizes the platform's potential to enhance interaction and support various pedagogical approaches. Their findings underscore the importance of creating a supportive online community, which is a critical aspect of our project as well. Heinrich et al. (2022) explored the use of Discord, Teams, and Moodle for course and cohort communication. Their research provides a comparative analysis of these platforms, offering insights into their respective strengths and limitations. Their work highlights how Discord can effectively complement other learning management

[2] About Discord | Our Mission and Values

systems to create a more dynamic and interactive learning environment. All these studies are supporting the usability and effectiveness of using Discord as a communication tool in teaching and learning. The novelty in our study is that this service is not integrated into any specific curriculum and acts as an independent resource accessible to all engineering students at our university, offering mathematics assistance throughout their entire academic journey.

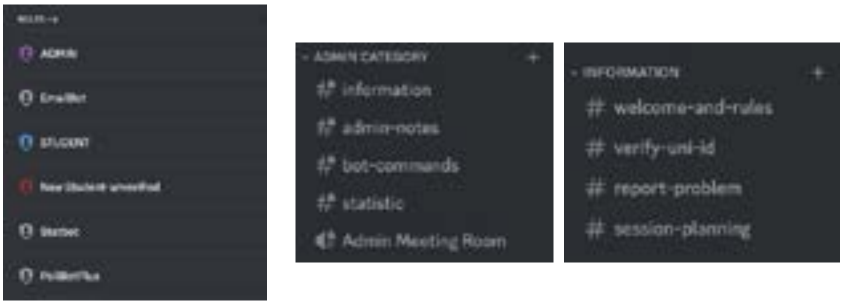
2 METHODOLOGY

2.1 Setting

The project provides support across the different mathematics courses given to both Master of Science in Engineering students and those pursuing a Bachelor's degree in Engineering Technology. The information about the project is given through verbal presentations, clarifying the project's purpose and objectives. Comprehensive information was shared through the courses on the learning management system used by the university, completed with instructions providing a link to join the server, a description and tutorial for new users on account verification and navigation on Discord server. The collective enrolment for these courses stands at approximately 300 students every year.

Two engineering students who have successfully completed the courses in question, employed as assistants at the mathematics department, operate the Discord server. They play a key role in leading and moderating the server, as well as providing direct support to other students. To ensure the quality of support offered, and to aid the student assistants in their development, an associate professor in mathematics mentors them. This mentorship includes regular meetings where the assistants can discuss educational strategies, difficult topics, and other challenges that arise.

2.2 Designing the Discord platform

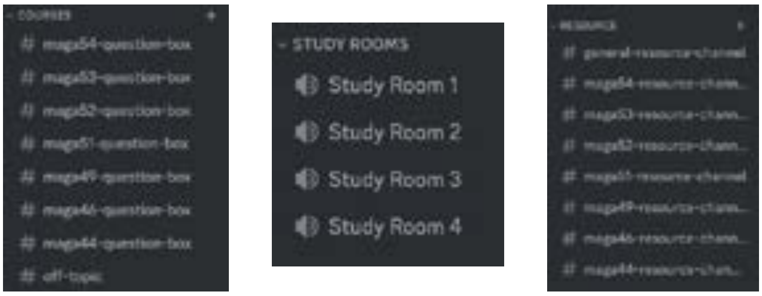


(a) (b) (c)

Figure 1 illustrate the structure of discord (a) Existing roles and bots on the discord server (b)the Admin Category and (c) the Information Category

In the Discord server, roles are segmented and assigned to each student based on their status and the permissions they hold within the server as shown in figure 1(a). The 'Admin' role is granted to helpers who have previously completed the mathematics courses. The 'New Student' role is designated for individuals who have not yet confirmed their student status, serving as a precaution to prevent spam and unauthorized individuals from joining the server. Once a student confirms their status, they are assigned the 'Student' role. This confirmation process is automated within the server using Emailbot. The server is organized into various categories to facilitate easy navigation and structuring for students who may be new to Discord.

Each category, in turn, is divided into text or voice channels. Text channels allow students to write, share images, videos, links, and react to messages. Voice channels offer a broader range of interactive opportunities, including video calls, voice calls, and screen sharing. Within the 'Admin' category, private channels exist where assistants can exchange materials, assist one another, and monitor server statistics as shown in figure 1(b). The 'Information' category features text channels such as 'Welcome' and 'Rules', which outline server guidelines, a simple tutorial on how to confirm one's identity, and a channel for students encountering verification issues as illustrated in figure 1(c). These are the only visible channels to unverified students. The 'Session Planning' channel contains scheduled sessions for the week, aimed at students who prefer to compile their questions and address them directly.



(a) (b) (c)

Figure 2 illustrate the structure of discord (a) Courses, (b) Study Rooms and (c) Resource

Another category features text channels related to the mathematics course as in figure 2(a). Here, students who are currently enrolled in the courses, as well as those who have previously taken it and are preparing for examinations, can post their questions. Polls are continuously conducted on the course content to identify topics that engineering students find challenging, enabling assistants to plan sessions where they can provide further explanations. These sessions might include using visualization tools like GeoGebra or simple diagrams to explain concepts. In the 'Study Rooms', figure 2(b), students receive personalized assistance and participate in group-discussions with their peers. This area allows for the streaming of tablet or computer screens. The 'Resources' section shown in figure 2(c) enables the sharing of external resources that have proven beneficial to assistants during their studies. This may include fundamental concepts deemed crucial for the course, guidance on utilizing mathematical handbooks, calculator functions, and more.

2.3 Research design

The research will be conducted within educational design research (McKenney & Reeves, 2018) involving several cycles as in Figure 3 where the Discord platform is re-designed according to the input from previous phases, implemented and used, and then evaluated both quantitatively and qualitatively.

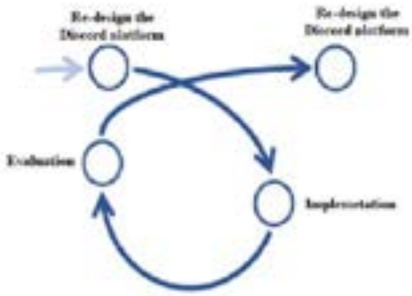


Figure 3 Continuous Improvement Cycle for Discord Platform Redesign

3 RESULTS

3.1 Engagement Statistics

The implementation of the Discord platform for round-the-clock help has seen considerable usage among engineering students. 122 verified students joined the server. There were a total of 1,145 messages sent over the study period, with an average of 52 messages per week see Figure 4(a). This consistent communication suggests a robust level of engagement with the platform for text-bases interactions.

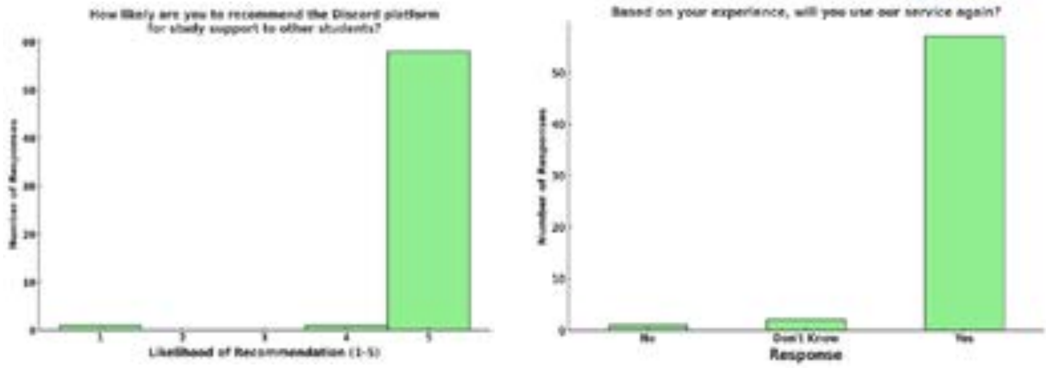
(a) (b)

Figure 4 (a) The chart displays messages sent through the text channels (courses) and (b)The chart displays the usage time of voice channels (study rooms) monitored weekly on the Discord server over the span from January 1, 2024; to June 1, 2024.

Furthermore, the voice chat usage statistics indicate a total of 566.15 hours spent in voice channels, with a weekly average of 25.7 hours. This data points to significant adoption of the platform's voice chat feature for study discussions and suggests a preference for auditory learning and collaboration among students, see Figure 4(b). Notably, 90 unique members, highlighting the widespread engagement and utilization of the voice chat feature across the students, contributed these hours.

3.2 Survey Feedback

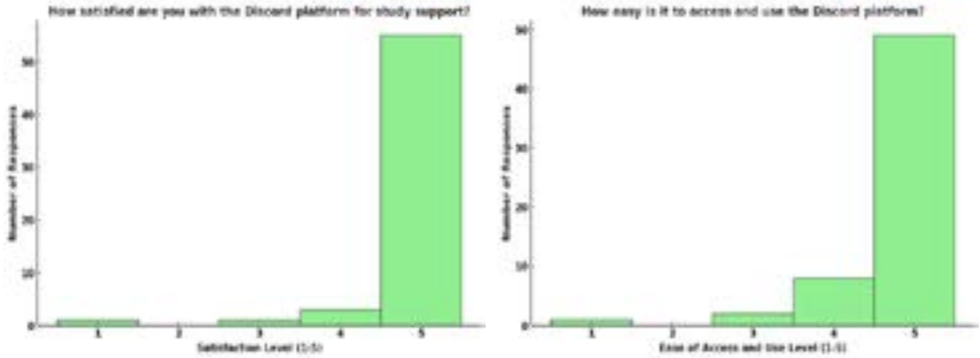
3.2.1 Quantitative



(a) (b)

Figure 5 (a) Bar graph chart showing the likelihood of survey respondents to recommend the Discord service (on a scale of 1-5 where 5 is the highest) (b) Bar graph depicting the likelihood of survey respondents reusing the Discord service.

The feedback collected from 60 respondents through a structured anonymous survey revealed that the platform was well received among the participants. One of the most striking outcomes from the survey was the high willingness to recommend the service, as 96.7% of the survey respondents indicated they would recommend the Discord study support to their peers see figure 5(a). A significant majority of 95% of respondents expressed their likelihood to reuse the service, with only 3.3% being uncertain see figure 5(b). This high level of endorsement and anticipated continued usage underscores the perceived value of the service among the students.



(a) (b)

Figure 6 (a) Bar graph showing the distribution of satisfaction levels with the study support provided by the Discord service (on a scale of 1-5 where 5 is the highest), (b) Bar graph illustrating the distribution of ease of access and use of the service.

When asked to rate their satisfaction with the study support received via the Discord server, the majority of students reported high levels of satisfaction, with the largest group - evident in the tallest bar in figure 6(a) - rating their satisfaction at the maximum level of 5 on a 5-point scale. This indicates that the support offered not only met but also often exceeded students' expectations, with 91.7% of respondents rating their satisfaction at the highest level. Ease of access and usability are critical for the success of any online platform. The survey results shown in figure 6(b) show a strong positive response, with 81.7% of students rating the ease of access and use at level 5. This reflects the user-friendly nature of the Discord platform and the effectiveness of the guidance provided to new users.

3.2.2 Qualitative

To complement the quantitative data, individual responses to the survey have been collected and analysed. These responses provide nuanced insights into the students' experiences, highlight specific aspects of the service that are particularly helpful or could be improved, and offer personal views that illustrate the impact of the service on their academic journey.

In response to the question "How has the Discord platform for study support affected your academic performance and stress levels?" students expressed a range of positive feedback. Many reported feeling more secure and less stressed due to the support provided by the platform. One student mentioned, "I feel more secure and less stressed," while another noted, "Very helpful, less stress about studies." The platform also significantly improved academic performance for several students. For instance, one student shared, "I can say that without Discord and the sessions with you, I wouldn't have understood anything in my course. Those two hours we had with you 2-3 times per week made a big difference in my studies. So a big thank you to you for giving your time and showing interest every time we came with questions." The quality of support and the availability of helpers were frequently highlighted, with students appreciating the various times and close support they received, as well as the ability to ask questions and receive good explanations. Another student reflected this sentiment by saying, "Received a lot of help from you and the discussions on the platform are also educational." Overall, the feedback indicates that the Discord platform has positively impacted students' academic performance and stress levels by providing accessible, reliable, and quality support.

In response to the question "What do you like most about the Discord platform for study support?", students provided a variety of positive feedback. Many students appreciated the instant access to help at any hour, with one student noting, "The instant access to help at any hour was a game-changer." Another student valued the sense of community, stating, "The community feeling and the shared purpose everyone brings to the platform" as a highlight. The platform's ability to reduce feelings of isolation was also mentioned, with a student sharing, "The sense of not being alone, even late at night when studying can feel overwhelming." Additionally, students praised the quality of assistance, with one commenting, "The rapid and clear explanations on tough subjects made a real difference." Overall, the feedback indicates that students highly value the accessibility, sense of community, and quality of support provided by the Discord platform for study support.

The response to “What can we improve?” provided a range of constructive suggestions. Students requested more advance notice of help sessions to aid in better planning and participation. An innovative idea was to introduce a mechanism for submitting questions anonymously to reduce anxiety. Feedback emphasized the importance of information accessibility, recommending that solutions discussed in voice chat be accompanied by screenshots posted in the chat for those who missed the live explanation. While some students felt no improvements were needed, with comments like "nothing, honestly" and "keep it up, you’re doing great," there was a concern about asking too many "silly" questions, indicating a need to foster an even more supportive atmosphere. The suggestions closed with affirmations of the platform’s value, particularly for distance learning, and a push for increased awareness of the resource. The underlying message was clear: the ethos of "students helping students" is vital and much appreciated.

4 SUMMARY AND ACKNOWLEDGEMENTS

This experience has highlighted the successful application of a Discord-based platform to provide round-the-clock study support to engineering students in mathematics courses. The platform's flexibility, accessibility, and capacity to foster a supportive community have made it an invaluable resource for students navigating the challenges of tertiary mathematics education. The positive engagement metrics and student feedback attest to the platform's effectiveness in enhancing learning outcomes and student satisfaction. Importantly, this service has significantly affected engineering education by providing a readily accessible support system that complements traditional learning methods. It empowers students to manage their academic workload more effectively, reduces feelings of isolation, and promotes continuous learning and collaboration outside of regular class hours. As an independent resource, it enhances the overall educational experience for engineering students, contributing to their academic success and well-being.

Future work will focus on implementing the suggested improvements to further enhance the platform's utility. Additionally, longitudinal studies to assess the impact of this support system on academic performance and retention rates in engineering programs could provide deeper insights into the long-term benefits of such initiatives.

REFERENCES

Bridson, K., Atkinson, J., & Fleming, S. D. (2022). Delivering Round-the-Clock Help to Software Engineering Students Using Discord: An Experience Report. In Proceedings of the 53rd ACM Technical Symposium on Computer Science Education V. 1 (SIGCSE 2022), March 3–5, 2022, Providence, RI, USA. ACM, New York, NY, USA.

Farah, F. A., & Eagle, W. E. (2021, August). Applicability of the Discord platform in the advancement of learning in the Introductory to Engineering Design course. In 2021 First-Year Engineering Experience.

Goeser, P. (2022). How Effective is the use of a Discord Server for an Engineering Learning Center?. In ASEE Southeast Section Conference.

Heinrich, E., Thomas, H., & Kahu, E. R. (2022). An exploration of course and cohort communication spaces in Discord, Teams, and Moodle. Australasian Journal of Educational Technology, 38(6).

Jablonka, E., Ashjari, H., & Bergsten, C. (2017). "Much Palaver About Greater Than Zero and Such Stuff"–First Year Engineering Students' Recognition of University Mathematics. International Journal of Research in Undergraduate Mathematics Education, 3(1), 69-107.

Lauricella, S., Craig, C., & Kay, R. (2024). Examining the Benefits and Challenges of Using Discord in Online Higher Education Classrooms. Journal of Educational Informatics, 4(2), 20–31.

McKenney, S., & Reeves, T. (2018). Conducting Educational Design Research (2nd ed.). Routledge.

Owston, R., & York, D. N. (2018). The nagging question when designing blended courses: Does the proportion of time devoted to online activities matter? The Internet and Higher Education, 36, 22-32.

Scheiter, K., & Gerjets, P. (2007). Learner Control in Hypermedia Environments. Educational Psychology Review, 19, 285–307.

Soeiro, R., David, G., & Neves, A. M. A. (2023, November 14). Discord in a university STEM learning environment: collective learning. https://doi.org/10.35542/osf.io/hfnct

Turan, Z., Kucuk, S. & Cilligol Karabey, S. (2022). The university students' self-regulated effort, flexibility, and satisfaction in distance education. International Journal of Educational Technology in Higher Education, 19, 35.

Vinerean, M. (2022). Various digital learning spaces for first-year mathematics courses. In Jakobsson, N., & Vikström, C. (Eds.). Bidrag från universitetspedagogisk konferens 2021. Karlstads universitet.

Vinerean, M., Liljekvist, Y., & Bengu, E. (2023). "Literally I grew up" Secondary-Tertiary Transition in Mathematics for Engineering Students beyond the Purely Cognitive Aspects. Open Education Studies, vol. 5, no. 1, 2023, pp. 20220184.

Winsløw, C., & Grønbæk, N. (2013). Klein's double discontinuity revisited: contemporary challenges for universities preparing teachers to teach calculus. Recherches en Didactique des Mathématiques, 34(1), 59–86.

PRACTISING ETHICS IN ENGINEERING AND SCIENCE EDUCATION

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ABSTRACT

Technological advancements are expanding continuously to affect more private, societal, and environmental aspects of our lives. This raises a serious need to equip those who lead and build such technologies with the skills that apply ethical principles to guide such development. If teaching ethics can provide such guidance, for technical disciplines it is often hard to translate principles into actions. In this paper, we describe a doctoral course whose learning experience provided a group of science and engineering researchers with a toolkit for practicing ethics. This toolkit consists of a participatory approach, stimulating peer–to–peer debates; and a

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system thinking perspective, to understand the interconnectedness and causality of ethical events. With these, researchers identified one's spectrum of ethical actions that could mitigate or prevent challenges. By discussing the effectiveness of these methods, we conclude by drawing a list of recommendations for future work. This to cover the growing need to equip scientists and engineers with skills that guide the understanding of what decisions can lead to ethical actions.

1 INTRODUCTION

1.1 Teaching Ethics in Engineering and Science

Innovation is one of those societal processes that supports society in addressing challenges, by creating breakthrough solutions for the benefit of the most. Vaccines, medical and communication technologies, and new materials are just a few examples of how humanity has advanced knowledge over the years toward healthier and safer ways of living on this planet. Nonetheless, despite clear evidence of beneficial impacts, innovation has also received criticism for the exact opposite. Following the emergence of ethical dilemmas drawn from the adoption and use of new technologies and science, industries and universities have started to look at guidelines for tackling the undesired consequences deriving from the introduction of innovative solutions in society (McGinn 2022). Nonetheless, deploying ethical frameworks and principles in engineering and science is a challenge on its own because of the difficulty of translating abstract and general principles in specific tasks (Schleidgen et al. 2023; Benke, et al., 2020). Hence, a need to develop tools that guide decision–making in technical research and practice (Ibrahim et al., 2007). These would support responsible technological and scientific advancements originating from actions tackling social and environmental challenges (Kamp, 2016).

An evaluation process aimed to understand what might generate or mitigate ethical dilemmas can't rely on accountability only, as this is not enough to stimulate actions (Beu et al. 2003). Hence, the goal of the course object of this paper was to explore how holistic and systemic approaches could be methods for guiding the understanding of what actions could tackle the complexity of ethical dilemmas and inform how to best mitigate undesirable outcomes (Grewatsch et al. 2023). We argue that building skills and knowledge on preventing or mitigating the consequences of developing, and using, science and engineering innovation requires understanding ethics as complex events that can be acted upon. This happens at the decision–making level through the awareness of the role human actions play in influencing these events (Beu et al. 2003; Macklin 1967). In this paper, we describe how participatory and systemic approaches address the need to equip science and engineering research with tools for facing some of today's social and environmental challenges (Chan and Lillian 2022; Kamp 2016). By doing so, we aim to fill a gap in technical curricula.

"The Practice of Ethics for Engineering Research and Profession" is an École Polytechnique Fédérale de Lausanne (EPFL) doctoral course that has tested a toolkit to practice ethics to support engineering and science researchers in developing a critical understanding of the roles and responsibilities of human actions (Macklin 1967). This was used to generate a response based on the researchers' agency in the system of their project. The course consists of three different activities: (1) four guest lectures from CERN, Nestlé Institute of Agricultural Sciences, EPFL

Learn Centre and Climact Centre that discussed how industries or academia address ethical challenges as an opportunity for innovation; (2) presentation from seven PhDs and one postdoc from across the EPFL to debate on the ethical dilemmas in their research topics; (3) a system mapping activity involving the analysis of ethical challenges as wicked problems to identify the leverage points that would tackle ethical dilemmas related to a topic. Outcomes were presented as posters in an EPFL venue.

In the first part of this paper, we describe the course's theoretical approach; the second discusses the methodology; the third part outlines how the course's methods and activities influenced and supported the researchers in (1) thinking ethics more holistically (2) seeing ethics as a reflective exercise in support of one's critical thinking, (3) understanding how to use leverage points to address ethical dilemmas, and (4) evaluating actions that could mitigate ethical challenges, for generating innovation that meets societal and environmental goals. We conclude by discussing the toolkit's limitations and recommendations for future work.

1.2 Learning the complexity of ethical challenges

Learning how to tackle social and environmental ethical challenges in science and engineering research is a journey that would involve (1) raising awareness of possible ethical challenges (Bazerman et al. 2016), (2) understanding these as relations generating undesirable consequences (Beu et al. 2003), and (3) identifying a framework for enabling action (Schleidgen et al. 2023). The combination of these three steps forms a cognitive process that enables one to think about interventions that mitigate or prevent ethical dilemmas. The course presented in this paper aimed at creating a learning experience encompassing these three steps. Overall, the teaching was geared towards providing tools and methodologies that could form a practice of ethics in science and engineering.

With a focus on decision–making, the course adopted a constructivist approach to learning where knowledge is created from reflecting on a situation that is then compared to personal experience (Mosalanejad et al. 2020). In such an approach, reflections help draw conscious attention to the consequences of personal decisions and the responsibilities that these decisions imply in the short and long term (Campbell and Kumar 2012). In the course, decision–making was discussed through the lenses of moral and rational thinking by outlining how values and moral judgment influence actions that can cause less harm or good (Le Bar 2009; Beu et al. 2003; Macklin 1967). The focus on moral rationing outlined the rationality and irrationality of certain decisions, which vary in relation to the speed and consciousness of decision–making (Campbell and Kumar 2012; Bazerman et al. 2016). Here, biases and values have a role in evaluating ethical dilemmas; fast and slow decisions can bounce one against the other depending on the consistency decisions have with one's existing beliefs; here, values can flag any inconsistency, thus requiring a deeper and more rational reflection (Campbell and Kumar 2012). This slower and conscious thinking leads to learning, as reflecting on the consistency of thinking enables self–analysis and the review of existing knowledge (Mosalanejad et al. 2020; Bazerman et al. 2016).

In the course, raising awareness of ethical challenges was constructed over reflections stimulated by debates. Through these, we discussed moral judgment, its relation to values, and how the latter manifest a choice of how people decide to position themselves in the real world (Le Bar 2009; Beu et al. 2003).

To engage learners in getting awareness of personal positions on topics like AI or sustainability, and understanding what influences these positions, active participation had a key role (Mosalanejad et al. 2020); peer-to-peer exchange of information helped map personal lived experience to the topics discussed (Bada et al, 2015). Furthermore, theoretical ethical frameworks like Consequentialism, Deontology, and Virtue Ethics (Beu et al. 2003), were introduced within the context of real–world scenarios (e.g., collecting health data) to stimulate reflections on how ethical principles can guide the development of ethical strategies and actions (Schleidgen et al. 2023; Widdershoven, et al.,2009). The course didn't choose to follow any of these frameworks; nor it present any specific ethical principle or standard, like those attempting to regulate AI research and innovation (Jobin, et al. 2019), or the four principles in biomedical sectors (autonomy, beneficence, non-maleficence, justice) (Beauchamp & Childress, 2013). This is because its focus was on teaching an empirical process of thinking ethics as events where personal experience becomes a way to act on it. Hence, lived experiences were the vehicle used to stimulate debates and provoke reflections (Widdershoven, et al., 2009). Other activities – including the analysis, theorisation, and practice of real cases – were used to help turn theories into applied strategies (Mosalanejad et al. 2020). Such a learning journey engaged learners in reflecting on the complexity of ethics and how such a complexity can be acted upon through holistic approaches (Grewatsch et al. 2023). The wicked problem maps describe how learners acknowledged this complexity (Fig.1). With this approach, the perception of ethical challenges shifted from open dilemmas to interconnected events that can be described, discussed and, reframed. With these, theories of ethics moved to practice.

2 METHODOLOGY : THEORIES INFORMING THE PRACTICE OF ETHICS

In this section, we discuss how theoretical concepts and methods within, and outside ethical theories shaped the practice of acting upon ethical challenges. We outline the steps taken for practicing the theoretical frameworks, which consist of: (1) actively participating in the discussion of ethics, whose activities are (i) Industry expert talks and (ii) ethical challenges presentation (2.1). (2) Describing ethics as a wicked problem, whose activities are (i) system thinking and (ii) leverage points (2.2).

2.1 Develop Learning on Ethics Through Participation

As a first step, the course introduced current debate on ethics across academia and industry through the real–world perspectives of industry leaders, who presented innovative approaches to ethical challenges. The four guest lectures provided insights into navigating ethical dilemmas at the macroscale of an organisation and the microscale of individual interactions. These lectures offered examples of practical tools and strategies on data accessibility, animal rights, collaboration within heterogeneous teams and, sustainable transitions. The guest speakers set the ground for participating in discussing different views confronted on different ethical challenges through a critical perspective (Bada et al, 2015). With participation, new knowledge and subject–specific skills found their ground for development (Carlson et al. 2022; Healey 2005).

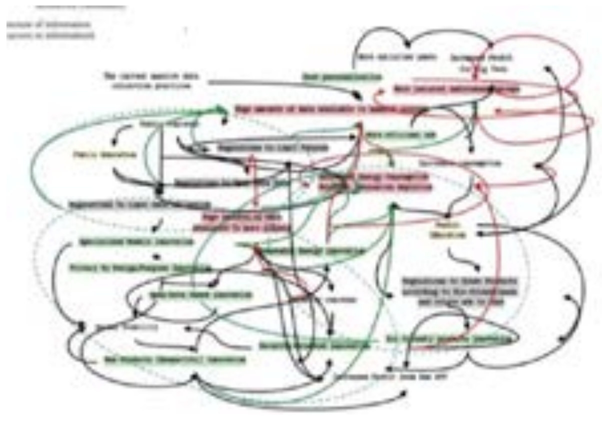
The course's second step involved learners presenting their research. Topics discussed were such as but not limited to: (i) language model ethical values (ii) environmental waste, (iii), scientific integrity: publish or perish, (iv), access to new technology, (v) security and privacy. Each of these presentations was used as boundary objects to open discussions on ethical dilemmas inherent in one's academic research (Leigh Star 2010). These peer–to–peer interactions made personal experience an active means of learning about real–life problems (Carlson et al. 2022). Indeed, presentations delved into the personal motivations driving one's research endeavours; they prompted the cohort to consider the influence of values on personal decision–making processes, reflect on the motivating factors behind their research topics, and analyse how personal, professional, and disciplinary values shape research approaches. This engaged one in a thorough examination of the ethical complexities embedded within each presentation. Debates created an intellectually stimulating environment promoting dialogue (Healey 2005; Wilson and Smetana 2011); this increased one's self–efficacy concerning the ability to discuss challenges in personal research (Bandura 1982; Beu et al. 2003); with it, learners were stimulated to act upon the information provided (Healey 2005).

Various interactive elements, such as utilising a Course Padlet for collecting reflections, further enriched the learning experience. Anticipated ethical challenges in personal research endeavours were also explored, thus contributing to a deeper understanding of the ethical dimensions of one's academic pursuits. This was stimulated by the task of formulating questions that turned learners from observers of a debate to part of the observed debate (Von Foerster 2003). For instance, the question: *"What are current (un)ethical practices that will be changed in the future?"* engaged in a live discussion on other practices that could negatively impact society. With these questions, ethical challenges were analysed through metacognition inducing a cognitive process that checks where knowledge breaks (Wilson and Smetana 2011). With these reflective exercises, participants cultivated a heightened awareness of ethical considerations in research, fostering a culture of critical inquiry and self-awareness. Formulating questions on ethical challenges moved the object of discussion to personal experience (Wilson and Smetana, 2011). This enables the mapping of new knowledge against existing one and engages in negotiating processes (Bada et al. 2015).

2.2 Ethics as a Wicked Problem: Using System Thinking and Leverage Points

The course's third step focused on system thinking; this supported the transition from theory to practise through the analysis of complex systems, i.e., the analysis of the interdependencies and feedback loops influencing the system's behaviour (Hoverstadt 2022). This method was introduced through the concept of wicked problems, i.e. a class of problems that requires the understanding of how to solve it to be able to define it. This means that to describe a wicked problem, it is necessary to list the different solutions (Rittel and Webber 1973). Using this concept for ethics was a means for recontextualising an ethical dilemma – i.e. something that implies a difficult choice to make– as a problem whose definition needs the listing of possible solutions (Lönngren and Van Poeck 2021).

From the initial participatory stage, aiming at raising awareness and stimulating active participation – i.e. participating through questions, idea sharing and by offering opinions (Masek et al. 2021) – participants were invited to use a system thinking perspective to describe the complexity of ethics (Grewatsch et al. 2023). Real–world



cases helped the cohort think holistically, i.e., to think of problems as parts of a larger whole (Hoverstadt 2022). Hence, the ethical challenges emerging from these cases were discussed as wholes emerging from the interactions of the different parts of the system. For instance, discussions on global digitalisations and sustainable transitions outlined the negative impacts on work and natural resources through exploitation. These examples contextualised the meaning of holistic thinking and extended one's understanding of the positive and negative impacts of research and innovation. The application of this approach consisted of creating maps illustrating complex issues like AI (data, privacy, robots.), sustainability (materials, processes, policies) and people (bias, profiling, behaviour, practice). This exercise was presented as a poster including (i) a description of the problem, (ii) a wicked problem map, (iii) and the leverage points map. With these maps, the theory of systems visualised the interconnected nature of problems encompassing economic, technological, social, and environmental dimensions (Buchanan 1992); leverage points, i.e. points of a system that can change the system's goal (Meadow 1997), defined where to intervene in the system, as visualised by Figure 1.

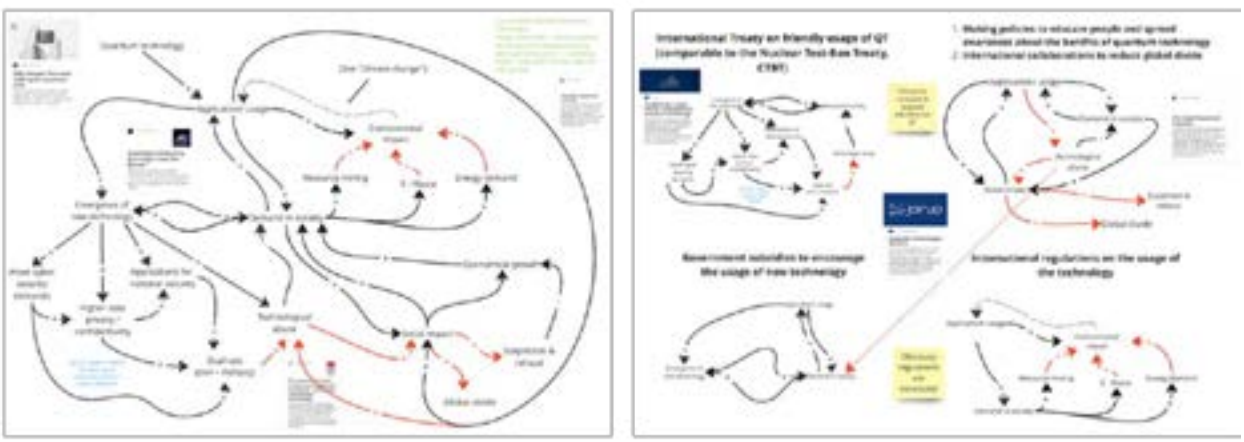


Fig. 1. The "Massive Data Collection" wicked problem map (up). Wicked Problem map and leverage point analysis on quantum technology (down)

This figure presents examples of wicked problem maps describing the ethical challenges of the massive data collection (up) and quantum technology (down). In the latter, it is outlined how quantum technology is a double-edged sword with profound social benefits, but also complicated challenges. Indeed, this technology can open revolutionary advances in computing power, cryptography and materials science, but also its use brings with it a complex web of social, environmental and ethical concerns (Possati 2023). Figure 1 illustrates this interconnectedness, where the transformative potential of this technology is faced with the complex socio-ecological and technological challenges that may arise. On the figure left side, the map describes problems that can self–stabilise and those that need leverage points for stabilisation. For example, quantum technology can have a negative impact on the environment, as it increases resource depletion and energy demand. This is a self-stabilising problem, as the technology itself is capable of providing solutions to this. On the other hand, problems related to the social impact and unethical use of the technology require leverage points for stabilisation. On the figure's right side, there are the leverage points represented through the system's feedback loops. These are classified as reinforcing or balancing loops and are graded with Meadow's twelve-point scale (1997). This classification helped the learners reflect that the leverages of the highest impact are the most difficult to realise (Dorninger 2020). For example, to avoid global inequality and make technology easily accessible to all, it was proposed the leverage of an international policy created to promote cooperation and make technology accessible to all. Preventing the misuse of technology can be leveraged by raising awareness of how to use it in the curriculum for engineering students. The map also proposes the introduction of regulations to quantum technology ethically, including relevant courses on ethics defining the use of this technology.

2.3 The Toolkit for Practising Ethics in Science and Engineering Research

In the previous sections, we described what activities developed a practice for acting upon ethical challenges. Altogether, these created a learning experience defining the toolkit for practicing ethics. Indeed, by teaching an empirical process of thinking ethics as complex events, the sequence of activities stimulated the participants' personal experiences in understanding what process can be followed to address an ethical challenge. With this toolkit, it was introduced an ethics procedural assessment based on the following steps: (1) awareness of complexity, (2) widening of opinion, (3) understanding of causality of events, and (4) points of action of highest impact. It needs to be noted that the transferability of this toolkit to other cultural contexts, disciplines, and levels of study would require further work due to the limited number of students and that this is the first course offering of this format.

3 DISCUSSION: RESULTS, LIMITATION AND RECOMMENDATIONS FOR FUTURE WORK

In this section, we first discuss the findings identified from the course's methods and related activities through the evaluation report and the learners' reflections (Table 1). We then discuss the limitations of the toolkit and make recommendations for improvement and future work (Table 2).

Table 1. Feedback on the course's methods and their application

Learners' reflection:	Evaluation report	Outcomes from application
Method: Participation & debates		
- Fostered active participation and a dynamic learning environment. - Provided a platform to express concerns and organise personal ideas. - Widened personal perspectives	- Provided numerous opportunities for dialogue and discussion - Questions and presentations helped augment one's point of view.	- Enabled to contemplate ethical issues in one's research work. - Extended the understanding of what beneficial can tackle ethical issues related to one's research work.

- Allowed to formulate open questions and engage in personal reflective exercises - Created a safe space		- Created a consultative approach.
Method: System thinking and wicked problem mapping		
- Encouraged to consider the interconnectedness of events. - Enabled to understand the opportunities one has inside the personal field of actions. - Encouraged two-way communication channels - Promoted collaborative problem-solving	Supported the understanding of how to apply its methods in research	- Allowed the application of theories and contextualise concerns - Helped describe interactions between various factors, and highlight personal influence - Widened opportunities for engaging in activities like advising in regulatory bodies - Helped understand what needs priority and efforts.

Table 2. Limitations of the toolkit for practicing ethics and recommendations for future work

Toolkit	Limitations	Recommendation
Industry talks	Some didn't enable conversation.	Guests, presentations should generate dialogue
Ethical presentations and debates	- Facilitation didn't always enable anyone's participation. - Debates relied on personal capacities of communication	- Ensure facilitation allows anyone to engage their lived experiences with the topic of discussion - The course scaling up should prioritise settings that allow equal participation in discussion. A limited number of students create safer spaces for debate.
System thinking & leverage points	More time should be allocated to this activity	- Ensure appropriate time for learning how to apply the method

4 CONCLUSIONS AND ACKNOWLEDGEMENTS

In this paper, we described a doctoral course that introduces a toolkit for practicing ethics in science and engineering research. We illustrate how this toolkit applied the course's methods for equipping researchers with skills for tackling ethical dilemmas. Thus, providing means for covering the gap in technical ethics education.

Through a participatory approach and system perspective, (1) we created a safe space of discussion enabling one to engage with the complexity of ethics; (2) we stimulated debate with peers that allowed personal introspection and the widening of opinions; (3) we enhanced one's capacity to assess the personal space of action to act and mitigate ethical dilemmas through personal experience; (4) we helped one shift the perception of ethics from open dilemmas to interconnected events that can be described, by visualising the system of an ethical challenge.

Through the learner's and evaluation report's feedback, we provided insights on the validity of the course's methods and activities and outlined the toolkit limitations. With these, we encourage future work to identify the toolkit's transportability to different cultural contexts, institutions, and levels of study. In this regard, we propose the following recommendations: (1) A debate on ethics should allow equal opportunities to participate in sharing personal experiences. (2) The number of participants needs to be at an appropriate scale to enable a safe space for discussing and engaging with ethical challenges. (3) Personal and professional lived experiences help understand the system of an ethical challenge and the personal space of agency.

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REFERENCES

Bada, Steve Olusegun, and Steve Olusegun. "Constructivism learning theory: A paradigm for teaching and learning." Journal of Research & Method in Education 5, no. 6 (2015): 66-70. DOI: 10.9790/7388-05616670

Bandura, Albert. "Self-efficacy mechanism in human agency." American psychologist 37, no. 2 (1982): 122. https://doi.org/10.1037/0003-066X.37.2.122

Bazerman, Max H., and Ovul Sezer. "Bounded awareness: Implications for ethical decision making." Organizational Behavior and Human Decision Processes 136 (2016): 95-105. http://dx.doi.org/10.1016/j.obhdp.2015.11.004

Benke, Ivo, Jasper Feine, John R. Venable, and Alexander Maedche. "On implementing ethical principles in design science research." AIS Transactions on Human-Computer Interaction 12, no. 4 (2020): 206-227. DOI: 10.17705/1thci.00136

Beauchamp, Tom L., and James F. Childress. 2013. Principles of Biomedical Ethics. 7th ed. Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199924585.001.0001.

Beu, Danielle S., M. Ronald Buckley, and Michael G. Harvey. "Ethical decision–making: A multidimensional construct." Business ethics: A European review 12, no. 1 (2003): 88-107. https://doi.org/10.1111/1467-8608.00308

Buchanan, Richard. "Wicked problems in design thinking." Design issues 8, no. 2 (1992): 5-21.

Campbell, Richmond, and Victor Kumar. "Moral reasoning on the ground." Ethics 122, no. 2 (2012): 273-312. https://doi.org/10.1086/663980

Carlson, Elisabeth, Martin Stigmar, Maria Engberg, Magnus Falk, Maria M. Stollenwerk, Petri https://doi.org/10.20429/ijsotl.2022.160306

Chan, Cecilia KY, and Lillian YY Luk. "Academics' beliefs towards holistic competency development and assessment: A case study in engineering education." Studies in Educational Evaluation 72 (2022): 101102. https://doi.org/10.1016/j.stueduc.2021.101102

Dorninger C, Abson DJ, Apetrei CI, Derwort P, Ives CD, Klaniecki K, Lam DPM, Langsenlehner M, Riechers M, Spittler N, et al. 2020. Leverage points for sustainability transformation: a review on interventions in food and energy systems. Ecol Econ. 171:106570. doi:https://doi.org/10.1016/j.ecolecon.2019.106570.

Egerer, S., Cotera, R. V., Celliers, L., & Costa, M. M. (2021). A leverage points analysis of a qualitative system dynamics model for climate change adaptation in agriculture. Agricultural Systems, 189, 103052 DOI: 10.1016/j.agsy.2021.103052

Grewatsch, Sylvia, Steve Kennedy, and Pratima Bansal. "Tackling wicked problems in strategic management with systems thinking." Strategic Organization 21, no. 3 (2023): 721-732 https://doi.org/10.1177/1476127021103863

Gudmundsson, and Karin Enskär. "Students Experiences of Participation in a Research Team: Evaluation of a Research-based Teaching Activity in Higher Education." International Journal for the Scholarship of Teaching and Learning 16, no. 3 (2022): 6. https://doi.org/10.20429/ijsotl.2022.160306

Healey, Mick. "Linking research and teaching to benefit student learning." Journal of Geography in Higher Education29, no. 2 (2005): 183-201. https://doi.org/10.1080/03098260500130387

Hoverstadt, P. (2022). The grammar of systems. Journal of the International Society for the Systems Sciences, 66(1).

Huttunen, Suvi, Maria Ojanen, Anna Ott, and Heli Saarikoski. "What about citizens? A literature review of citizen engagement in sustainability transitions research." Energy Research & Social Science 91 (2022): 102714. https://doi.org/10.1016/j.erss.2022.102714

Ibrahim, Solava, and Sabina Alkire. "Agency and empowerment: A proposal for internationally comparable indicators." Oxford development studies 35, no. 4 (2007): 379-403. https://doi.org/10.1080/13600810701701897

Jobin, A., Ienca, M. and Vayena, E., 2019. The global landscape of AI ethics guidelines. *Nature machine intelligence*, *1*(9), pp.389-399. https://doi.org/10.1038/s42256-019-0088-2

Kamp, Aldert. Engineering education in the rapidly changing world: Rethinking the vision for higher engineering education. TU Delft, Faculty of Aerospace Engineering, 2016.

LeBar, Mark. "Ethical value." (2009). DOI: 10.1002/9781444315837.ch15

Leigh Star, Susan. "This is not a boundary object: Reflections on the origin of a concept." Science, technology, & human values 35, no. 5 (2010): 601-617.https://doi.org/10.1177/0162243910377624

Lönngren, J., & Van Poeck, K. (2021). Wicked problems: A mapping review of the literature. International Journal of Sustainable Development & World Ecology, 28(6), 481-502. https://doi.org/10.1080/13504509.2020.1859415

McGinn, Robert E. "Startup Ethics: Ethically Responsible Conduct of Scientists and Engineers at Theranos." Science and Engineering Ethics 28, no. 5 (2022): 39. https://doi.org/10.1007/s11948-022-00393-2

Macklin, Ruth. "Actions, consequences and ethical theory." The Journal of Value Inquiry 1 (1967): 72-80. https://doi.org/10.1007/BF00149467

Masek, A., Ismail, A., Hashim, S., & Mohd, S. F. (2021). Defining students' active participation in a group discussion session from different perspectives. Academia, (23-24), 67-84. https://doi.org/10.26220/aca.3599

Meadows, D. (1997). Places to Intervene in a System. Whole Earth, 91(1), 78-84.

Mitelut, Catalin, Ben Smith, and Peter Vamplew. "Intent-aligned AI systems deplete human agency: the need for agency foundations research in AI safety." arXiv preprint arXiv:2305.19223 (2023).

https://doi.org/10.48550/arXiv.2305.19223

Mosalanejad, Leili, Amir-Mohammad Ebrahimi, Mansour Tafvizi, and Nahid Zarifsanaiey. "A constructive blended approach to ethical reasoning: the impact on medical students' reflection and learning." Shiraz E-Medical Journal 21, no. 7 (2020). https://doi.org/10.5812/semj.96510

Possati, Luca M. "Ethics of quantum computing: An outline." Philosophy & Technology 36, no. 3 (2023): 48. https://doi.org/10.1007/s13347-023-00651-6

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. Policy sciences, 4(2), 155-169. https://doi.org/10.1007/BF01405730

Schleidgen, Sebastian, Alexander Kremling, Marcel Mertz, Katja Kuehlmeyer, Julia Inthorn, and Joschka Haltaufderheide. "How to derive ethically appropriate recommendations for action? A methodology for applied ethics." Medicine, Health Care and Philosophy 26, no. 2 (2023): 175-184. https://doi.org/10.1007/s11019-022-10133-9

Von Foerster, Heinz, and Heinz von Foerster. "Cybernetics of cybernetics." Understanding understanding: Essays on cybernetics and cognition (2003): 283-286. https://doi.org/10.1007/0-387-21722-3_13

Wilson, N. S., & Smetana, L. (2011). Questioning as thinking: A metacognitive framework to improve comprehension of expository text. Literacy, 45(2), 84-90. https://doi.org/10.1111/j.1741-4369.2011.00584.x

Widdershoven, Guy, Tineke Abma, and Bert Molewijk. "Empirical ethics as dialogical practice." *Bioethics* 23, no. 4 (2009): 236-248. DOI:10.1111/j.1467-8519.2009.01712.x

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Teaching Engineering Students How to Teach: Training Teaching Assistants for Diverse Responsibilities

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Conference Key Areas: *Building the capacity and strengthening the educational competencies of engineering educators* and *Engineering skills, professional skills, and transversal skills*
Keywords: *Teaching assistants, active learning, scaffolding learning processes, teacher training, teaching self-efficacy*

ABSTRACT

Teaching assistants are widely used at universities around the world, and they are an important part of the teaching and learning ecosystem at their institutions. They help support teachers and facilitate learning processes for students. For many teaching assistants, this work will also represent their first experience with formal teaching. Thus, it is crucial that they receive training within the field of pedagogy and didactics to prepare them for their new teaching responsibilities and ensure a consistent and high quality in their instruction. Since they are relatively inexperienced when they start working as teaching assistants, they both need to develop an understanding of the theories and methods of teaching and learning in higher education, as well as lay the foundation for a professional identity as a teacher, helping them develop sustainable teaching practices and teaching self-efficacy.

This practice paper presents the design of a teaching assistant training course at the Technical University of Denmark, which is focused on developing an understanding

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of teaching and learning in higher education for the new teaching assistants, as well as facilitating their development of teaching self-efficacy.

1 INTRODUCTION

Teaching assistants are an often-used resource at universities to support teachers and help facilitate learning for students (Filz and Gurung 2013; Ren, Krishnamurthi, and Fisler 2019). The responsibilities of a teaching assistant may vary a lot depending on the course they are taking part in teaching and their collaboration with the responsible teacher. Examples of the kind of tasks teaching assistants are given responsibility for could be grading assignments, facilitating learning activities such as laboratory exercises, supervising group projects, or even being given responsibility for parts of lectures. Therefore, they play an important role in teaching and guiding students through their courses and study programmes. A common characteristic of teaching assistants is, that they are usually relatively inexperienced within the field of teaching, especially within the context of higher education. While some teaching assistants may have some more or less formal experience with teaching, for example one-on-one tutoring or similar, most teaching assistants have never stood at the front of a classroom before. Thus, their responsibilities as teaching assistants often represent their first real experience with formal teaching.

Teaching assistants are in a rather unique position as teachers given their close proximity and similarity to the students they teach, because teaching assistants are most often students themselves, and may have recently completed the same course they are now teaching (Pawlak, Irving, and Caballero 2020). Research shows that students are likely to perceive teaching assistants as more approachable, understanding and motivating (Kendall and Schussler 2012; Ren, Krishnamurthi, and Fisler 2019) which means many students may be more likely to approach a teaching assistant for help than a teacher. In other words, teaching assistants are a vital resource for universities to provide not only the much-needed capacity to accommodate the rising numbers of students in higher education (Forbes et al. 2017), but most importantly because they represent a safe and approachable source for support and learning for students. There is a huge potential then to increase student learning through the strategic use of teaching assistants. However, this potential is dependent on the teaching assistants' abilities. This underlines the importance of universities prioritising pedagogical training targeting teaching assistants, so they may be adequately prepared to take on their new teaching responsibilities. This is no simple task, as a training course will have to provide the necessary and specific knowledge and skills relevant to the diverse teaching responsibilities of teaching assistants, while also providing a pedagogical foundation for understanding teaching and learning.

Training of teaching assistants is generally under-researched, and though there are some examples to be found on the topic, many of these are often either aimed at specific disciplines (e.g. Marbach-Ad et al. 2012, or Mirza et al. 2019, or Reeves et al. 2016) or specific tasks, such as laboratory exercises (e.g. Dragisich, Keller, and Zhao 2016, or Nikolic et al. 2015). Other examples provide a framework for training teaching assistants, where the course design may require a lot of time and resources and/or big structural changes at the university in order to implement the model (e.g. Odden et al. 2023). While these very specific disciplinary course and extensive models of training may be meaningful in certain contexts, they require many resources to adapt and implement, which makes it difficult to transfer these frameworks to new teaching contexts. This practice paper, however, presents a detailed description of a course design that is easily adaptable and can help increase the proficiency of teaching assistants without using an enormous amount of resources.

This practice paper aims at providing an outline of a universally adaptable framework for a training course for inexperienced teaching assistants, called The Teaching Assistants' Education. The training course presented here has been designed as a universal crash course in pedagogy and didactics, providing an understanding of theories of learning, diverse methods for teaching and strengthening teaching assistants' teaching self-efficacy to prepare teaching assistants to provide quality teaching. Because teaching assistants can have very diverse responsibilities, the training course is also designed to accommodate teaching assistants with many different types of responsibilities. The universal design also means that the course may be transferred and adapted to different higher education contexts relatively easily, which will be elaborated more on later in the paper.

2 PREPARING THEM FOR THEIR RESPONSIBILITIES: DESIGNING A TRAINING COURSE

The Teaching Assistants' Education has been made mandatory for first-time teaching assistants to participate in, to ensures that every teaching assistant at the university has a foundation on which to base their teaching practices. The course is offered once per semester, and between 100-200 teaching assistants participate each semester. The course introduces them to the theories of teaching and learning as preparation for their new responsibilities as teaching assistants, and the course is specifically designed to provide a foundation that can support the teaching assistants as they begin the journey to develop their professional identity and competencies within teaching. This is also reflected in the learning objectives for the course:

- Describe the role of the teaching assistant in relation to students' learning and identity-building
- Explain the concepts of learning and learning processes
- Give constructive and concrete feedback to scaffold student's learning
- Choose and apply appropriate strategies to handle challenges that can occur in the work of a teaching assistant

The course consists of a full course day (6 hours), *the introduction day*, which is placed right before the beginning of a new semester. Towards the end of the semester, there is a shorter meeting (2 hours), *the follow-up meeting*, where the teaching assistants have a scaffolded discussion revolving around their individual experiences with teaching from the semester. Between the introduction day and the follow-up meeting, the teaching assistants have time to apply their new knowledge and skills in their own teaching, and alongside their work, they are required to reflect on their own practice and write a case based on their experiences, which they have to bring to the follow-up meeting. The training course is thus parallel to their teaching during the semester. Below is an illustration of the training course in relation to the academic semester:

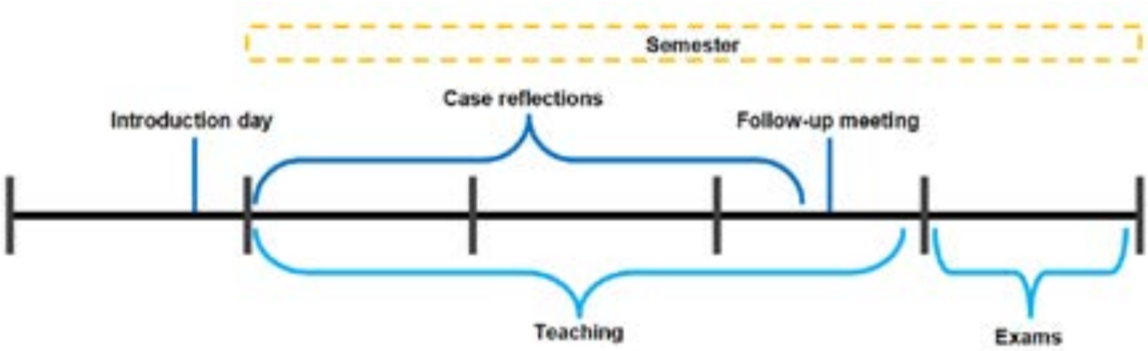

Fig. 1. Overview of the Teaching Assistants' Education

The pedagogical framework for the training course is based on an active learning philosophy and case-based learning. During the course, the teaching assistants are expected to participate in many different activities, where they will reflect on and discuss different topics, both individually, in pairs, in groups and in plenum. The purpose is to create a reflective classroom, where everybody can share experiences, ideas, and questions regarding teaching, learning and the role of teaching assistants. This creates a learner-centred classroom, where the teacher takes on a secondary role, facilitating and scaffolding the learning process of the students, which has been shown to be efficient in achieving learning outcomes (Weimer 2013; Felder and Brent 2016).

To scaffold the learning objectives and prepare the teaching assistants, the course focuses on two main aspects of the teaching assistants' role: the first aspect is about preparing them to scaffold sustainable and constructive learning processes for the students in their classrooms, and the second aspect concerns laying the foundation for their individual development of teaching self-efficacy and curiosity for further professional development. While the teaching assistants usually know which teaching activities, they will be responsible for when they are hired, they are often unprepared for how they can scaffold a constructive learning process for a full classroom. Therefore, they need to learn methods and tools for teaching to help them with the task ahead.

2.1 Understanding Teaching and Learning

Teaching assistants need both specific and cross-curricular competencies (Rico et al. 2013) in order to be able to facilitate learning processes; firstly, they need specific competencies related to their field, so they are familiar with the themes and materials of the course they are teaching. For example, if a teaching assistant helps teach a Computer Science-course where they focus on programming in Python, the teaching assistant will need to be able to, at least to a certain extent, use Python for programming, in order to support the students. Secondly, teaching assistants need cross-curricular competencies within teaching and communication, in order to employ effective teaching practices. Because teaching assistants are usually hired based on their competencies within a specific field or their high performance in a specific course, the field-specific competencies are already present when they begin working with teaching. Therefore, this training course focuses on the cross-curricular competencies within the field of teaching and learning.

In designing the training course, the diverse roles and responsibilities of teaching assistants were considered along with evidence-based teaching methods in STEM-teaching (Felder and Brent 2016). From this, four core pedagogical topics were inferred: 1) Active learning, 2) (cognitive) learning processes, 3) communication, and 4) formative and summative feedback. While teaching these topics, the course is designed to be exemplary of the same pedagogical principles in order to show how these teaching methods can be implemented in practice. Therefore, as previously mentioned, the course contains lots of varied activities and reflective exercises to scaffold the teaching assistants' learning processes. The course contains very little traditional lecturing, putting focus on the participants rather than on the teacher. The responsibility of the teacher is to support and facilitate the participants' active engagement with the course material through asking questions and providing feedback on the teaching assistants' progress.

This method of instruction has a positive effect on the learning processes of the teaching assistants, who are often curious and motivated to learn about pedagogy and didactics due to its' relevance to their work. However, these concepts can be quite foreign to them, as the teaching assistants are used to working in the field of engineering, which can be quite different from the fields of social science and humanities. As they explain it:

"*There is the hard stuff and then there is the soft stuff, and for us the soft stuff is usually the hard stuff.*" (Teaching assistant during the training course)

Therefore, the course contains careful scaffolding with exercises tied closely to teaching practice, in order to create a clear connection between pedagogical and didactical concepts, such as active learning, to the real-life practice of teaching assistants.

2.2 Scaffolding Teaching Self-efficacy and Professional Development

As previously described, teaching assistants play an important role in helping students learn, but at the same time they are rather inexperienced when it comes to teaching. Therefore, a major focus for this training course is motivating the teaching assistants for further professional development.

To address this, a part of the training course focuses on communication, scaffolding and problem-solving. Specifically, the training course seeks to support the teaching assistants in developing teaching self-efficacy, which is an important motivator to develop teaching practices for sustainable learning and has even been shown to improve the academic performance of students (Fong, Dillard, and Hatcher 2019). The concept of teaching self-efficacy is here adapted from Tinto (2017), where a model for student persistence is conceptualized, shows a connection between students' self-efficacy, their perception of curriculum and sense of belonging. Tinto describes self-efficacy in students as a belief in one's own ability to rise to (extrinsic) expectations and overcome educational challenges (Tinto 2017). Transferring the concept to teaching assistants, this means feeling confident in one's own abilities to handle challenges that may arise while teaching in a constructive manner and being able to facilitate sustainable learning processes (Fong, Dillard, and Hatcher 2019).

One of the activities during the introduction day that was specifically constructed to support the development of teaching self-efficacy is called *The Toolbox*. The purpose is to make the teaching assistants reflect on how to solve common teaching problems, so that they may be prepared if or when these problems occur in their classrooms. The Toolbox presents 7 different generalized challenges that are chosen based on cases which have previously been presented at the training course by teaching assistants. An example could be: "*How can you handle frustrated and/or unmotivated students*?". The teaching assistants are then asked to discuss each challenge and come up with solutions for handling them. Discussing these problems in a case-based way gives them a real-life feeling, and knowing the cases come from other teaching assistants lends credibility to the activity, making it highly appreciated by the teaching assistants:

"*As a new TA, I did really appreciate the opportunity to get a "toolbox" for assessing various situations, and be suited to help the students in the best possible way. I felt more prepared for the job as TA."* (Teaching assistant, from the course evaluation)

3 CEMENTING THEIR NEW SKILLS AND ASSESSMENT OF LEARNING GAINS

There is no formal exam for the training course, rather an on-going assessment takes place during the course, where the active and engaged participation of each teaching assistant counts as their exam. In order to pass the course, the teaching assistants will need to participate in all course activities. This is explicitly stated in the beginning of the course, and it is reiterated during the course, that active participation is a requirement. Therefore, passing the course is not only a question of physically being in the classroom, but also being mentally engaged in the contents and activities. The didactic design of the course and the assessment format was developed according to the model of constructive alignment, which necessitates a clear connection between the learning objectives, learning activities and the assessment of a course (Biggs and Tang 2011). The ambition of the assessment format is then to direct teaching assistants' attention towards the contents and activities of the course, and create a positive washback effect (Tsagari and Cheng 2020), motivating the teaching assistants to be more actively engaged.

Another important part of the assessment of the course is the case-discussions during the follow-up meeting, where each teaching assistant brings along a real-life case. Here, the teaching assistants show how they have used the knowledge and skills they learned during the introduction day in their teaching. During the case-discussions they are invited to analyse and reflect on their own experiences, as well as the experiences of other teaching assistants coming up with different ways of handling each situation, to deepen their understanding and insight into teaching practices. They will also practice active listening and asking questions, as well as engage in meta-discussions about the role and responsibilities of teaching assistants. This case-based activity is aligned with activities from the introduction day as well as their learning objectives, ultimately supporting the student's development of teaching competencies.

4 KEEPING THE COURSE RELEVANT

Because the tasks and responsibilities of teaching assistants are so diverse and subject to change, the content of the training course and its learning objectives are re-examined every semester using feedback from the course evaluations, as well as the cases from the Toolbox exercise. This ensures that the course is constantly kept up to date on the roles and responsibilities teaching assistants are given at the university and makes sure the content of the course is relevant and useful for future teaching assistants. Part of the revision process is reading through the cases from the teaching assistants, because it provides a detailed and valuable insight into the practices and challenges of the teaching assistants. During this process, if a new or particularly complex case shows up, they are saved and worked in to the curriculum for the upcoming semester. An example of this is, that two years ago, we received cases regarding teaching when there is a language barrier between the student and the teaching assistant. These cases created awareness of a need to prepare for handling this issue, and the case was then incorporated into the Toolbox exercise. Since the incorporation, there has been fewer teaching assistants reporting the issue.

The teaching assistants are asked to give feedback twice during the course. The first time is a short evaluation after the introduction day, where they are asked to write down something they think should be maintained on the course (for example an exercise or a topic) and something that could be developed further. Below are some examples:

Fig. 2. Excerpt from the short evaluation, Autumn 2023

This feedback serves two purposes: firstly, it immediately brings to light if there is anything that has been unclear during the introduction day that may need to be revisited or if there are some resources lacking that need to be provided for the teaching assistants. In other words, it provides an opportunity to rectify any misunderstandings quickly. Secondly, it provides valuable insight which can be used to develop and improve the course in the future, so that the content can stay relevant to teaching assistants even if their tasks and responsibilities may change.

The teaching assistants are also asked to evaluate the entire course at the end of it in a more thorough evaluation. However, there are usually around two months between the introduction day and the follow-up meeting. Thus, asking for immediate feedback after the first session is also a pragmatic decision, ensuring that feedback is given while their experiences are still fresh in their memory.

5 SUMMARY

The Teaching Assistants' Education has been offered now for more than 10 years and evaluations of the course are usually overwhelmingly positive, with teaching assistants expressing they find the course both useful and relevant. According to the feedback given by the teaching assistants, the training course facilitates positive professional development, enabling them to help further scaffold sustainable learning processes for students in close collaboration with university faculty. The teaching assistants specifically highlight the case-based activities, where they discuss real-life cases, as something that helped them gain an understanding of teaching and learning. They also describe that the course helped them feel more confident in their teaching abilities and gave them the necessary tools to handle any difficulties they encountered:

> "*I always have the results of our discussions from the introduction day in the back of my mind about how to be the best possible TA as I can. For example to be proactive when nobody's asking for help, because I can now say from experience that they often struggle with something even though they don't say it! Also be non-judgemental if they ask a supposedly "dumb" question, and instead just guide them through the problem until they understand, since everybody learns in a different pace.*" (Teaching assistant, from the course evaluation)

Implementing a training course such as this thus positively impacts the teaching self-efficacy and proficiency of teaching assistants, which in turn should have a positive impact on student learning.
Obviously, how this course design may be adapted to a different higher education context is dependent on many different factors, such as the number of new, inexperienced teaching assistants hired each year at the educational institution in question, as well as the diversity of the tasks teaching assistants are given and the resources available to support them in their professional development. The course design presented in this practice paper is designed to be flexible, so it can adapt to the dynamic landscape of higher education, and therefore it can easily be adapted to fit another context at other universities by modifying the real-life cases and questions the teaching assistants have to work with during the introduction day, as well as adding or subtracting specific teaching methods, according to their relevance for the teaching assistants in question. Considering the particularities of the context, different adaptations may be more or less meaningful. Therefore, it is important to understand the concrete needs of the teaching assistants at a given university. For example, at larger universities, which usually also have a higher number of teaching assistants, it may therefore be more meaningful to offer several, more specialised training courses for teaching assistants that are more targeted at teaching methods related to either specific scientific fields or specific tasks and responsibilities. In other cases, it may be more meaningful to adapt a more universal framework, such as the one presented in this paper, for example if a university has a relatively small number of teaching assistants or a higher diversity in responsibilities for each teaching assistant.

REFERENCES

Biggs, John Burville, and Catherine So-kum Tang. 2011. *Teaching for Quality Learning at University*. 4. ed. Maidenhead: Society for Research into Higher Education & Open University Press.

Dragisich, V., V. Keller, and M. Zhao. 2016. 'An Intensive Training Program for Effective Teaching Assistants in Chemistry'. *Journal of Chemical Education* 93 (7): 1204–10. https://doi.org/10.1021/acs.jchemed.5b00577.

Felder, Richard M., and Rebecca Brent. 2016. *Teaching and Learning STEM: A Practical Guide*. First edition. San Francisco, CA: Jossey-Bass.

Filz, T., and R.A.R. Gurung. 2013. 'Student Perceptions of Undergraduate Teaching Assistants'. *Teaching of Psychology* 40 (1): 48–51. https://doi.org/10.1177/0098628312465864.

Fong, C.J., J.B. Dillard, and M. Hatcher. 2019. 'Teaching Self-Efficacy of Graduate Student Instructors: Exploring Faculty Motivation, Perceptions of Autonomy Support, and Undergraduate Student Engagement'. *International Journal of Educational Research* 98:91–105. https://doi.org/10.1016/j.ijer.2019.08.018.

Forbes, J., D.J. Malan, H. Pon-Barry, S. Reges, and M. Sahami. 2017. 'Scaling Introductory Courses Using Undergraduate Teaching Assistants'. In *Proceedings of the Conference on Integrating Technology into Computer Science Education, ITiCSE*, 657–58. https://doi.org/10.1145/3017680.3017694.

Kendall, K., and E.E. Schussler. 2012. 'Does Instructor Type Matter? Undergraduate Student Perception of Graduate Teaching Assistants and Professors'. *CBE Life Sciences Education* 11 (2): 187–99. https://doi.org/10.1187/cbe.11-10-0091.

Marbach-Ad, G., K.L. Schaefer, B.C. Kumi, L.A. Friedman, K.V. Thompson, and M.P. Doyle. 2012. 'Development and Evaluation of a Prep Course for Chemistry Graduate Teaching Assistants at a Research University'. *Journal of Chemical Education* 89 (7): 865–72. https://doi.org/10.1021/ed200563b.

Mirza, D., P.T. Conrad, C. Lloyd, Z. Matni, and A. Gatin. 2019. 'Undergraduate Teaching Assistants in Computer Science: A Systematic Literature Review'. In , 31–40. https://doi.org/10.1145/3291279.3339422.

Nikolic, S., P.J. Vial, M. Ros, D. Stirling, and C. Ritz. 2015. 'Improving the Laboratory Learning Experience: A Process to Train and Manage Teaching Assistants'. *IEEE Transactions on Education* 58 (2): 130–39. https://doi.org/10.1109/TE.2014.2335712.

Odden, Tor Ole B., Anders Lauvland, Maria Vetleseter Bøe, and Ellen Karoline Henriksen. 2023. 'Implementing the Learning Assistant Model in European Higher Education'. *European Journal of Physics* 44 (3): 035701. https://doi.org/10.1088/1361-6404/acb39e.

Pawlak, Alanna, Paul W. Irving, and Marcos D. Caballero. 2020. 'Learning Assistant Approaches to Teaching Computational Physics Problems in a Problem-Based Learning Course'. *Physical Review Physics Education Research* 16 (1): 010139. https://doi.org/10.1103/PhysRevPhysEducRes.16.010139.

Reeves, T.D., G. Marbach-Ad, K.R. Miller, J. Ridgway, G.E. Gardner, E.E. Schussler, and E.W. Wischusen. 2016. 'A Conceptual Framework for Graduate Teaching Assistant Professional Development Evaluation and

Research'. *CBE Life Sciences Education* 15 (2). https://doi.org/10.1187/cbe.15-10-0225.

Ren, Y., S. Krishnamurthi, and K. Fisler. 2019. 'What Help Do Students Seek in Ta Office Hours?' In *Proceedings of the 2019 ACM Conference on International Computing Education Research (ICER)*, 41–49. https://doi.org/10.1145/3291279.3339418.

Rico, Mercedes, Julian Coppens, Paula Ferreira, Héctor Sánchez, and J. Enrique Agudo. 2013. 'Everything Matters: Development of Cross-Curricular Competences in Engineering Through Web 2.0 Social Objects'. In *Ubiquitous and Mobile Learning in the Digital Age*, edited by Demetrios G. Sampson, Dirk Ifenthaler, Pedro Isaias, and J. Michael Spector. New York: Springer.

Tinto, Vincent. 2017. 'Through the Eyes of Students'. *Journal of College Student Retention: Research, Theory & Practice* 19 (3): 254–69. https://doi.org/10.1177/1521025115621917.

Tsagari, Dina, and Liying Cheng. 2020. 'Washback, Impact, and Consequences Revisited'. In *Language Testing and Assessment*, edited by Elana Shohamy, Iair G. Or, and Stephen May, 3rd ed. Encyclopedia of Language and Education, 3rd Ed. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-02326-7.

Weimer, Maryellen. 2013. *Learner-Centered Teaching: Five Key Changes to Practice*. Second edition. San Francisco: Jossey-Bass. https://ebookcentral.proquest.com/lib/kbdk/reader.action?docID=1119448.

USING STUDY AND RESEARCH PATHS IN STATISTICS WITH REAL DATA TO RAISE QUESTIONS AND AWARENESS

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ABSTRACT

In this paper, we link different approaches in engineering education. On the one hand, the research in mathematics education at tertiary level, which gives a big importance to the inquiry-based learning approach, and, specifically in engineering degrees, which identifies, among others, active student learning on open-ended real-life tasks as promising innovative practices. On the other hand, the research in

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statistics education, where importance of inquiry is commonly accepted and which highlights the importance of the use of real and realistic data. Finally, the service-learning approach, which is clearly addressed to connect engineering education to social challenges. We present two inquiry-based activities called study and research paths, a methodology under the theoretical framework of the Anthropological Theory of the Didactic, that show the great potential of this type of teaching methodologies in engineering degrees, especially in the sense of raising questions, hands-on learning, awareness and responsibility in engineering graduates, when service-learning approach is used too.

1 INTRODUCTION

Nowadays, research in mathematics education at tertiary level gives more and more importance to inquiry-based activities. For example, the Erasmus+ PLATINUM project, carried out by eight European universities in seven countries, aims to develop an inquiry-based approach in teaching mathematics at university level related to the programmes in mathematics, science, engineering, economics, among others. (Jaworski et al. 2021)

When reviewing promising innovative mathematics teaching practices in engineering education, and the implications for curriculum reform, (Pepin et al. 2021) identify four themes that appear to address this question, being one of them “active student learning on open-ended real-life tasks and self-regulation [...] students develop their own learning trajectories, in order to overcome a ‘compartmentalized curriculum’ and atomistic approaches to learning...” (Pepin et al. 2021, p. 181-182). They also add that: “The mathematical competencies in and for engineering are developed by working on real-life professional tasks/problems/ challenges (rather than on mathematical topic areas that might or might not be used later in projects), with support and guidance from the instructor. The curriculum design involves the development or identification of complex learning tasks/challenges and their ‘monitoring’ (in terms of assessment of student learning), in addition to the provision of an infrastructure (for instructors and students) to work in such innovative environments.” (Pepin et al. 2021, p. 181-182).

The importance of inquiry in statistical education is commonly accepted, since it fosters statistical investigations (Watson 2009), statistical thinking (Pfannkuch & Wild 2004) and statistical problem-solving. According to the recommendations given by the Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Report, introductory statistics courses at university level should integrate real data with a context and purpose. In addition, the desired result of all introductory statistics courses is summarised in 9 goals, being the first one: “Students should become critical consumers of statistically-based results reported in popular media, recognizing whether reported results reasonably follow from the study and analysis conducted.” (Gaise 2016, p. 8). This goal stays in line with (Gürdur et al. 2022) that states that “the engineers of the future should not only be fluent in digital technologies but also in data.” A good and critical understanding of the data can lead to changes and improve how things have been done.

On the other hand, the service-learning approach is a form of experiential education that integrates practical experience with academic knowledge, and some of its objectives are to engage students in community service projects and to foster civic values, such as ethics and social awareness. It has been widely utilized across various disciplines, including medicine, nursing, psychology, and engineering, to enhance learning outcomes and foster civic values, such as ethics and social awareness (Huda et al. 2018), (Duffy et al. 2000). Also (Jiménez-Pérez et al. 2023) claim that "service learning is seen as evaluable strategy for students to contribute to the community and fulfil their social responsibilities." In engineering education, emphasis on the application on real-world contexts is stated "Integrating service-learning into engineering education offers opportunities for students to apply technical knowledge in real-world contexts, fostering their professional development and social responsibility." (Ferri & Furlong, 2019). More specifically, Community-Based Service Learning (CBSL) is a widely adopted learning strategy in engineering that promotes social values and civic engagement among students. (Baker 2018; Huda et al. 2018; Brown and Bauer 2021).

One of the goals of our study is to show that, using the research in mathematics education about inquiry-based learning, and transferring more responsibilities to the students, so that they have a more active role in their learning process, as well as choosing topics of social impact, the learning outcomes can make an impact to the students, in terms of raising awareness on some specific topics of general interest.

2 THEORETICAL FRAMEWORK

The theoretical framework used to design this proposal is the Anthropological Framework of the Didactic (ATD) (Chevallard 2015). This framework distinguishes between two main paradigms, the paradigm of visiting works, in which students visit the works of knowledge taught by the teacher; and the paradigm of questioning the world, where questions go first and the knowledge works, among others, are used to answer these questions. Under this paradigm of questioning the world, we can find the so called *study and research paths* (SRP) (Bosch 2018). SRPs can be classified as inquiry-based activities and they start with a generating question Q_0, which is presented to the students and they, as a whole class, have to answer. In the process of finding a final answer $A^\heartsuit$, new questions arise, which can be answered using empirical data, secondary information, knowledge works...

SRPs can be described and/or analised in terms of three dialectics, called *mesogenesis*, *topogenesis* and *chronogenesis* (Barquero & Bosch 2015). The mesogenesis corresponds to the evolution of the inquiry *milieu*, that is, the incorporation of new information and partial answers and their validation to transform them into new ready-to-use knowledge tools to proceed with the inquiry. The topogenesis refers to how responsibilities will be shared between teachers and students during the different steps of the inquiry process. The chronogenesis describes the possible pace for the inquiry, that is, the progress made through the consideration of an initial question Q_0 and the new questions derived from it, as well as the intermediate answers that are found or provided. A tool to represent the chronogenesis is the so called questions and answers map (Q-A map).

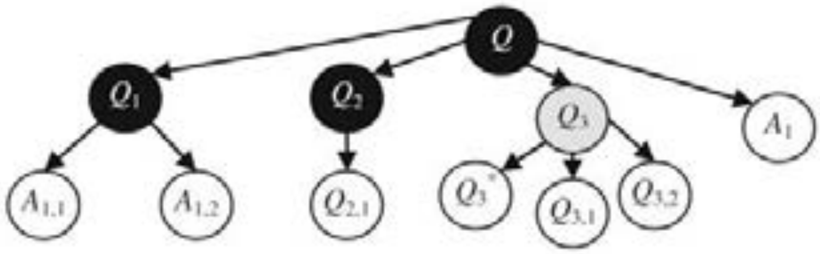

Fig. 1. An example of a question-answer map (Winsløw et al., 2013, p. 271)

Some SRPs have already been implemented in different educational levels and in different areas of mathematics education, but also in other subjects. At tertiary level, we can find some implementations that have been gathered in (García et al. 2019) and (Barquero et al. 2022), and they explain different modalities of SRPs and some commonalities and specificities in the way the three dialectics are organised. Some other SRPs have been carried out in engineering degrees (Bartolomé et al. 2019), (Florensa et al. 2018), (Queré 2022).

In the framework of the ATD, the novelty of the SRPs presented in this paper lies mainly in their articulation around social responsibility. In analyzing their development, emphasis is placed on how this aspect takes center stage, with students becoming involved and learning statistical content in an integrated manner with the practice of social and environmental responsibility.

3 DESIGN, IMPLEMENTATION AND SOME RESULTS OF THE SRPS

3.1 Design

Our proposals took place in the subject of statistics in the second semester of two consecutive years 2021-22 (Freixanet et al. 2022, 2023) and 2022-23 in the ICT Systems Engineering degree at the Escola Politècnica Superior d'Enginyeries de Manresa (EPSEM), one of the schools of the Universitat Politècnica de Catalunya UPC. Around forty students each year took the course. Four weekly sessions are devoted to the subject, two of them with the whole group, and the other two with half of the group in the computer lab. The instructional proposals were designed as SRPs, the students worked in teams of three to five students and they were given a first generating question or a topic to work on.

The theme of the first proposal (SRP1) centered around Water, with the guiding question being, "What concerns us about water in terms of sustainability?" This was closely tied to the ongoing project "AquaeSTEAM," concurrently undertaken within the school. The primary objectives of this project were to foster scientific culture and develop resources for interdisciplinary education across all levels, aligning with the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda for Sustainable Development. For the second proposal (SRP2), the inquiry was focused on the electrical consumption of the EPSEM. This inquiry was introduced by the school's maintenance head. A shared focal point in both SRPs was social responsibility, aiming to raise students' awareness of the environmental impact of our actions.

The design also took into account the second goal mentioned in the GAISE report, and let the students raise the questions that were going to lead their research, they wanted to carry out. Thus, provoking a share of responsibilities between the students and the teacher in the problematisation process (Freixanet et al. 2024), that is, in finding their own generating question that would lead their own inquiry, making sure that the data provided was statistically "studiable" and actually answered their proposed question.

3.2 First steps

Although both proposals were designed as SRPs, these proposals had significant differences in the process of finding the generating question for each team. Whereas in SRP1, the students raised questions first and had to find the data that could answer them, in SRP2, the students were given some sets of data, which they first explored, which led to raise many questions, which, at the same time, and after a process, led to find the main generating question of each team. In both implementations, though, very interesting questions were raised by the students during the process of finding their own generating questions. More details are given in (Freixanet et al. 2024).

3.3 Some results

Some generating questions that were studied in SRP1 were the following:

- Team B2: To what extent does the water consumption vary if some works are carried out in bathrooms?
- Team B5: How is the water consumption of the region Vallès Occidental and how is it comparable to the consumption in Catalonia?
- Team A6: What is the water footprint of the technology of first-year ICT Systems students?
- Team B1: Has the 2020 confinement affected the level of water consumption in Barcelona?

As example of some interesting results, see Figure 2, displaying some variables.

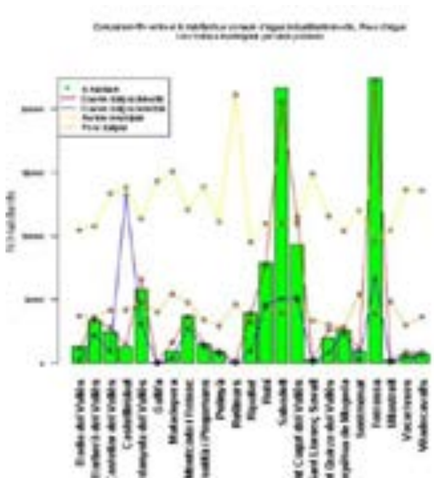

Fig. 2. Graph showing the number of inhabitants, the domestic and industrial water consumption and the price of water in each city of the region in Catalonia studied (SRP1 - Team B5)

We highlight the study carried out by team B2, in which the students proposed some changes in the bathrooms of a residence of elderly people, in order to save water, having previously asked the residence for data about water consumption, talked to some constructors and studied the water footprint.

MONTH	VIUB2 (water consumption m3)
GENER	436
FEBRER	439
MARÇ	433
ABRIL	482
MAIG	460
JUNY	559
JULIOL	426
AGOST	533
SETEMBRE	413
OCTUBRE	495
NOVEMBRE	428
DESEMBRE	394
TOTAL	5.498

Fig. 3. Water consumption of a residence of elderly people per month (SRP1 - Team B2)

In SRP2, some of the questions were:

- Team A1: How do morning or afternoon classes have an impact on the consumption of electricity?
- Team A3: How do temperatures affect the consumption of electricity?
- Team A4: What impact does the non-lectivity have on the consumption of electricity?
- Team B1: How does the open and closed hours and the amount of people in the school affect the consumption of electricity?
- Team B4: Does the exam period affect the consumption of electricity?

Some interesting results show, mainly, a diagnostic from which some conclusions can be withdrawn and hence, improvement proposals can be made.

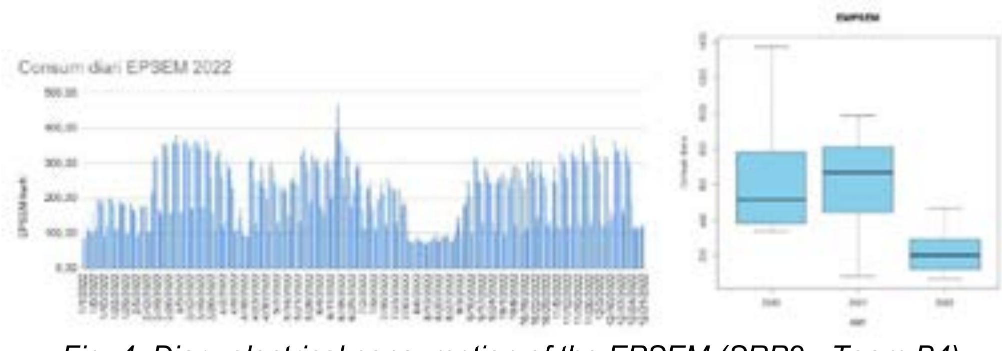

Fig. 4. Diary electrical consumption of the EPSEM (SRP2 - Team B4)

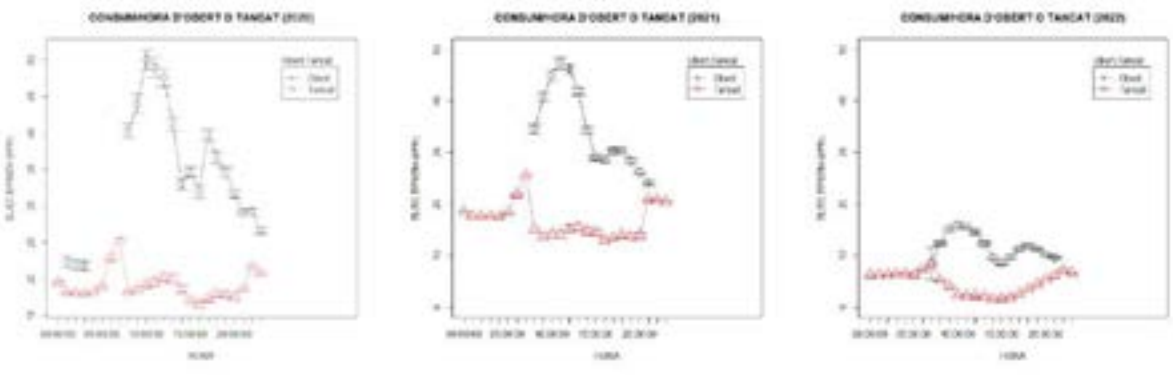

Fig. 5. Consumption of electricity of EPSEM in 2020, 2021 and 2022 when closed and opened in different years (SRP2 - Team B1)

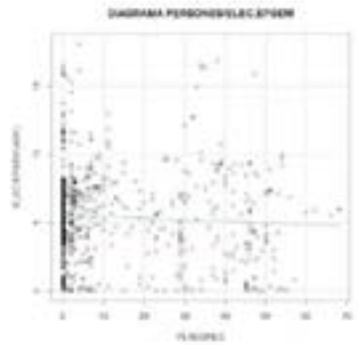

Fig. 6. Correlation between the number of people in the school and the consumption of electricity (SRP2 - Team B1)

We highlight a proposal from team B1, who encountered a lot of problems to process the data provided, which was hand-written. This data showed information about the people that entered the building on days with no classes: weekends, bank holidays, holiday periods... They suggested this control should be digitalised using the student card or a QR code. This way, the data could be analysed more easily and paper would not be used.

4 ANALYSIS AND CONCLUSIONS

Implementing inquiry-based activities, such as SRPs, in the subject of statistics provides students with the opportunity to become proficient in handling data, interrogating it, comprehending it, posing questions, being critical, making decisions, and proposing solutions. Indeed, these activities enhance students' statistical skills, which, in a world abundant with data, are essential for conducting diagnostics and formulating improvement proposals.

Analysis of the development of SRP1 confirms the key characteristics of service – learning activities. Motivation stemmed from the significance of water as a natural resource, particularly in relation to climate change, and the desire to reduce consumption and promote reuse. Social benefits included studying consumption data to raise awareness and educate, as well as generating proposals for reduction and reuse. Collaborative efforts involved external agencies such as city and county councils, environmental groups, neighbourhood associations, and public water service companies. Similar patterns were identified in the development of SRP2.

The impact on students was evaluated through a combination of academic assessment tests related to statistics and surveys and interviews focusing on their understanding of responsibility. Results indicated a positive impact on students, including enhanced learning of content and competencies, reflected in good academic performance, and increased awareness of social responsibility and personal reflection, as evidenced by survey responses and interview feedback. Furthermore, the impact on teaching staff was also positive, as they experienced simultaneous improvement in teaching effectiveness and social service engagement. Lastly, it is worth highlighting the positive impact on the institution itself, as engaging with such organizations fosters the growth of the local social network.

REFERENCES

Alsina, M., Alfonso, P., Sidki, N., Bel, G. & Gaona, R. (2022). "Service-learning in engineering: analysis of students experiences in development cooperation.". *Fiftieth Annual Conference of the European Society for Engineering Education (SEFI 2022, 19-22 September 2022). Barcelona, Universitat Politècnica de Catalunya.* https://doi.org/10.5821/conference-9788412322262.1126

Alsina, M., Gaona, R., Ventura, P., Bel, G. & Fornell, D. (2022). "Service-learning experience through outreach and engagement with science and technology museum.". *Fiftieth Annual Conference of the European Society for Engineering Education (SEFI 2022, 19-22 September 2022). Barcelona, Universitat Politècnica de Catalunya.* https://doi.org/10.5821/conference-9788412322262.1126

Baker, Lottie. (2018). "From Learner to Teacher Assistant: Community-Based Service-Learning in a Dual-Language Classroom." Foreign Language Annals 51 (4): 796–815. https://doi.org/10.1111/flan.12363

Barquero, B., & Bosch, M. (2015). Didactic Engineering as a research methodology: From fundamental situations to study and research paths. In A. Watson & M. Ohtani (Eds.), *Task design in Mathematics Education* (pp. 249-272). Springer. https://doi.org/10.1007/978-3-319-09629-2_8

Barquero, B., Bosch, M., Florensa, I. & Ruiz-Munzón, N. (2022). "Study and research paths in the frontier between paradigms". *International Journal of Mathematical Education in Science and Technology*, *53*(5), 1213-1229, https://doi.org/10.1080/0020739X.2021.1988166

Bartolomé, E., Florensa, I., Bosch, M., & Gascón, J. (2019). "A „study and research path" enriching the learning of mechanical engineering". *European Journal of Engineering Education,* 44(3), 330-346.

Bosch, M. (2018). Study and Research Paths: a model for inquiry. In B. Sirakov, P. N. de Souza, M. Viana (Eds.), Proceedings of the International Congress of Mathematicians, ICM 2018 (Vol.3, pp. 4001-4022). World Scientific Publishing.

Brown, A. & Bauer, M. (2021). "Merging Engineering Education with Service-Learning: How Community Based Projects Encourage Socially Conscious Engineers". Athens Journal of Education, 8(1): 9–21.

Chevallard, Y. (2015). Teaching Mathematics in tomorrow's society: a case for an oncoming counter paradigm. In S. J. Cho (Ed.), *Proceedings of the 12th International Congress on Mathematical Education* (pp. 173-187). Springer. https://doi.org/10.1007/978-3-319-12688-3_13

Duffy, J., Tsang, E. & Lord, S. M. (2000). „Service Learning In Engineering: What, Why, And How?" Paper presented at *2000 Annual Conference, St. Louis, Missouri*. 10.18260/1-2—8694.

Ferri, B. A. & Furlong, K. P. (2019). "Integrating Service-Learning into Engineering Education: Opportunities and Challenges." *Advances in Engineering Education*, 7(1).

Florensa, I., Bosch, M., & Gascón, J. (2018). "Enriching engineering education with didactics of mathematics: Study and research paths in engineering education." *IEEE Global Engineering Education Conference (EDUCON)* (pp. 751-759).

Freixanet, M. J., Alsina, M. & Bosch, M. (2022). “A practical approach to statistics through SRP”. *Fiftieth Annual Conference of the European Society for Engineering Education (SEFI 2022, 19-22 September 2022). Barcelona, Universitat Politècnica de Catalunya.* https://doi.org/10.5821/conference-9788412322262.1126

Freixanet, M.J., Alsina, M. & Bosch, M. (2023). “Incorporating a Study and Research Path in a course of Statistics for Engineering”. *In M. Trigueros, B. Barquero, R. Hochmuth, & J. Peters (Eds.), Proceedings of the Fourth Conference of the International Network for Didactic Research in University Mathematics (INDRUM 2022, 19-22 October 2022)* (pp. 375-384). University of Hannover and INDRUM.

Freixanet, M.J., Alsina, M. & Bosch, M. (2024). “The problematisation process in the teaching of statistics through study and research paths”. (Submitted)

GAISE College Report ASA Revision Committee (2016). “Guidelines for Assessment and Instruction in Statistics Education College Report 2016”. American Statistical Association. http://www.amstat.org/education/gaise.

García, F.J., Barquero, B., Florensa, I., Bosch, M. (2019). “Diseño de tareas en el marco de la Teoría Antropológica de lo Didáctico”. *Avances de Investigación en Educación Matemática*, *15*, 75-94. https://doi.org/10.35763/aiem.v0i15.267

Gürdür Broo, D., Kaynak, O. & Sait, S. (2022). “Rethinking engineering education at the age of industry 5.0”. *Fiftieth Annual Conference of the European Society for Engineering Education (SEFI 2022, 19-22 September 2022). Barcelona, Universitat Politècnica de Catalunya.* https://doi.org/10.5821/conference-9788412322262.1126

Jaworski, B., Gómez-Chacón, I. Hochmuth, R., (2021). “Conceptual foundations of the PLATINUM project”. *Inquiry in University Mathematics Teaching and Learning. The PLATINUM Project*. https://doi.org/10.5817/CZ.MUNI.M210-9983-2021-2.

Jiménez-Pérez, M.I., Perfecto-Avalos, Y. & Orellana-Haro, M.C. (2023). “Nurturing community: using community-based service learning in biopharmaceutical engineering education”. *Fifty-first Annual Conference of the European Society for Engineering Education (SEFI 2023, 11-14 September 2023). Dublin, Technical University of Dublin*. https://doi.org/10.21427/E3T9-TV19

Huda, Miftachul, Kamarul Shukri Mat Teh, Nasrul Hisyam Nor Muhamad, and Badlihisham Mohd Nasir. 2018. “Transmitting Leadership Based Civic Responsibility: Insights from Service Learning.” *International Journal of Ethics and Systems* 34 (1): 20–31.https://doi.org/10.1108/ijoes-05-2017-0079.

Pepin, B., Biehler, R. & Gueudet, G. (2021). „Mathematics in Engineering Education: a Review of the Recent Literature with a View towards Innovative Practices”. *International Journal of Research in Undergraduate Mathematics Education* (2021) 7:163–188. https://doi.org/10.1007/s40753-021-00139-8

Pfannkuch, M., & Wild, C. (2004). Towards an understanding of statistical thinking. In D. Ben-Zvi & J. Garfield, (Eds.), The challenge of developing statistical literacy, reasoning, and thinking (pp. 17-46). Kluwer Academic Publishers.

Quéré, P. V. (2022). “Bridging the mathematics gap between the engineering classroom and the workplace”. *International Journal of Mathematical Education in Science and Technology*, 53(5), 1190-1212.

Watson, J. M. (2009). “The development of statistical understanding at the elementary school level”. *Mediterranean Journal of Mathematics Education*, 8(1), 89-109.

Winsløw, C., Matheron, Y., & Mercier, A. (2013). “Study and research courses as an epistemological model for didactics”. *Educational Studies in Mathematics*, 83(2), 267–284. https://doi.org/10.1007/s10649-012-9453-3

4TU.RESPONSIBLE SUSTAINABILITY CHALLENGE: DEVELOPING AND RUNNING AN INTER-UNIVERSITY CHALLENGE-BASED MASTER HONOURS PROGRAMME

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ABSTRACT

We showcase our 4TU Responsible Sustainability Challenge Master Honours track as a successful case of ongoing inter-university educational collaboration. The experiences of this endeavour could be used as a guiding example for similar collaborations. The organisational cooperation among the universities was evaluated through qualitative analysis based on interviews with eight involved collaborators. Our experiences show that to utilise the benefits of inter-university collaborations for both students and institutions, a careful consideration of the organisational structure is needed beforehand. It is especially important to evaluate the prerequisite conditions of the collaboration, educational alignment, and administrative tasks, as

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well as develop a suitable coordination system that would regulate the vision and the practical implications of the development and operation of the course.

1 INTRODUCTION

1.1 Interdisciplinary & Inter-university Future

The current developments in industry require engineers to work increasingly along other disciplines to understand the needs of diverse fields and specialisations (Van Den Beemt et al. 2020). The demands of industry consequently require educational institutions to further integrate interdisciplinarity within their degree programmes. This will allow students to develop and practice collaboration skills and other transversal skills necessary for understanding and working with people from other disciplines. This need is currently addressed within single universities by developing (intra-faculty) dedicated courses. However, courses shared among universities are less utilised as a learning framework for interdisciplinarity (Dimitrienko et al. 2020). The current practice paper aims to showcase one such success case of an inter-university collaboration.

Inter-university education is collaboratively developed, taught, and supported by multiple universities (Coombe 2015). This can provide an opportunity for students to engage with a wide range of disciplines, experts, teachers, and stakeholders, creating a fertile ground for the development of transversal skills (Dawson et al. 2024). Transversal skills such as critical thinking, creativity, and interpersonal skills, appear to be of crucial importance in the future engineering industry (Kovacs et al. 2020). Furthermore, by training skills on the intersection of scientific areas and increasing the number of available human and material resources, e.g. knowledge base, expertise, facilities (Dimitrienko et al. 2020), students and future employees are better equipped for the changing requirements of industry and academia (Blagorazumnaia & Trifonova 2023). However, such inter-university cooperations requires a stable ground of collaboration and clear agreements among institutions.

1.2 Development of the collaborative 4TU.Federation Master Honours track

The 4TU.Federation (4TU) is an inter-university federation of four technical universities in the Netherlands, namely Eindhoven University of Technology, Delft University of Technology, University of Twente and Wageningen University & Research, which work together in the vision of "*connecting, representing and innovating in the areas of education, research and valorisation*" (4TU.Federation 2024). The involved universities cooperate in research to build upon each other's knowledge and offer more opportunities to their students. To develop their collaboration further, the 4TU.Federation piloted an inter-university Master Honours track under the title 4TU *Responsible Sustainability Challenge (4TU.RSC)*. As a track, 4TU.RSC serves as a specialisation among the Honours programmes of the collaborating universities in which students can follow a predetermined trajectory of development centred around the dedicated topic of sustainability, in which individual components (i.e. project work, online lectures and on-site events at the universities) contribute to the overall learning goals shared by these universities. The initial idea was developed by all four universities, however, Wageningen University only partook in the initial development, as they did not offer a Master Honours programme during the time of development and could therefore not embed the track in their Honours curriculum.

In practice, 4TU.RSC is delivered as an extracurricular track for selected Master students, working on a sustainability challenge while receiving coaching, workshops, and lectures provided by educators of the three universities. The track is organised, developed, and provided under the Honours programmes of the three collaborating universities. The Honours programmes are provided for ambitious and talented students who want to do something next to their study. A key characteristic of the Honours programmes at the participating universities in this collaboration is that students must apply for them and are subsequently selected if they fit the criteria of the Honours programme of each participating university. The exact method of student recruitment and selection differ between the universities..

Since the Honours programmes are outside of the official curriculum, more experimentation with education is possible. Integrating a new course in any institution involves usually a demanding and long procedure. Additionally, Honours students are considered and selected on being motivated and able to work in complex and innovative educational structures, making them very good at handling a programme with a lot of parties, teachers, and stakeholders. These were the main considerations for the 4TU.RSC to be developed and provided by the Honours programmes.

2 METHODOLOGY

The main objective of this practice paper is to provide insight into the creation and running of inter-university education. To those ends all involved organisation staff were approached and asked to participate in an interview (appendix A). Eight semi-structured interviews were conducted with 4TU.RSC track coordinators, Honours programme managers/coordinators, educational experts, and 4TU representatives. The interviewees were involved at various stages of the preparation and/or delivery processes for each of the two running periods of 4TU.RSC. All interviewees gave their informed consent via video or voice agreement to be recorded and transcribed. The transcripts of the interviews were coded by two researchers using a deductive approach (Azungah 2018). Similar content was coded under the same code, with the count of that code increasing by one for each instance in the transcripts.

3 RESULTS

The list of codes from the transcripts could be divided into three broad categories: the requirements for, the benefits of, and the challenges in organising and running inter-university education. The following paragraphs present shortly the main categories as those were defined based on the information shared by the interviewees. Topics which were mentioned four times or more by the interviewees are included in the results within their categories:

a. *Requirements*, or the prerequisites necessary to build such a collaboration.
b. *Benefits*, or the added value of such collaborations.
c. *Challenges*, or the difficulties that such collaborations introduce.

3.1 Requirements

The first main area consisted of the requirements regarding the process of developing, initiating, and operating inter-university educational programmes. The most often mentioned requirement was alignment among Honours programme structures and institutional overarching Honours programme learning goals. Each of the 4TU universities have different structures in the Honours programmes. These differences relate to the application period, the selection criteria, and the number of credits in an Honours programme. Even the level of centralisation of the Honours programmes differs, where some universities have (a part of the) organisation on the faculty level while others maintain a university-wide programme. All these factors created a complex web of policy, scheduling issues, and requirements which the organisational team had to navigate before the track creation process could begin. The track was re-evaluated after the first year, and some strategy changes were made to be as accessible as possible for students from all universities. These changes included a restructuring of the division of credit to allow the different partner universities to take ownership over study modules which were close to their expertise.

As the content of the track, especially the learning goals and visions, needed to be aligned among the institutions and the Honours programmes, administrative complications were also introduced in the original prerequisites for setting up the collaboration. For instance, some of the collaborators defined the Master level of the learning objectives differently, had varying understanding of the appropriateness of challenge-based learning (CBL) outcomes for this educational level, and had different approval requirements for new tracks.

Given this intense administrative and aligning work, collaborative and co-creative team spirit appeared also as a prerequisite. The openness to hear other perspectives and to discuss concerns, ideas, doubts, etc. among the collaborating members made aligning the programme structure and learning goals easier. All members appeared to contribute their own expertise and knowledge and be responsible for accomplishing several tasks on behalf of the common goal. The flat hierarchy among the contributing members supported their responsibility and was the driving force towards a good collaboration. The same spirit of openness and collaboration was also extended towards the external parties throughout the whole process of preparation and operation of the track. Given the CBL character of the programme, education experts and stakeholders (e.g. companies contributing as experts from practice) were also involved in the co-creation process of the track. This diversity of expertise and points of view embedded in the programme development contributed to its extensive multidisciplinary character and enriched its knowledge database.

3.2 Benefits

The main reason of the 4TU collaboration on this track was the preparation of the students towards an inter-disciplinary future career and the understanding of differences between schools of thought within the same discipline. Interestingly, some of those benefits were also mentioned in the interviews conducted as advantages for the universities. Each institution, and their representatives, embodied a role to fulfil specific tasks. The programme required more involvement from all parties in a mostly unexplored type of collaboration. This meant that some members of the team were present and involved in elements of the track creation process where they normally would not be. This allowed for perspectives and practices to be shared, and new learning to be introduced. Hence, the interdisciplinary knowledge of the universities was equally improved.

The co-creation of this track further enhanced the network of each of the universities. The programme allowed the team members to get even more familiar with the other 4TU universities and get acquainted with professionals from diverse departments. Sharing perspectives, enriching the knowledge databases, and exchanging good practices among institutions were the most prominent benefits of the collaboration spirit that was enhanced through the development and delivery of this track. An important addition was strengthening the relationships between the Honours programmes. Given the strong ties between the programmes, enabling additional future collaborations was proposed as an important outcome of this collaboration. Finally, given the interaction with external experts and local companies as stakeholders, the network of the institutions was enriched even further in industry, allowing for other kind of collaborations and possible connection of the local students to relevant companies.

3.3 Challenges

Next to the prerequisites and benefits of this inter-university educational collaboration, there are several challenges that also need to be taken into consideration. The most named challenge is coordination. From the very beginning of this endeavour, no specific coordinator was assigned among the universities. The goal of this choice was to ensure a flat hierarchy, and equal involvement of each member. However, the cooperation between the different educational institutions, with different approaches, organisation and even teaching backgrounds, imposed complications in the collaboration. Practical matters, such as meetings, agreements and more abstract issues, such as the vision and the collaboration plans, were undetermined. Multiple interviewees suggested that clear guidance regarding important topics of the cooperation would have ensured smoother interaction, and improved cooperation.

Due to this lack of coordination, practical implications were often mentioned to arise in the collaboration between the different members. It was not always clear under whose responsibility some tasks belonged, what the planning of the track was, and which adjustments to the local programmes or promotion strategies needed to occur. This was also reflected in the student evaluations of the pilot, who provided the feedback that communication was often unclear and late. Next to coordinating among the inter-university organisational team, the local institutions needed to ensure alignment with their own curricula. Furthermore, developing such a complex interdisciplinary track required more dedication and time investment. Finally, even though the track was running under the Honours programmes of each institution, not every programme operates in the same way regarding timetables, student entry requirements, and even rules and regulations. Central coordination could offer early solutions to those matters.

Instead, to ensure solving those raising issues and dealing with the newest developments, the members of this collaboration needed to have regular meetings. Those meetings appeared to be more productive when they occurred in person. In the online meetings, several interviewees reported to have the impression of less commitment and/or lower motivation. Meetings in person appeared to be more productive and better for the team spirit. However, regular physical meetings require time and financial investment. The traveling hours of the teachers and the coordinators needed to be weighed against the increased team spirit and the successful cooperation.

4 DISCUSSION

Taking into consideration the input of the members of the organisational team of 4TU.RSC, there are some relevant conclusions that could serve as valuable guiding sources in future inter-university innovative educational projects. Thereby, it is important to underline that such collaborations are not only profitable for the students partaking in this education, but also for the educators and the institutions. Strengthening the collaboration spirit, learning from the interdisciplinary environment and the different practices and approaches of each university, as well as continuously networking with old and new stakeholders enlighten the reasons of such endeavours.

However, while preparing and delivering such inter-university courses, it is fundamental to take several implications into account. Firstly, coordination might be a key for smooth collaboration. A designated individual or group of people in this coordinating position could safeguard the vision and alignment to the local institutions, take the key decisions, arrange practical implications, such as adjustments, administrative challenges, and promotion to students, as well as decide when physical or online meetings are necessary for the best collaboration procedure. The 4TU.RSC initiators choose for a flat hierarchy structure, which led to equally successful results. The coordination tasks were adopted organically by various parties. However, having such a central role could smoothen the cooperation, especially during the development period.

Prior to initiating inter-university courses, it is important to test if the universities intending to start the course provide a good organisational foundation for such an endeavour. Meaning that the participating universities must be flexible enough to adapt to potential organisational limitations of the partnering universities. The most important factor is the evaluation of the alignment between the learning goals of such an inter-university course and the local institutional courses, as well as the administrative complications that might come along such an innovation, such as scheduling issues between universities, adjustment of educational level definitions that might be relevant for international forms of such collaborations, and more. Above that, all those prerequisites can only be successful if a collaborative and co-creative team spirit is present or can be developed among the involved members. The 4TU collaboration had a significant advantage on that front, given the already existing collaboration. Until the initiation of 4TU.RSC, the 4TU mainly focused on research and promotion of the good practices of each university. The 4TU.RSC was their first educational track developed, but the strong cooperation ties were already well established.

5 Conclusion and Acknowledgements

In conclusion, inter-university courses appear to have many advantages for both the students and the institutions. The experience of developing and providing the 4TU.RSC Honours track has shown that alignment is one of the most important factors for a successful collaboration. This must be evaluated by the participating institution, and the case of the 4TU.RSC has shown that dedicated coordination may make this process more efficient and thorough. Future attempts in establishing inter-university courses can take the present paper into account when establishing the collaboration structure. However, further longitudinal and empirical data would also be required to carefully assess the applicability of inter-university collaborations.

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6 REFERENCES

4TU.Federation. "4TU in Only 1 Minute". 2024, https://www.4tu.nl/en/about_4tu/4tu-in-1-minute/. Accessed on: 8th of April 2024

Azungah, Theophilus. "Qualitative Research: Deductive and Inductive Approaches to Data Analysis." *Qualitative Research Journal* 18, no. 4 (October 31, 2018): 383–400. https://doi.org/10.1108/qrj-d-18-00035.

Blagorazumnaia, Olga, and Larisa Trifonova. "Educational Policy in the Context of Globalization and International Cooperation." *Journal of Research on Trade, Management and Economic Development (Online)/Journal of Research on Trade, Management and Economic Development* 10, no. 1(19) (August 1, 2023): 134–45. https://doi.org/10.59642/jrtmed.1.2023.10.

Coombe, Leanne. "Models of Interuniversity Collaboration in Higher Education – How Do Their Features Act as Barriers and Enablers to Sustainability?" *Tertiary Education and Management* 21, no. 4 (October 2, 2015): 328–48. https://doi.org/10.1080/13583883.2015.1104379.

Dawson, Henry, Gayle Davis, Kirstin Ross, Marie Vaganay Miller, and Alastair Tomlinson. "Using Staged Teaching and Assessment Approaches to Facilitate Inter-university Collaboration and Problem-based Learning." *Frontiers in Public Health* 12 (March 11, 2024). https://doi.org/10.3389/fpubh.2024.1334729.

Dimitrienko, Yury I., Anastasia V. Chibisova, and Victor Yu. Chibisov. "Inter-University Networking in Mathematical Digital Blended Learning." *ITM Web of*

Conferences 35 (January 1, 2020): 03014. https://doi.org/10.1051/itmconf/20203503014.

Kovacs, Helena, Delisle Julien, Mirjam Mekhaiel, Dehler Zufferey Jessica, Roland Tormey, and P. Vuilliomenet. “Teaching Transversal Skills in the Engineering Curriculum: The Need to Raise the Temperature.” *Infoscience*, November 20, 2020. https://infoscience.epfl.ch/record/283739?v=pdf.

Van Den Beemt, Antoine, Miles MacLeod, Jan Van Der Veen, Anne Van De Ven, Sophie Van Baalen, Renate Klaassen, and Mieke Boon. “Interdisciplinary Engineering Education: A Review of Vision, Teaching, and Support.” *Journal of Engineering Education* 109, no. 3 (June 30, 2020): 508–55. https://doi.org/10.1002/jee.20347.

APPENDIX

Interview questions

Personal Data:

What was your role within the 4TU.RSC program?
Which tasks did you fulfil for the 4TU.RSC program?
During which moments were you involved in the 4TU.RSC program? (preparation 1st round, round 1 running, preparation 2nd round, round 2 running)
What expertise did you bring to the 4TU.RSC program?

Preparation Period (preparation 1st & 2nd round):

Which processes were necessary for setting up (or iterating) the 4TU.RSC program?
Who did you need to communicate with in order to organize the 4TU.RSC program?
Which were the most complicated discussion points in the development of 4TU.RSC program?
How did the teamwork/ collaboration process develop among the involved members?
What were the most valuable opportunities that 4TU / inter-university collaboration provided?

During Course Progression:

What difficulties did you experience in the cooperation/ coordination of the course?
How did you ensure the quality of the program throughout the process?
How did you ensure smooth collaboration among the involved members?
Were there points of disagreement among the involved members?
What were the most valuable opportunities that providing 4TU / inter-university education provided?

Closing & Next Steps:

How did you evaluate the cooperation with all the members?
What were the most important learning points after the completion of the cooperation?
How did you decide on the next steps (progression, next level, alternative iteration) of the program?
What would you propose for future similar inter-university collaborations?

A co-curricular approach to addressing the variation of practical skills in students from diverse backgrounds.

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ABSTRACT

Responding to the diversity in practical electronics skills among first-year undergraduate students, the University of Sheffield implemented "Diamond Wednesdays," a co-curricular activity (CCA) outside the traditional curriculum. Recognizing that students arrived with varying levels of practical experience due to differences in pre-university education, including disparities in international educational backgrounds, Diamond Wednesdays sought to address this gap in an informal, technician-led environment. This initiative leverages unused laboratory time on Wednesday afternoons, a period traditionally reserved for student activities and sports, to offer optional, non-assessed sessions focused on building, testing, and troubleshooting electrical circuits. The program has demonstrated significant

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success since its inception in September 2019, with an increasing number of participants across various year groups, including postgraduates, seeking to refine their basic electronics skills. The introduction of remote learning options during the pandemic further expanded the reach and flexibility of Diamond Wednesdays by incorporating online resources. Feedback from participants has been overwhelmingly positive, with the initiative receiving high satisfaction ratings and qualitative praise for providing a supportive, non-judgmental space for skill development. Diamond Wednesdays is an example of the educational impact possible from empowering and utilising the expertise of the technical staff. It represents a scalable, efficient model for addressing skill disparities among engineering students, fostering a culture of collaboration between technical staff and students, and enhancing the overall educational experience without imposing additional demands on academic staff. The success of this program highlights the potential for similar co-curricular initiatives to complement traditional engineering education and support students' diverse learning needs.

1 INTRODUCTION

The Electronics and Control laboratory in the University of Sheffield's Diamond building delivers timetabled, practical classes to a range of engineering disciplines. Typical classes in the laboratory may include RLC circuits, transformers, coupled circuits and transistors. The multidisciplinary approach utilised in the laboratory (Kapranos 2018) means students attending classes in the laboratory may be enrolled in one of several degree programmes, as listed in table 1. Students arrive with different entry qualifications, different learning needs and different cultural/educational backgrounds. In aggregate, international students comprise 30% of participants in laboratory activities. Students arrive with different entry qualifications, different learning needs, and different cultural/educational backgrounds. The author's previous career in secondary (high school) education provided familiarity with the practical skills of first-year UK students. From daily interactions with students in the electronics and control lab, it is clear that the practical skills of international students are different. In aggregate, international students comprise 30% of participants in laboratory activities, and, as can be seen from Table 1, the Electronics and Electrical Engineering degree programs have a high proportion of international students.

The majority of students participating in activities in the laboratory are first- and second-year undergraduates. Despite this limited remit, the large cohort sizes (referenced in table 1) on multiple degree programmes generate substantial demands. The laboratory has a capacity of 144 seats, a high throughput, with a frequency utilisation of 84% and delivers around 63,700 student contact hours a year. Tactics to allow operation at this scale are employed, such as all students following the same activity at the same time (Di Benedetti et al. 2022). Consequently, there is little opportunity for students to spend more time than allotted to perfect or repeat prescribed tasks.

A team of five technical staff members work in the laboratory to enable the high levels of throughput. Unlike the traditional role of lab technical staff, principally concerned with equipment maintenance and safety management, the technical staff also contribute to the teaching, with contractual job titles of “teaching technicians".

In the Diamond building laboratories, there is a strong culture of integration between academic and technical staff. For example, all staff sit together in the same office, rather than having academic and technician offices physically separated, as is more common in higher education. Technical staff are empowered to make changes to laboratory delivery and encouraged to implement innovative ideas. The practice presented here is an example of how valuing technical staff contributions can lead to enhanced educational opportunities for students.

Table 1. Range of programmes and background of student in the Electronics and Control lab sorted by % of overseas students.

Programme	Cohort Size	% Overseas
Electrical and Electronic Engineering	305	65
Chemical Engineering	154	31
Computer Science and Engineering	587	29
Bioengineering	117	27
Mechanical Engineering	428	25
Aerospace Engineering	434	15
Mechatronics and Robotics	240	8
General Engineering	132	3

2 PROBLEM IDENTIFICATION

One of the first laboratory sessions for first year undergraduates is a “Workstation Lab”, designed to introduce students to using standard test equipment. Students build a circuit as the foundation of their testing. This circuit includes a prototype (breadboard) circuit and a soldered printed circuit board (PCB).

The technical staff observed that many of the undergraduate students, though knowledgeable, lacked certain basic skills in their practical electronics lab sessions. Through informal discussions with students, it was established this was due to the diversity of pre-university education. Some UK students had received less practical education during their secondary school years (age 12-18) than anticipated in the design of the teaching sessions. Many students, in particular international students, had never previously used a soldering iron and were finding great difficulty in understanding what it was for and the reasons why it is used. It was noticed that some students struggled to understand how the breadboard worked, therefore making it difficult to build the circuit accurately.

The results from the lab session assessment showed where students lacked the basic understanding of how to build prototype circuits accurately and neatly. These observations showed a lack of basic skills negatively affected the students’ progress, particularly in early lab sessions. Frustrations became obvious from both the students and the academic staff, evident in staff-student interactions.

Addressing the variation in practical skills among students of different educational and cultural backgrounds, to allow them to participate in the timetabled sessions designed with the expectation of prior experiences with these skills from previous education, present significant challenges. The already high utilisation of the lab means that additional timetabled sessions are not possible and redesigning the teaching to accommodate remedial training would consume more academic staff time resources. An innovative solution, led by technician expertise, is presented here.

3 DIAMOND WEDNESDAY

It is acknowledged in the literature that little research has been conducted in the field of co-curricular and extracurricular activities. Bartkus et al. (2012) suggest that a barrier may be the ambiguous and unclear definition of what constitutes an extracurricular activity, as no generally-accepted definition has been established in the literature. The review defines a co-curricular activity (CCA) as 'one that requires a student's participation outside of normal classroom time as a condition for meeting a curricular requirement,' which represents the work presented here. An extensive review conducted by the UK's Higher Education Academy to examine the role of extracurricular activities on students and their futures (Stuart et al., 2008) also acknowledges in the report that prior to this date, little research on extracurricular activities had been conducted. Findings of the report indicate that certain groups of students, particularly ethnic minorities, do not engage in co- or extracurricular activities. Among the report's recommendations are that 'universities need to pay attention to this unfortunate divide in the students' experience.' Participating in any form of extracurricular activity can have a positive effect on academic performance, even if the activity is not explicitly related to the field of study (Daniyal et al., 2012). A significant study in 2018 (Buckley and Lee, 2018), including a survey with 849 valid responses, analysed the impact of extracurricular activities on student experience. It was found that there are many benefits to participation in extracurricular activities, provided they do not distract too much attention from curricular activities. Very little published work can be found on the impact of co-curricular activities that are directly linked to curricular content.

Diamond Wednesdays was created as a CCA to support students with practical electronics skills. There are many engineering CCAs at the University of Sheffield. These are typically student-led teams formed to develop prototypes that compete in inter-institutional competitions. In contrast, Diamond Wednesday is technician led and focuses on the teaching of practical electronics skills such as using hand tools and the building, testing and fault finding of electrical and electronic circuitry. In all other respects, Diamond Wednesdays can mirror and take advantage of the existing paradigm of a co-curricular activity, allowing students to immediately understand its nature. It is an optional, community driven, non-assessed skills teaching session on Wednesday afternoons in the Diamond building's Electronic and Control laboratory.

The solution is innovative for two reasons. Firstly, there are no timetabled teaching sessions taking place in the laboratory on Wednesday afternoons. In the UK, higher education institutions mutually agree to avoid timetabling on Wednesday afternoons to allow for inter-university sporting fixtures to take place. This is a time when many student clubs and societies operate. Secondly, the technician-led approach to resolving the pedagogical challenge makes optimal use of their expertise and talents. It also provides a solution that avoids placing any additional burden on the academic staff.

4 ADVERTISING

As Diamond Wednesdays were not part of the formal timetable, it was necessary to raise awareness of the opportunity among students who needed support. The multidisciplinary nature of the laboratory provision presented a challenge, as students may be registered in one of several different programs. It was also necessary to promote an informal atmosphere to encourage students who may be less confident to seek further help.

It was decided that the principal mode of advertisement would be through the University's and faculty's existing social media channels, including Facebook, Instagram, and Twitter (now X). These platforms were used to highlight and publicise the work students were doing during the sessions. Social media accounts were set up for Instagram and Twitter (now X), including a hashtag of #DiamondWednesdayTUOS, to link all the posts together and allow students to respond easily.

Academic staff were encouraged to promote these sessions during lectures and tutorials and posters were strategically placed in areas where students are used to congregate.

Fig. 1. Social media posts. Left and middle from 2019. Right 2022.

5 TEACHING DESIGN

The experience gained from traditional, scheduled laboratory sessions highlighted a necessity for the provision of supplementary instruction in fundamental skills for students who initially lack the requisite competencies to achieve early success in their course. Following consultations with laboratory technicians and academic staff, consensus was reached that the most notable deficiency among students was their soldering skills. To address this skills gap, straightforward, guided activities were developed to facilitate swift and effortless skill acquisition.

These activities encompassed the use of fundamental hand tools, including side cutters and wire strippers. In alignment with the instructional needs, interactive pedagogical approaches, such as demonstrations and personalised assistance, were employed. For soldering specifically, live demonstrations of soldering were also performed for groups of (around 10) students, so they could see what to do. This was considered more appropriate than listening or reading from a worksheet, to teach a psychomotor skill (Biggs 1996).

Using the experience of the technical team, further guided worksheets and associated teaching material were produced to construct simple circuits and introduce the basic operations of a breadboard. Members of the technical team undertook trials of the instructions to pinpoint potential enhancements and acquaint themselves with the content, thereby enabling more effective assistance to students.

Fig. 2. Early version of soldering worksheets. 2018.

A series of activities, with incrementally increasing complexity, were designed. The level of required academic understanding was minimised to allow students to focus on the practical skills. The academic rigour required for an engineering programme remains in the traditional, timetabled classes and the Diamond Wednesday activities provide optional, remedial support for students requiring additional assistance. Emphasis was placed on building rather than understanding the circuits. Fabrication neatness and accuracy were the main learning outcomes, as ad-hoc and messy wiring can inhibit higher level understanding, such as fault finding.

Reflections on the approach identified two drawbacks. Firstly, the range of student ability was not reflected by any differentiation in the tasks. Some worked more quickly than others. Secondly, the demand for the sessions increased as awareness grew. The model was shown to be popular and useful, but changes in the approach were required.

6 REMOTE LEARNING

Opportunities to address these issues of differentiated content and scaling were provided during the Covid-19 pandemic. Like most higher education institutions, lab staff invested a significant amount of effort developing methods to deliver practical teaching using online learning (Bangert et al. 2022). Diamond Wednesday activities pivoted to online modes of delivery including the development of a Google Site.

Early versions of the site contained data and circuit diagrams alongside teaching notes. To facilitate more interactive remote content, an online circuit building platform was introduced. Online Laboratory sessions utilise the ‘TinkerCAD’ software, which allows students to digitally simulate building and testing circuits on breadboards.

Later developments included foundational basic knowledge content and several video clips as active demonstrations of skills and circuit building.

Following feedback and demand from students, a section on programmable circuits using ‘Arduino’ Microcontrollers was also added. Additionally, a project ideas section was introduced, enabling students to explore ways to integrate these circuits into practical applications.

One of the most popular circuits during the pandemic became the Distance Sensor. Students were given plans and diagrams of how to build a ‘social distance metre’ which proved to be popular at the time. The informal and non-assessed nature of Diamond Wednesdays allow the creation of more playful activities without compromising the rigour of the taught programmes.

7 EVALUATION

Since September 2019, 54 Diamond Wednesday (Diamond+ Electronics) face-to-face sessions have successfully taken place. In total (to date) 579 students have attended face to face. The average number of students per face-to-face session is 11, with the maximum and minimum number of attendees as 60 and 2, respectively. The breakdown per academic year can be seen in table 2.

Table 2. Student participation in Diamond Wednesday by academic year.

Aca. Year	19/20	20/21	21/22	22/23	23/24
Students	185	23	213	74	154 (projected)

In addition to the face-to-face sessions, many students interact with online material developed during the pandemic. Students have maintained contact via email, the google site and social media. Remote access from students in the UK and international was particularly apparent during the pandemic from website access data based on location, shown in figure 4.

Fig. 4. Diamond Wednesday website access based on location.

In the Diamond Building, all laboratories are equipped with a touch screen tablet to allow students to rate their satisfaction on a 5-point scale, indicated with different types of face icons.   Providing feedback is anonymous and optional. The Diamond

Wednesday sessions have received 123 responses with an average rating of 4.45 out of 5. This is significantly above the average for the Electronics and Control laboratory of 3.97 (standard error of 0.02).

There is qualitative evidence of the success of the sessions. The original purpose of Diamond Wednesday was to provide remedial, practical tuition to first year undergraduate students. There are increasing numbers of second year, third year, and postgraduate students asking for more time and opportunity to work with basic electronics to enhance their skills. It has also been observed that the teaching material for formal, timetabled classes have been adapted under the assumption that Diamond Wednesdays are an established part of the student provision.

8 Discussion

Academic staffing alongside physical estates, practical activities and differentiated, customizable curriculums are expensive. At a time when Higher Education institutions are facing significant financial pressures from reduced funding and increased inflationary costs, as well as existential threats from AI and alternative education providers, there is a pressing need to innovate how teaching is provided.

Diamond Wednesdays is an example of utilising the expertise of technical staff by empowering them to identify problems then design and implement solutions. The activities are run without needing to increase the already high workload of academic staff. By using the options, co-curricular “club” paradigm, the sessions can run at times when the estate would otherwise not be utilised. These attributions of Diamond Wednesday make it a very efficient model for teaching delivery.

The popularity and high student satisfaction of Diamond Wednesdays demonstrates its success. This is attributed to the optional nature of the teaching sessions. Students can practise, and fail, in a non-judgmental setting. While the lack of academic staff has an efficiency advantage, not having staff in the session that would typically be responsible for assessing students' performance can make authentic participation less intimidating.

The optional nature of the sessions allows students a degree of customization of their curriculum. The Diamond Wednesday sessions run, and students can choose, without obligation, to attend if they need extra support. Through advertising, students can select which activities they do or do not need in addition to in-person practical education.

Future developments are planned for Diamond Wednesday. Consideration is now being given to adapting the academic-led, timetabled teaching material based on the premise of Diamond Wednesday being available to students, with a threshold of practical skills being assumed. There is a plan to run consultation with students to gather their ideas and co-create content. Finally, spreading the co-curricular methodology to other practical skills within the Engineering faculty is under investigation.

The Diamond Wednesday Google site has been released as an open educational resource. The authors would welcome collaborations from other institutions to share and enhance the resource if it can be mutually beneficial.

REFERENCES

Bangert K, Bates J, Beck S, et al. “Remote practicals in the time of coronavirus, a multidisciplinary approach.” *International Journal of Mechanical Engineering Education*. 2022;50(2):219-239. https://doi.org/10.1177/0306419020958100

Bartkus, K.R., Nemelka, B., Nemelka, M., and Gardner, P. (2012). 'Clarifying The Meaning of Extracurricular Activity: A Literature Review of Definitions'. *American Journal of Business Education*, 5(6), pp. 693-701. Available at: http://www.cluteinstitute.com/

Biggs J. 1996. “Enhancing Teaching Through Constructive Alignment.” *Higher Education* 32 (3): 347–364. https://www.jstor.org/stable/pdf/3448076.pdf

Buckley, P. and Lee, P. (2018). 'The impact of extra-curricular activity on the student experience'. *Active Learning in Higher Education*, 22(1), pp. 37-48. Available at: https://doi.org/10.1177/1469787418808988 .

Daniyal, M., Nawaz, T., Hassan, A., and Mubeen, I. (2012). 'The effect of co-curricular activities on the academic performances of the students: A case study of the Islamia University of Bahawalpur, Pakistan'. *Bulgarian Journal of Science and Education Policy (BJSEP)*, 6(2).

Di Benedetti M, Day H, Archibald, S. Scaling-up practical teaching: the one-thousand student week. A: SEFI 50th Annual conference of The European Society for Engineering Education. "*Towards a new future in engineering education, new scenarios that european alliances of tech universities open up*". Barcelona: Universitat Politècnica de Catalunya, 2022, p. 1911-1915. DOI 10.5821/conference-9788412322262.1286.

Kapranos P. 2018. *The Interdisciplinary Future of Engineering Education, Breaking Through Boundaries in Teaching and Learning*: Routledge.

Stuart, M., Lido, C., Morgan, J. and May, S. (2008). 'The impact of higher education accreditation on student experience and learning outcomes'. Published by the Higher Education Academy.

Statistics in engineering degrees: a case study of a community service

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***Conference Key Areas**: Teaching foundational disciplines of Mathematics and Physics in engineering education*

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ABSTRACT

Mathematics is an important part of engineering studies; however, in recent years, the way of dealing with these subjects has changed and the type of students has changed as well. As it is well known, mathematics is a tool or a set of tools to develop the future work of engineers. This study presents a pedagogical approach that allows students to acquire mathematical competences while performing a service to the community. A case study of Service-Learning and the mathematical competences involved in a statistical project are analysed here. During the academic year 2023-2024, a group of students consisting of Industrial Engineering, Statistics and Labour Relations students collaborated with the ASCOL association (association against leukaemia and blood diseases) to carry out a statistical study of the data collected by the association.

1 INTRODUCTION

1.1 Mathematical competences

In engineering studies, mathematics is above all know-how. It is more a matter of knowing a method and a way of acting than of knowing content, i.e. mathematics is a tool for the development of engineering activities and proposals.

The activities in which mathematics is involved consist of dealing with more or less complex situations in the real world that admit a very peculiar rational treatment, which many authors have called mathematization, involving appropriate symbolisation, mathematical reasoning and rigorous rational manipulation in order to reach an effective mastery of the reality being explored.

Learning (and mathematical learning in particular) is, above all, a personal activity. Indeed, part of the changes brought about by the Bologna agreement includes self-learning which challenges teachers to develop strategies that may allow students to build their knowledge autonomously. However, the task of teaching must be a collective one, since the teacher teaches (in the university context) groups of students. New teaching challenges demand new answers, far removed from memoristic expositions and merely repetitive or more or less laborious problems of the mathematical operations involved. Moreover, the teaching scenario has changed radically in recent years due to the rise of information technologies. Nowadays, the traditional classroom has become another scenario as we find ourselves in the context of ubiquitous learning.

The competences stablished by Alpers et al. during the Mathematics Working Group Seminar of the SEFI, in 2013 (Alpers et al 2013), were updated by Mogens Niss and Tomas Højgaard, which revised the concept of competence in 2019 and proposed the following definition: “Competence is someone’s insightful readiness to act appropriately in response to the challenges of given situations” (Niss and Højgaard 2019, p. 12). More specifically, “A mathematical competency is someone’s insightful readiness to act appropriately in response to a specific sort of mathematical challenge in given situations” (Niss and Højgaard 2019, p. 14).

The mathematical competencies are separated into two categories:

1. To propose and answer questions in mathematics and using mathematics.
2. Handling the language, constructs, and tools of mathematics.

These categories are further divided into the known eight competencies:

1. Mathematical thinking.
2. Problem handling.
3. Modeling mathematically.
4. Reasoning mathematically.
5. Mathematical representation.
6. Using mathematical symbols and formalisms.
7. Mathematical communication.
8. Making use of mathematical aids and tools.

To put into practice these competencies several authors have published studies and proposals developed among their students. Dias Rasteiro et al. presented a study about the last competence, with the use of Information and Communication Technology (ICT) in their classes, that was presented in the previous edition of the SEFI Annual conference (Dias Rasteiro et al. 2023). Studies about mathematical competencies is a constant in several conferences about mathematical education (Zeidmane 2012; Richtarikova 2023).

1.2 Service-Learning

In the current context several university teachers are using new methods and pedagogical approaches to make students involved in their learning process and to acquire the desired mathematical competencies. Service-Learning (SL) could be defined as a pedagogical approach that integrates academic goals with community service. It provides students with a practical and meaningful learning experience. and allows them to apply theoretical concepts in real-life situations. Findings indicate that experiences with diversity correlate with enhanced civic attitudes, intentions, and behaviours, with interpersonal interactions having a stronger impact than curricular and cocurricular diversity experiences (Bowman 2011). Jacoby (2015) emphasizes that SL not only benefits students academically, but also promotes personal development and social responsibility. Service-Learning affects academic performance, motivation, skill development, and experiential learning in students and provides significant improvements in those aspects (McNatt 2020; Muñoz-Medina et al. 2021).

Moreover, the development of Service-Learning activities increases the improvement of interpersonal skills and social awareness among students, demonstrating an increase in interpersonal competence and sensitivity to community needs (McNatt 2020). These findings underline the importance of SL as a useful pedagogical strategy to enhance the learning of future engineers. In the case of Service-Learning in mathematics courses, Queiruga-Dios et al. found that only 0.83 % of the studies related to SL in Scopus database were related to mathematics (Queiruga-Dios et al. 2021).

Real word problems provide a challenge for mathematics learners due to their requirement to translate verbal descriptions into mathematical expressions or equations. Students often find obstacles in solving word problems due to difficulties in understanding the language of mathematics and in identifying relevant problem information. Additionally, that type of real-life problems often involves multiple steps and require higher order thinking skills such as problem-solving and critical reasoning, further contributing to their complexity. This is what students address when they participate in Service-Learning challenges, they must solve a community problem, or they must do something to improve the lives of the people around them (Queiruga-Dios et al. 2023; Verschaffel 2020).

The community-based research project that involved an interdisciplinary team was a collaborative effort aimed at addressing local community needs through a multifaceted approach. Bringing together experts from diverse fields such as engineering, social sciences, statistics, and volunteers from the non-profit association, the project aimed to tackle complex issues impacting the community. By leveraging the unique expertise and perspectives of each team member, the project sought to develop innovative solutions that would not only address immediate concerns but also foster long-term sustainable development.

Throughout the project, the interdisciplinary team conducted thorough research, engaged with community stakeholders, and implemented practical interventions aimed at improving community well-being. For example, engineers may have focused on developing sustainable infrastructure solutions, while social scientists conducted surveys and interviews to better understand community dynamics and needs, and statisticians worked on the data analysis.

The interdisciplinary nature of the team allowed for a comprehensive and holistic approach to problem-solving, considering various aspects such as social, economic, and cultural factors. By collaborating across disciplines, the team was able to generate creative ideas, develop innovative strategies, and implement effective interventions that addressed the multifaceted needs of the community.

Overall, the community-based research project exemplified the power of interdisciplinary collaboration in addressing complex societal challenges and fostering positive change at the local level. Through teamwork, expertise, and community engagement, the project demonstrated how interdisciplinary approaches can lead to more inclusive, sustainable, and impactful outcomes for communities confirming what was stated by (Bowland et al. 2015).

The proposed project was to collaborate with ASCOL non-profit association in the analysis of a set of data that volunteers got from patients and their families. Thus, the goal was to analyse the results of two questionnaires conducted by the association.

2 METHODOLOGY

2.1 Materials and methods

The Service-Learning approach was used with a group of Industrial Engineering students. These students attend electrical, electronic, and automatic or mechanical engineering classes, but mathematics courses are common for all of them during their first and second years. Sophomore students from the Statistics course collaborate with students from the Statistics Degree (Data Collection Techniques for Scientific Research course) and Labour Relations Degree (Statistical Techniques of Social Research course) during the first semester of the 2023-2024 academic year. This collaboration was done in the development of SL projects. In the case of the Statistics course, this teamwork accounted for 20 % of the final mark, in Data collection for 60% and in the Statistical Techniques course for 10 %.

The total number of students from the three courses was 217, of which 53 are studying one of the Industrial Engineering degrees, 51 from the Statistics degree and 113 from the Labour Relations degree. All were offered the opportunity to take part in the project, and among the volunteers, 4 students from each degree were randomly selected. Some of the other students participated in the development of other different SL projects, such as data analysis of an NGO that distributes food to people in need, a mathematics outreach activity among elderly people, an escape game with children, etc.

The SL project follows the steps detailed in (Queiruga-Dios et al. 2023), i.e., identification of the community needs by interviewing community members, preparation and activity design (seeking additional partners to address the identified needs and determining the learning objectives related to the curriculum), implementation and development, reflection (once the service has been completed, this may lead to proposing a new project to further improve the life of the community), documentation, evaluation, and recognition (it is important to recognise the work done and the positive impact on the community). The first phase was a 3-party meeting with students-teachers-association. During this meeting teachers explained what a community service and Service-Learning project is and then the President of ASCOL described the tasks and objectives of the association and what were their needs related to the data.

Then, two working groups were set up with two members from each degree. Thus, each group was made by 6 students. It was considered appropriate to have members from all the degrees in each group to enrich them and to promote interdisciplinarity and teamwork among students that did not know each other before.

A second session was held in the ASCOL headquarters to present the place and the ASCOL volunteers and members and to share information with faculty and students about the questionnaire to be analysed by each team.

The first questionnaire was called “Survivors” and aims to find out the current situation of people who have or have had haematological cancer. Information was collected from 148 patients from different parts of Spain. The second questionnaire was a study of the needs of haematological patients, both patients and relatives. It initially consisted of 334 entries (some answers were discarded because they were not complete or did not make sense). Two MS Excel files with the answers obtained from both questionnaires and the objective of the study (try to find any conclusion from the answers) were provided. The variables to be analysed were defined by each group according to their concerns and what they considered interesting to analyse. In fact, the contact person from the association did not have a clear idea about the results that they wanted to find. That is why she proposed that each group analyse the answers and look for an interesting conclusion for patients and families.

From that moment, each group worked autonomously establishing the objective of their study and the distribution of the tasks they were going to carry out according to their knowledge of statistics.

The students of the Data Collection Techniques for Scientific Research course were responsible for cleaning the databases (coding variables, eliminating records with missing data, etc.) and converting them into SPSS format. The engineering students were responsible for carrying out a descriptive analysis of the data and creating various graphs to visualise the results. The rest of students then carried out inferential analysis of the data to explore possible relationships between the variables. The comparison of means between two independent groups was carried out with Student´s *t*-test. To analyse the association between categorical variables, the χ^2 test was applied. A significance level of 5% was used in all cases.

To make students learn about different tools, MS Excel was used for graphing and SPSS v. 23.0 for descriptive and inferential analysis in all cases.

Each of the groups presented the results of the analysis to their respective teachers and ASCOL members. They also carried out an evaluation of the Service-Learning activity in which they had participated.

3 RESULTS

This section will include the description of some results obtained from the statistical analysis of the questionnaires provided by ASCOL, as well as some of the reflections made by the students participating in the project.

After cleaning the database, the students who analysed the “Survivors” questionnaire worked with a data matrix composed of 148 individuals and 99 variables.

The database analysed by the other group consisted of 334 individuals and 51 variables after cleaning. Of the group of subjects studied, 68.3 % were patients, followed by 29.0 % family members, while the rest belonged to the categories of ex-patients, survivors and ASCOL workers. Of these, 62.0 % were female and 38.0 % men, mostly from the provinces of Valencia, La Coruña and Salamanca (Figure 1).

Fig. 1. Map describing the workplace of the participants of the study "Needs of haematology patients" (Number of respondents)

The implementation of a collaborative Service-Learning project with an association of leukaemia patients and their families provides a unique opportunity to apply and develop the mentioned mathematical competences in the following aspects:

1. Team members must apply mathematical thinking to understand the structure of the data and formulate relevant research questions related to leukaemia and its impact on families.
2. The project involves tackling complex problems related to the interpretation and analysis of the data collected. Students must plan and execute strategies to effectively organize, clean and analyse the data, as well as identify possible solutions or recommendations based on the results obtained.
3. The data collected can be used to develop mathematical models that represent the prevalence of leukaemia and its associated factors in the population studied. These models help to better understand the dynamics of the disease and its impact on families.
4. During the process of data analysis, students should apply mathematical reasoning to interpret results critically and reach informed conclusions. They must be able to identify potential errors in the analysis and evaluate the validity of the conclusions drawn.
5. Visual representation tools, such as graphs and diagrams, are used to effectively communicate the results of the study and facilitate the understanding of the information by ASCOL members and other stakeholders.
6. During statistical analysis, students use symbols and mathematical formalisms to express statistical concepts, formulas and analysis procedures. This enables them to communicate precisely and concisely the methods used in the study.
7. Students should be able to communicate the results of the study in a clear and understandable way, both in written and oral form. They should explain the statistical findings in a way that is accessible to ASCOL members, as well as to other health professionals and the public.

8. During data analysis, students use mathematical aids and tools, such as MS Excel and SPSS, to perform calculations, generate graphs and carry out statistical analyses.

In summary, carrying out a collaborative Service-Learning project with an association of leukaemia patients and families provides a valuable opportunity to apply and develop a wide range of mathematical skills in a practical and meaningful context. This interdisciplinary approach enables students to use mathematics as a powerful tool to understand and address real problems in the community.

Regarding the students' reflections on their participation in the Service-Learning project, two aspects stand out. On the one hand, students recognize that they have become more aware of the psychological needs faced by both patients and carers of people affected by haematological cancer. They also value positively their participation and the possible help they have been able to give to the association. On the other hand, they consider that their participation in the project has helped them to understand the usefulness of what they have studied in class.

Some European universities are integrating Service-Learning as part of the pedagogical methods they use. In fact, in several of them (such as the University of Salamanca), SL-based courses have been proposed. In this way the needs of the community could be addressed.

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REFERENCES

Alpers, B. A., M. Demlova, C. H. Fant, T. Gustafsson, D. Lawson, L. Mustoe, D. Velichova. “A framework for mathematics curricula in engineering education: a report of the mathematics working group”. In *SEFI Mathematical Working Group Seminar*, Salamanca, 2013.

Bowland, S. E., V. Hines-Martin, J. Edward, and A. S. Haleem. “Reflections on interdisciplinary teamwork in service-learning”. *Partnerships: A Journal of Service-Learning and Civic Engagement* volume 6, no. 2 (2015): 19-35.

Bowman, N. A. “Promoting participation in a diverse democracy: A meta-analysis of college diversity experiences and civic engagement”. *Review of Educational Research* volume 81, no. 1 (2011): 29-68.

Dias Rasteiro, D. M. L., A. Hernandez Encinas, A. Queiruga-Dios, M. J. Santos Sánchez, et al. “Using Technology to Teach/Learn Mathematics, How Are We As

Teachers Fostering Mathematics Education Mobility?” In *51st Annual Conference of the European Society for Engineering Education (SEFI)*, Dublin, Ireland, 2023.

Jacoby, B. *Service-learning essentials: Questions, answers, and lessons learned*. Jossey-Bass. San Francisco: John Wiley & Sons, 2015.

McNatt, D. B. “Service-learning: An experiment to increase interpersonal communication confidence and competence”. *Education+ Training* volume 62, no. 2 (2020): 129-144.

Muñoz-Medina, B. N. M., S. Blanco, and M. G. Alberti. “Impact of service-learning on the motivation of Engineering and High School Students”. *International Journal of Engineering Education* volume 37, no. 4 (2021): 1060-1070.

Niss, M., and T. Højgaard. Mathematical competencies revisited. *Educational studies in mathematics* volume 102 (2019): 9-28. https://doi.org/10.1007/s10649-019-09903-9.

Puzi, N. I. M., N. A. Azli, S. Osman, and Y. M. Yusof. “Evaluation of Mathematical Competencies among Electrical Engineering Students”. *Asean Journal of Engineering Education*, volume 6, no. 2 (2022): 54-58. https://doi.org/10.11113/ajee2022.6n2.104.

Queiruga-Dios, A., D. M. Rasteiro, B. Sánchez Barbero, Á. Martín-del Rey, and I. Mierlus-Mazilu. “Service-Learning Activity in a Statistics Course”. In *International Conference on Mathematics and its Applications in Science and Engineering,* July 2023, 317-324. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-49218-1_23.

Queiruga-Dios, M., M. J. Santos Sánchez, M. Á. Queiruga-Dios, P. M. Acosta Castellanos, and A. Queiruga-Dios. “Assessment methods for service-learning projects in engineering in higher education: A systematic review”. *Frontiers in Psychology* volume 12 (2021): 629231. https://doi.org/10.3389/fpsyg.2021.629231.

Richtarikova, D. Forms of Assessment in view of Development of Mathematical Competencies. In *International Conference on Mathematics and its Applications in Science and Engineering,* July 2023, 209-217. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-49218-1_15.

Verschaffel, L., S. Schukajlow, J. Star, and W. Van Dooren. “Word problems in mathematics education: A survey”. *ZDM* volume 52 (2020): 1-16. https://doi.org/10.1007/s11858-020-01130-4.

Zeidmane, A. “Development of mathematics competences in higher education institutions”. In *2012 15th International Conference on Interactive Collaborative Learning (ICL)*, September 2012, 1-7. IEEE. https://doi.org/10.1007/10.1109/ICL.2012.6402071.

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Addressing issues related to running and assessment of teamwork in engineering education: Improvements observed when using Individual Peer Assessment of Contribution (IPAC)

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ABSTRACT

Teamwork is heavily used and become the norm in Engineering education across all years and disciplines. Academics running such projects/learning activities are well aware of the benefits but also the challenges of such activities, that includes for

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example the logistics (particularly in large teams), ensuring student engagement, equal opportunities, students training and development, and fair assessment. This paper reviews six different case studies in engineering that represent the pathway taken by students in various engineering degrees at UCL. The paper identifies the main challenges faced by practitioners when running and assessing teamwork and mitigations taken to address them. In particular, we emphasise the benefits of using Individual Peer Assessment of Contribution to teamwork (IPAC), and how it helps to successfully mitigate issues that were encountered otherwise. We believe this paper will be useful for any HE lecturer in engineering (even other fields) that runs teamwork such that they improve or reinforce awareness on these challenges, see how others approach them and the impact of those approaches, potentially giving them either ideas for improvement or confirmation of their own practice. We have combined this paper with a workshop and aim to incorporate a reflection on practices at other institutions and broader range of academics.

1 INTRODUCTION

1.1 Use of teamwork in HE

While technical knowledge is still important for graduates, it needs to be paired with other experientially learnt skills such as collaboration or communication (World Economic Forum, 2023), and so skills-based learning within Engineering curricula has increase to prepare graduates for the changing post-university environment (Graham, 2018). The introduction of team projects to programmes has been a key approach to providing students with supported opportunities to learn these more experiential skills but incorporation does not come without challenges that staff will need to address. This is particularly true for large scale teaching which is common within Engineering programmes (Truscott *et a*l, 2023).

1.2 Challenges of Teaching Teamwork in Higher Education

Riebe et al (2016) in their systematic review of various case studies, categorised challenges associated with delivering and assessing teamwork in the Higher Education (HE) context into two themes, i.e., teamwork pedagogy and transaction costs.

Challenges associated with teamwork pedagogy include: (I) *Instruction strategies*, whereby educators and learners lack prior experience, view teamwork as an inefficient use of time and find moving away from tutor-centred teaching challenging (Holt et al, 1997), (II) *Curriculum design* – the degree to which team skills development is incidental or intentional in the curriculum. The intentional inclusion of teamwork training and instructions into the design phase of the curriculum is typically done using the constructive alignment model (Biggs, 1999), and this can be time and cognition intensive. (III) *Team composition*, in terms of team size, diversity, and formation, if incorrectly approached, could result in a negative learner perspective of teamwork productivity with social loafing or free riding being the main concern for learners (Hansen, 2006; Page et al, 2003; Sashittal et al, 2011; Shaw, 2004; McCorkle et al, 1999), and (IV) *Assessment* – which centres on identifying strategies for individual grading and how to address free riding as an assessment concern for learners (Freeman et al, 2002; Ohland et al., 2012).

Willamson's (1979) transaction cost theory assumes that engagement is a function of the benefits or costs derived from developing, coordinating, monitoring, participating in, interacting with, and evaluating teamwork pedagogy. In terms of teaching teamwork skills, these transaction costs may be incurred by seeking to meet employer and accrediting professional bodies' expectations (Burbach et al, 2010; Kliegl, 2013), as a function of the tutors' readiness to develop resources (Albon et al, 2014), developing strategies and interventions (Kedrowicz, 2007) and teaching teamwork skills (Jackson et al, 2014). The transaction costs also encompass how willing and ready learners are to participate in teamwork learning activities (Bacon, 2005), and available resources in institutions which promote teaching and learning teamwork (Ahern, 2007).

It is critical that engineering graduates develop an ability to work effectively within various team configurations or team types e.g. production, service, management, project, virtual, multidisciplinary, etc (Sundstrom et al., 2000); but also different team styles management e.g. consensus or voting or single leader decision making (Yang 2010). Therefore, understanding the dynamics and requirements of diverse team types is crucial for engineering graduates and educators alike. Tuckman's model (Tuckman and Jensen, 1977) introduced the five team developmental stages i.e. Forming, Storming, Norming, Performing, and Adjourning. These stages provide a dynamic framework for teaching teamwork wholistically to diverse team in varying contexts typically encountered in HE.

Various authors have attempted to address some of the teamwork challenges and developed solutions including introducing learner-team training tools and simulations (Hubbard, 2005;), role play (Crumbley et al, 1998), setting rules and accountability within the team by use of team contracts (Pertegal et al 2019, Ramdeo et al 2022) and introducing learners to the stages of teamwork using the Tuckman's (1965) model. Another popular solution has been the use of self and peer assessment, which we call hereafter IPAC (Individual Peer Assessment of Contribution to teamwork). The IPAC assessment methodology allows the learners to assess the level of contributions of each of their peers, including themselves, from which an IPAC factor or score is generated after moderation by the tutor. The IPAC can then be used in combination with the team mark to generate and individual marks for the team members that reflects the achievements of the team but also the individual contribution (Garcia-Souto, 2019). The assessment methodology is used broadly and has been reported as having significant potential to improve students' experience and engagement and reduce the temporal and efficiency related costs (Hansen, 2006; Page et al, 2003; Delaney et al, 2003; Delaney et al, 2013; Garcia-Souto et al, 2019; Seatwo, 2019).

The IPAC assessment methodology is broadly used at University College London, implemented using the IPAC system developed at our institution that makes it easy to run and insightful for staff and students (Garcia-Souto, 2019). Other universities are also using this IPAC system successfully.

Despite its challenges, teamwork remains a strong training and learning opportunity in the Higher Education (HE) engineering context. It is therefore of interest to find ways in which the challenges are managed, and the opportunities enhanced and enriched. In this paper we bring together the perspectives of 5 members of staff who lead team project units within a common HE environment. Through case studies of each practitioner's teaching activity, we bring together a list of types of challenges faced by those leading team projects and start to build a range of potential solutions or mitigations that can be used by others. We aim to widen our community of practice through a linked workshop at the 2024 SEFI conference.

2 METHODOLOGY

2.1 Selection of case studies and analysis

Six different case studies from the UCL Intergrated Engineering Programme (IEP) have been identified and analysed in this paper. The IEP is a teaching framework covering the majority of engineering undergraduate programmes within 8 engineering departments (Mitchell *et al.*, 2019). Throughout the IEP there are several team projects, both single discipline and interdisciplinary, that take place with a range of cohort sizes. The case studies included in this paper were selected because they are representative of the pathway of students within a range of engineering degrees, and they cover a range of class sizes, years of study, engineering fields, different team formations and length and weight of the project towards final degree mark. The practitioners brought together in this paper, work within a range of departments and bring different experiences and approaches to teamwork.

A thematic investigation and analysis were performed covering the selected case studies by practitioners. First the activity lead of the different case studies had a chat about their own experiences, from which a list of possible challenges cathegories was drawn by the first author. Then the lead for each case study was individually requested to reflect and elaborate in writing on each challenge, their perception of impact, describe their approach to mitigate it and how successful it was according to own perception. Finally, the first author performed thematic analysis on the written answers, that was then checked and corroborated by the other authors/case study leads. Our results show the main/common approaches that fit all cases, and also specific/local approaches based on case.

2.2 Case studies

The case studies analysed in this paper cover the pathway of engineering students at UCL from year 1 to year 4 in various disciplines and various class sizes as summarized in table 1. The IEP Challenges (case study A) is the first team project experience for all year 1 students and so students are trained and supported on developing teamwork skills (Truscott *et al*, 2021). Then the students take the "scenario projects" within their own disciplines that are a series of six one-week intensive projects spread across the first and second years (case studies B and C given as examples). At the end of the year 2, all students undertake the How to Change the World project (HtCtW) along with management students, and they work in multi-disciplinary teams, with people they have not met before. In the later years of the degree, students take a more significant team project within their own discipline (case studies E and F as examples), carrying out a significant weight towards their final degree classification.

Table 1. Case studies summary

Case	Name	Eng field	Year study	Class size	Type of teams	Team size	Proj. length	Weight (%) × ECTS
A	IEP Challenges	All	1	>900	Across 7 disciplines	5-8	7 weeks	70% × 7.5
B	Scenario Design Projects (x6)	Chem Eng	1-2	130 - 220	Within discipline	5-7	1-week full time (x6)	~25% × 7.5 (x6)
C	Scenario Design Project in BME	Biomedical Eng	2	70	Within discipline	4-5	1-week full time	25% × 7.5
D	How to Change the World (HtCtW)	All	2	>800	Across 7 disciplines	4-8	2 weeks full time	5% × year 2
E	Design group project	Chem Eng	3	130 - 200	Within discipline	5-6	3 months	45% × 15
F	Design group project	Biomedical Eng	4	20	Within discipline	4-5	6 months	90% × 22.5

3 RESULTS

The analysis was done on the teamwork nature of the activities without reference to the discipline or particulars of the case studies, making results meaningful to the wider engineering community. The challenges identified are given, as well as the proposed mitigations to solve them and how successful they were based on staff perceptions in comparison with their earlier approaches.

List of challenges:

A. Uneven student contribution/engagement and implications towards the assessment.
B. Validity of assessment: This includes concerns of whether each student gets a mark that is representative of their contribution to the teamwork. Concerns are typically felt by students, staff, external examiners, accrediting bodies when all students in a team will receive a unique mark.
C. Diversity in the team: scenarios included here are differences in students' technical knowledge and skills, differences on social skills and ways of interacting/collaborating with people, neurodiversity, differences on working patterns and responsibilities outside of the team project, differences in culture, differences on their communication skills both written and oral in English, etc.
D. Teams with SORA/EC students (SORA indicates reasonable adjustments that should be offered to a student due to long-term conditions, and EC stands for Extenuating Circumstances): Some students might have SORAs or

experience some personal issue that might affect their ability to perform in the team. Some might choose to communicate this to the team, but not all.

E. Readiness of students to do teamwork: This includes e.g. (i) ability of students to work in teams successfully, (ii) awareness of the possible diversity in a team and how to work with a diverse range of teammates, (iii) clarity on suitable students' expectations from teammates, particularly when peer assessing individual contributions, (iv) ability of the students on giving and receiving feedback in a way that is professional, critical yet constructive.
F. Team formation (rather than cohesion): Teams originally defined by tutors might be seen not to be appropriated quite early in the project. This includes (i) difficulties at the onset of the project, perhaps due to prior personal interactions between the students of academic/non-academic nature; (ii) some students might not be active in the module e.g. they are going for interruption of studies, changed their diet, etc but the module leads are not aware of it.
G. Team cohesion: Some teams can find it difficult to work together for various reasons once the project is well underway. These include clashes on personality particularly under stress, strong conflicting opinions or ideas on the desired direction of the project, differences on styles of working, or even a break-down of personal relations in or out of the project.
H. Staff workload: This includes time commitment in all aspects of the teamwork, i.e. preparation of the teams, training of students on how to do teamwork, monitoring student engagement and performance and intervening, when necessary, assessment, mitigations/arrangements needed for specific individuals/cases, and dealing with student querying/challenging their individual marks. This strongly relates to the student numbers.
I. Readiness of staff to run teamwork: Are we all ready to lead a teamwork activity? Which knowledge and skills are needed to successfully run teamwork, is there any training to close the gap?

List of mitigations per challenge:

Challenge A: Uneven student contribution/engagement -successfully mitigated

- Use the IPAC assessment methodology, so students are aware of the individual accountability to the team members, and acts as a deterrent of unjustified lack of engagement. Feedback to students from peers is valuable.
- Provide training to students in earlier years, while in 3rd/4th years need less training as they are already aware of the IPAC methodology and work expectations.
- Check points with staff are helpful, i.e. regular meetings with a member of staff, either as a team or with individual students. This is particularly common in large teamwork components in senior years, e.g. cases E/F.

Exceptional cases of very significant lack of engagement are dealt by staff, with the possibility of removing the student from the team. If the lack of engagement is justified, the staff offers deferral or alternative assessment.

Challenge B: Validity of assessment – successfully mitigated

The IPAC methodology (which includes standard tutor revision and endorsement of the marks) almost solves this challenge entirely. It is particularly useful when team dynamics are not obvious to staff. It handles students' concerns in a formal/standard way, and students are mainly comfortable with the peer assessment and happy with the methodology. It is uncommon for individual students to raise concerns with their IPAC marks, but such cases are reviewed by staff.

In long projects we recommend the use of IPAC for formative purposes at the start/middle of the project. It is an insightful "check point" for staff and it allows students to improve /continue with good practice in their project. It avoids surprising IPAC mark at the end, almost eliminating individual students that complain about their own mark.

<u>Challenge C: Diversity in the team – successfully mitigated</u>

Teams are encouraged to use the diversity and individual skills to their advantage. Particularly in year 1 (or first few times doing teamwork in HE), staff discuss with the students the value of diversity, but also train them in soft skills like communication or teamwork styles. The staff might try to balance the diversity when making the teams – this is further discussed under challenge F.

Teams write a contract at the start of the project. This engages students onto an upfront discussion on how to accommodate/take advantage of the diversity in the team. The typical student team contract reflects that students expect team members to put equal "effort" on the project as opposed to equal "output".

The IPAC assessment is used for students' self-reflection, which supports students to understand and enhance their role in the team. The feedback that each student receives from their peers often also help them to see how their teammates value them, and encouragement in the areas that could need further development.

<u>Challenge D: Teams with Summary of Reasonable Adjustments (SoRA)/ Extenuating Circumstances (EC) students- successfully mitigated</u>

- When SORA students are known to staff in advance, they are distributed across the teams. SORA/EC students are supported by staff when needed and encouraged to participate in the team project if possible.
- Team contract provides an opportunity for students to disclose personal circumstances that might be relevant in the teamwork and for the team to be aware/adjust to the needs of all individuals.
- Make clear to students, which adjustments can be applied in the teamwork for students with SORAs or ECs, and equally those that cannot be applied. Adjustments are subjected to reason, e.g. a SORA student might be given a 2-weeks extension in most of their individual assignments, but it does not apply to team submissions. SORA/EC students that cannot participate in the team project are "effectively withdrawn" from the team and a suitable alternative assessment offered.
- Projects should be feasible to completed even if missing a team member.

<u>Challenge E: Readiness of students to do teamwork - mitigated</u>

This challenge applies more significantly to year 1, when the students are new to teamwork. A significant improvement is observed from year 2 onwards. We found useful to give students training in year 1 on key aspects of teamwork, communication, conflict, etc as part of a taught year-1 module and have a team project focused on the development of teamwork skills (case study A). This sets up a strong foundation of students' skills to do teamwork. Students are also further supported/guided in following years. Marking criteria for the IPAC assessment is presented/discussed with students to clarify and standardize student expectations.

The IPAC assessment also gives students an opportunity for self-reflection and insights on their own performance by anonymous peer regarding their performance and ability to work in a team, which help them with their self-development.

There is always room for improvement by adding more training and mentorship.

Challenge F: Team formation – successfully mitigated

Team formation can be addressed in three different ways.

- Random or semirandom teams' membership. This is the common practice in large classes run across engineering degrees (case studies A and D).
- Semirandom but staff-planned such that students work with as many different students as possible within their degree. This seems to solve quite a few issues and it provides a good training to students. It is typically used in small/medium classes that run within a single degree programme (case studies B and C).
- Diversify membership: In small/medium classes undertaking a very large project within an engineering degree, teams are formed by tutors with consideration to balance gender, academic performance, cultural diversity and typically no more than 1-2 SoRA students (case studies E and F).

Observations on what works:

- Students respond more positively to team membership when the IPAC methodology is in place, even with random and diverse memberships.
- Staff might avoid putting together students with unsolvable standing conflicts due to prior/outside academia personal issues. This is particularly useful in long projects like year 3/4 design team project modules.
- Often the number of students in a team varies within a given activity. This does not seem to present a challenge provided the project can offer flexibility and is suitable to be completed by the smallest team.
- Staff monitors engagement in the early stages of the project e.g. running a formative IPAC or checking attendance to in-class events. If issues within the team are detected, staff decides in a one-to-one basis if teams/particular students just need some initial support or as last resort if some teams need to be re-adjusted. This also identifies non-active students, even if registered.

Challenge G: Team cohesion

Training and general support is provided to students, particularly in year 1. As consequence, it is rare that a team will become truly dysfunctional. However, if a team does break down as a result of external and/or internal factors, tutors provide support meeting with the team or individual students as need. Often team difficulties become significant learning experiences for team members. If the issues are significant, then this is addressed on a case-by-case basis. Dysfunctional groups are either identified by self-referral or reviewing the IPAC scores, hence it is useful and insightful to run the IPAC methodology at some point at the beginning or middle of the project even if only for formative purposes.

Challenge H: Staff workload

Team projects can require significant planning, preparation, and coordination hence staff workload is high and needs to be shared across various staff, especially in large classes. Typically, we have (1) one or two staff activity organizers that lead the planning and running of the activity, monitors and liaise with the class and deploy resources and personnel as needed; and (2) a range of PGTAs/academic staff/technical staff that support different areas of the teamwork activity and also act as supervisor for various teams. The activity organizers typically stay the same, while support personnel is more variable, specially PGTAs, and need training each year. We recommend having at least two staff members that can act as activity organizers for resilience, since it would be very challenging to replace a single activity organizer at short notice e.g. in case of illness/accident.

Challenge I: Readiness of staff to run teamwork

Teamwork seems to be typically led by self-driven staff that generally appreciate the value of teamwork for students' development and have a natural inclination to seek training and peer dialog about best practice. However, there is however no official or mandatory training. Activity leads acknowledge that staff training is needed, and often both offer training/guidance themselves to the support staff/PGTAs and refer them to relevant seminars when available. We believe that a more standard and comprehensive training for staff would be useful.

4 SUMMARY AND ACKNOWLEDGEMENTS

Based on the case studies presented, the authors believe that the IPAC is helpful in addressing some of the challenges related to the running and assessment of teamwork (challenges A, B, C D & F). It facilitates a quick and neat way of providing formative peer feedback, which students can then reflect upon to improve on future teamwork activities and submissions. In that sense, the IPAC assessment method takes a similar approach to the Tuckman's model (Tuckman and Jensen, 1977) and its stages of team development, using peer-feedback to foster the development of teamwork skills across diverse contexts. The IPAC facilitates students' assessment literacy, as they participate in aspects of the grading and helps build emotional intelligence in providing constructive feedback. The IPAC also provides students a sense of fairness in assessment and team allocation, it directly encourages constructive student engagement, and it is seen as a fair intervention for addressing free riding or uneven contributions.

Although the IPAC methodology has mitigated many of the challenges faced, it has its limitations. The IPAC marks need to be reviewed, in few cases moderated by staff, first of all because marks must be endorsed by staff but also as a student's safeguarding process especially for cases involving SoRAs and EC students. Typically, only a few cases might need moderations, and these academic judgments are based on the peer comments and available staff observations. Other important aspects to good teamwork are (i) student training and mentorship by staff; and (ii) team management tools such as the use of a student-developed team contract at the start of the project, which will encourage good communication and understanding of needs between the team members.

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REFERENCES

Albon, R. and Jewels, T., “Mutual performance monitoring: Elaborating the development of a team learning theory” *Group Decision and Negotiation,* 23, (2014): 149-164. doi:10.1007/s10726-012-9311-9.

Bacon, D. “The effect of group projects on content-related learning.” *Journal of Management Education,* 29, (2005): 248-267. doi:10.1177/1052562904263729.

Biggs, J., “What the student does: teaching for enhanced learning.” *Higher Education Research & Development* 18, (1999): 57-75. doi:10.1080/0729436990180105.

Burbach, M., Matkin, G., Gambrell, K., and Harding, H. “The impact of preparing faculty in the effective use of student teams” *College Student Journals,* 44, (2010): 752-761.

Freeman, M. and McKenzie, J. “SPARK, a confidential web-based template for self and peer assessment of student teamwork: Benefits of evaluating across different subjects.” *British Journal of Educational technology,* 33, (2002): 551-566. doi:10.1111/1467-8535.00291.

Garcia-Souto, M. P. “Is It Safe to Use Peer Assessment of Individual Contribution Level When Assessing Group Work?” In *EDULEARN Proceedings: EDULEARN19 Conference,* (2019). Palma, Spain: IATED. doi:10.21125/edulearn.2019.1842.

Garcia-Souto, M.P., Azma, Y., Grammenos, R., Kador, T., Striolo, C., Whyndham, M., Vogel, M., Richardson, M., Gibson, A., Britton, J., Robinson, T., Hughes, G., “Individual peer assessment of contribution to group work (IPAC): Key points and recommendations.” (2019): In: *Proceedings of the SEFI 47th Annual Conference: Complexity is the New Normality,* Budapest, Hungary (2019). 1553-1565.

Graham, R., “The Global State of the Art in Engineering Education.” (2018): Boston, MIT School of Engineering.

Hansen, R. “Benefits and problems of with student teams: Suggestions for improving team projects.” *Journal of Education for Business,* 82, (2006): 11-19. doi:10.3200/JOEB.82.1.11-19.

Holt, D., Michael, S., and Godfrey, J. “The case against cooperative learning.” *Issues in Accounting Education*, 12, (1997): 191-193.

Hubbard, R. “Project management tools that facilitate team projects.” *International Journal of Case Method Research & Applications* 17, (2005): 368-373.

Kedrowicz, A. and Nelson, B. “Dramatizing engineering education: The performance of teamwork” Paper *presented at the American Society for Engineering Education Conference and Exposition* (2007): Accessed from https://peer.asee.org/2180 (7th May 2014).

Kliegl, J. and Weaver, K. “Teaching teamwork through coteaching in the business classroom.” *Business and Professional Communication Quarterly,* 77, (2013): 204-216. doi:10.1177/1080569913507596.

McCorkle, D., Reardon, J., Alexander, J., Kling, N., Harris, R., and Iyer, R.V. “Undergraduate marketing students, group projects, and teamwork: The good, the bad and the ugly?” *Journal of Marketing Education,* 21, (1999): 106-117. doi:10.1177/0273475399212004.

Mitchell, J. E., A. Nyamapfene, K. Roach and E. Tilley, “Faculty Wide Curriculum Reform: the (unnamed teaching framework)” *European Journal of Engineering Education*, 46:1, (2019): 46-66, doi: 10.1080/03043797.2019.1593324.

Ohland, M., Loughry, M., Woehr, D., Bullard, L., Felder, R. M., Finelli, C., Schmucker, D. “The comprehensive assessment of team member effectiveness: Development of a behaviourally anchored rating scale for self and peer evaluation.” *Academy of Management Learning & Education,*11, (2012): 609-630. doi:10.5465/amle.2010.0177.

Page, D. and Donelan, J.G., “Team-building tools for students.” *Journal of Education for Business,* 78, (2003): 125-128. doi:10.1080/08832320309599708.

Pertegal-Felices, Maria Luisa ; Fuster-Guillo, Andres ; Rico-Soliveres, Maria Luisa ; Azorin-Lopez, Jorge ; Jimeno-Morenilla, Antonio, 2019, “Practical Method of Improving the Teamwork of Engineering Students Using Team Contracts to Minimize Conflict Situations” PISCATAWAY: IEEE , Vol.7, p.65083-65092, Article 8713459

Ramdeo, Shalini ; Balwant, Paul ; Fraser, Simon Harold, Bingley. 2022. “Not another team assignment! Student perceptions towards teamwork at university management programs” Emerald Publishing Limited, Higher education, skills and work-based learning, Vol.12 (6), p.1122-1137

Riebe, L., Girardi, A., and Whitsed, C. “A Systematic Literature Review of Teamwork Pedagogy in Higher Education.” *Small Group Research*, 47(6), (2016): 619-664. doi: 10.1177/1046496416665221.

Sashittal, H., Jassawalla, A., and Markulis, P. “Teaching students to work in classroom teams: A preliminary investigation of instructors’ motivations, attitudes and actions” *Academy of Educational Leadership Journal,* 15(4), (2011): 93-106.

Seatwo, A. “Enhancing group work learning with the Individual Peer Assessed Contribution (IPAC)”, In *Proceedings of the SEFI 47th Annual Conference: Varietas Delectat... Complexity is the New Normality,* Budapest, Hungary (2019). 998-1009. SEFI.

Shaw, J.B., “A fair go for all? The impact of intragroup diversity and diversity-management skills on student experiences and outcomes in team-based class projects.” *Journal of Management Education,* 28, (2004): 139-169. doi:10.1177/1052562903252514.

Sundstrom, Eric, Michael McIntyre, Terry Halfhill, and Heather Richards. 2000. “Work Groups: From the Hawthorne Studies to Work Teams of the 1990s and

Beyond." *Group Dynamics: Theory, Research, and Practice* 4 (1): 44–67. doi: 10.1037/1089-2699.4.1.44.

Truscott, F. R., E. Tilley, J. E. Mitchell, and A. Nyamapfene, "Staff Experiences of Leading Large-Scale Multi-Departmental Project-Based Learning for Year 1 Engineering Students." *Paper presented at Annual Conference of the European Society for Engineering Education, Dublin*, 2023, p1337-1344, Belgium, SEFI, doi: 10.21427/7Y9A-6C85.

Truscott, F. R., E. Tilley, K. Roach and J. E. Mitchell, "Perspectives on putting a large scale first year interdisciplinary project module online" *PBL 2021*, (2021): doi:10.26226/morressier.60ddad35e537565438d6c49b.

Tuckman, B. "Developmental sequence in small groups." *Psychological Bulletin* 63, (1965): 384-399. doi:10.1037/h0022100.

Tuckman, Bruce W., and Mary Ann C. Jensen. 1977. "Stages of Small-Group Development Revisited." *Group & Organization Studies* 2 (4): 419–27. doi: 10.1177/105960117700200404.

Williamson, O.E., "Transaction-cost economics: The governance of contractual relations." *The Journal of Law & Economics,* 22, (1979): 233-261. doi:10.1086/466942.

World Economic Forum, (2023), "Future of Jobs 2023", Switzerland, World Economic Forum

Yang, Maria C. 2010. "Consensus and Single Leader Decision-Making in Teams Using Structured Design Methods." *Design Studies* 31 (4): 345–62. doi: 10.1016/j.destud.2010.03.002.

COURSE-BASED UNDERGRADUATE SUSTAINABILITY RESEARCH EXPERIENCE FOR EQUITABLE ENGINEERING EDUCATION

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Conference Key Areas: *Curriculum development and emerging curriculum models in engineering; Teaching the knowledge, skills, and attitudes of sustainable engineering*
Keywords: *Research-based curriculum, educational equity, undergraduate research, ethical sustainability, knowledge creation and practice*

ABSTRACT

Building a research-based curriculum across all fields of study is more important in the fast-paced, knowledge-driven world. To fully benefit from such a curriculum, engineering educators and students must recognize the significance of integrating sustainability into knowledge creation and practice, along with educational equity serving as the rationale for pedagogical design. This practice study highlights the impact of embedding sustainability research experience in two undergraduate electrical engineering courses at the University of Ottawa, Canada as a path of reinventing engineering education. In the second-year professional practice course, students learned about sustainability as a value that combines factual and ethical components through knowledge-based research. In the fourth-year power engineering course, the students investigated sustainability as a value practice in energy-related subjects through design-based research. Upon evaluation of the courses and student progress, it was evident that notable knowledge gains had been made after completing the experience. Further, this compensatory experience helped narrow the performance gap between high-achieving and low-achieving students. Surveys and feedback from students demonstrated remarkable improvements in their knowledge and competencies. The author emphasizes the significance of developing research skills for crafting usable sustainability knowledge

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early on as strategic competencies in undergraduate engineering education. These competencies promote educational equity, enrich ethical design thinking, and prepare students for graduate studies and unpredictable professional careers in a changing world.

1 INTRODUCTION

Many academic institutions promote integrating research-based learning (RBL) into their various educational programs (Healey and Jenkins 2009; Dekker and Wolf 2016). RBL is a teaching methodology that emphasizes the importance of inquiry or investigation at multiple levels of education. It not only involves the use of research outcomes but also cultivates students' understanding of processes and methodologies, fostering a research-oriented culture involving both students and teachers (Noguez and Neri 2019). This enriching culture enables students to not only learn from discoveries and research methods but also actively participate in the research process to develop competencies and reflection (Wessels et al. 2021). In addition, it helps them become partners in the knowledge-creation process and the disciplinary ways of thinking and practicing (Hunter et al., 2007).

The traditional approach to RBL is for a few students only, typically juniors or seniors, to work closely with a professor on a research project outside of class in the academic year or over the summer (Hansel 2018). The chance for those students to collaborate with faculty on research can be a transformative experience. Undergraduates who participate in research internships or apprenticeships report positive outcomes, such as learning to think like a scientist, finding research exciting, and intending to pursue graduate education or research careers (Kardash 2000). The impact of such research experiences on graduation rates has not been systematically tested. Previous studies support the idea that research participation can potentially increase graduation rates and reduce equity gaps (Olivares-Donoso and González 2019). However, ensuring that all students can engage in RBL is an issue of educational equity (Hansel 2018). Therefore, a course-based undergraduate research experience (CURE) may address the inequities of the traditional RBL approach. It allows all students to engage in research, irrespective of their social backgrounds and learning preferences. This could spark students' interest in pursuing research careers and promoting diversity within the research community.

Recent literature published on undergraduate engineering research recommends the use of backward design when executing research experiences by defining the goals before the development of the course (Cooper et al. 2019). The CDIO framework, which follows a "conceive, design, implement, operate" approach, has been updated to include new educational practices such as sustainable development (SD), digital learning, simulation-based learning (SBL), engineering entrepreneurship, internationalization, research-integrated education, and industry engagement, in addition to the original core CDIO standards (Malmqvist et al. 2020). The research option recommends including one or more research experiences as part of student learning.

Although substantial evidence supports the notion that a greater number of students should engage in research, several obstacles must be addressed to achieve this goal. These obstacles include faculty time constraints, insufficient knowledge and expertise, insufficient support and mentoring, a shortage of funding, and a general lack of interest among undergraduates in conducting research (Dadipoor et al. 2019). Moreover, students have limited time to take advantage of research opportunities due to an overburdened curriculum and inadequate planning (Adebisi 2022).

This practice study introduces the initiative “course-based undergraduate sustainability research experience (CUSRE),” which was implemented in the Fall of 2023 and Winter of 2024 at the University of Ottawa, Canada. The author (instructor) opted to add a CUSRE that promotes “sustainability as a value creation and practice” to a second-year professional practice course and a fourth-year power engineering course. The two independent CUSRE modules were created to align with a standard semester structure for electrical engineering. The focus of CUSRE 1 is on knowledge-based research (KBR) while CUSRE 2 concentrates on design-based research (DBR). The study provides an overview of the courses’ pedagogical design, the CUSRE methodology, and the learning experience outcomes.

2 SUSTAINABILITY AS VALUE CREATION AND PRACTICE

The inclusion of sustainability in engineering education should be anchored in a strong philosophical endeavour. The concept of "eudaimonia," derived from Aristotelian virtue ethics and encompassing well-being, happiness, and flourishing, serves as a framework for this endeavour (Cirkony et al. 2023).

Values are enduring beliefs about what is good or desirable, encompassing personal, social, and moral considerations. They play a crucial role in ethics, which deals with human actions. Generally, values pertain to issues of human dignity and rights, cultural diversity, democracy, justice, fairness, social equity, and the rule of law (Holmes et al. 2022). Values can also be used as a measure of how useful technology is in sustainability contexts (Taebi 2016).

By presenting values as aspirational rather than solely preventative, educators can prioritize the public's well-being in ethical decision-making. According to Callard (2018), aspiration refers to the intentional and self-driven effort of individuals to enhance their worth. It encompasses a sense of purpose, envisioned outcomes, and aspirations. As this pursuit of value necessitates personal growth and development for a more gratifying existence, it facilitates sustainable transformation. Therefore, formal education should prioritize transformative learning that is inspired by aspirations.

The notion of sustainability is multifaceted and comprises both factual and value-based components, as noted by Carew and Mitchell in 2008. While sustainability can be traced back to ancient times, it has only recently gained widespread recognition as a critical issue that requires immediate attention from all stakeholders. One way to incorporate sustainability into daily actions is by using the SD Goals (SDGs). Among these stakeholders, the upcoming cohorts of engineering graduates who can play a crucial role in shaping sustainability for socio-technical development (García-Aranda et al. 2023). This requires the education system to consistently impart the necessary pedagogies for envisioning sustainability as knowledge creation and practice.

The literature provides several experiences on RBL for sustainability. Arizona State University (ASU 2024) has established a sustainability undergraduate research experience (SURE) program that provides students with research opportunities to help build career skills and enhance competitiveness for jobs and graduate school. Through the program, students improve their knowledge, skills, and experiences in exploration and discovery to develop evidence-based solutions for sustainability. Stanford University (2024) developed a sustainability undergraduate research in geoscience and engineering (SURGE) program for students from any U.S. institution interested in Earth and environmental sciences, energy, ocean sciences, or civil engineering. In 2014, the University of California at Los Angeles (UCLA 2024) founded the Undergraduate Research Scholars Program (URSP) as a signature undergraduate course of the sustainable grand challenge. The URSP unites undergraduate students across all disciplines in their research experiences in urban sustainability.

3 PEDAGOGICAL DESIGN

Canadian engineering degrees typically have a duration of four years. The School of Electrical Engineering and Computer Science at the University of Ottawa offers several degree programs including electrical engineering, computer engineering, and computer science. In addition to typical technical topics, the programs incorporate topics such as economics, entrepreneurship, and professional practice.

This study considers two undergraduate electrical engineering courses taught by the author. The second-year professional practice course (72 students) has been offered for several semesters in different formats. It covers topics like engineering ethics, leadership and entrepreneurship, sustainability, and artificial intelligence (AI) practice. The fourth-year power systems course (68 students) covers renewable energy systems, power transmission and distribution systems, and buildings. Several significant changes in the curriculum and pedagogy were implemented over the years based on student feedback and reflection on learning outcomes.

The mandate for both courses is to promote collaborative undergraduate research experience by amalgamating various learning methodologies like case-based learning (CBL), and project-based learning (PBL). The learning activities are designed to be modular and flexible, with yearly modifications to provide personalized education and discourage copying. Fig. 1 illustrates a proposed research-based curriculum for the two courses. It emphasizes the importance of the CUSRE as a catalyst for developing questions, investigating the questions, and sharing the findings. The CUSRE facilitates other compensatory learning components like hands-on research cases and projects where students work to examine phenomena and build solutions for real and often interdisciplinary problems. Tests are highly competitive and individualistic.

The learning activities of the two courses can be classified similarly to Bloom's taxonomy, starting with descriptive and analytical experiences, leading to synthetic experiences, and ultimately culminating in design and development approaches (Sleeter 2007). It is essential to note that Bloom's taxonomy is not represented as a pyramid, with a wide base of facts and a small peak of creativity, but rather as a broad wedge or straightforward table. This representation emphasizes the equal significance of analyzing, evaluating, and creating levels (Armstrong 2024). Depending on the types of competencies covered by the study, acquiring topic-specific competencies may be generally mapped as KBR for sustainability, while DBR embraces realizing solutions for sustainable real-life problems. It is important to note that most of the learning activities are group-based (two students only), which encourages participatory and compensatory education to reduce the performance gap between high-achieving and low-achieving students.

One important aspect of pedagogy design is the distinction between the planned curriculum (what is intended to be taught) and the actual curriculum (what students end up learning). Some of this difference is attributed to a "hidden curriculum" (Tormey et al. 2015) which refers to the implicit learning that occurs during implementation. Many research experiences involve the implicit development of skills that are naturally built simply by participating in the process. Sometimes students may not be aware of the experiential impact that scaffolds such research skill development.

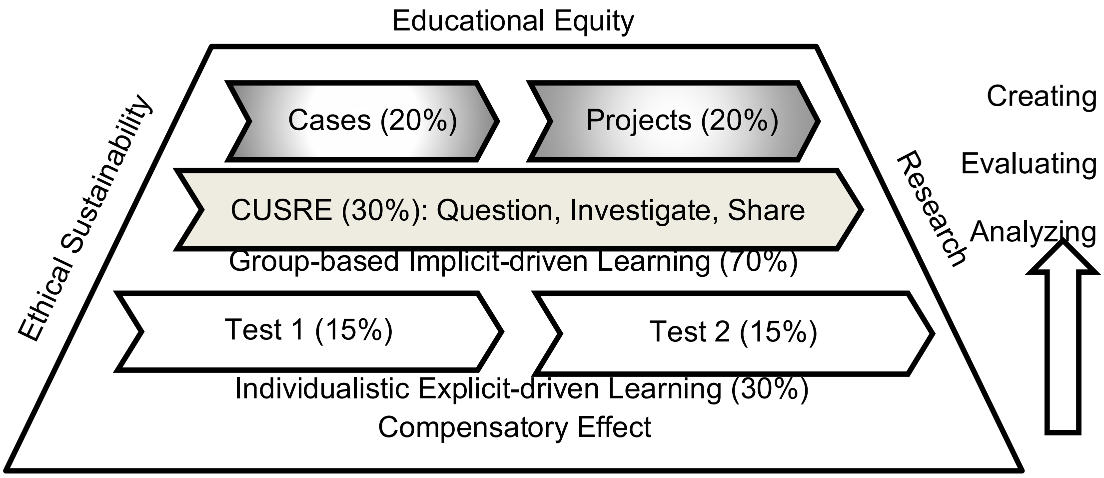

Fig. 1. The research-based curriculum for the two courses

4 CUSRE IN ENGINEERING

Engineering research differs from scientific research in that it is focused on operational knowledge (how and why of creating design concepts to solve problems), rather than factual and conceptual knowledge (understanding the fundamental principles of how phenomena work). Hence, it is vital to consider both KBR and DBR when creating undergraduate research experiences that could prove advantageous to academic institutions, faculty mentors, and students.

The inequities of the traditional RBL approach may be addressed through CURE which was initially created by McLaughlin and Coyle (2016) and evaluated by McLaughlin et al. (2017). The CURE is a course that encourages students to engage in RBL where research is embedded into the learning process. All students registered in a class investigate certain topics, use scientific practices, collaborate with others, and iterate their work. The outcomes of the research are unknown and communicated in some manner. The CURE offers the capacity to involve all students in research (Auchincloss et al., 2014) and can serve all students who enrol in a course—not only self-selecting students who seek out research internships or who participate in specialized programs. Moreover, the CURE can be integrated into introductory-level courses (Harrison et al., 2011) and thus have the potential to exert a greater influence on students' academic and career paths than research internships that occur late in an undergraduate's academic program and thus serve primarily to confirm prior academic or career choices (Hunter et al., 2007). Research internships often require an application or searching and networking to find faculty interested in involving undergraduates in research (Auchincloss et al., 2014). However, entry into a CURE is logistically straightforward where students simply can enrol in the course.

In 2023, the author structured two CUSRE modules and embedded them within the teaching and learning plan of the two courses. Educational equity sets CUSRE apart from CURE and SURE and underpins the decision to select CUSRE as the designated method for the pedagogical design of the two courses. Fig. 2 presents the two CUSRE modules that can assist in executing KBR and DBR. In the early CUSRE 1, students learn about education for SD by investigating its factual and ethical knowledge. In the advanced CUSRE 2, the students investigate how intelligent technologies contribute to the design of sustainable wind power through research replication (direct and conceptual) with a focus on design and simulation.

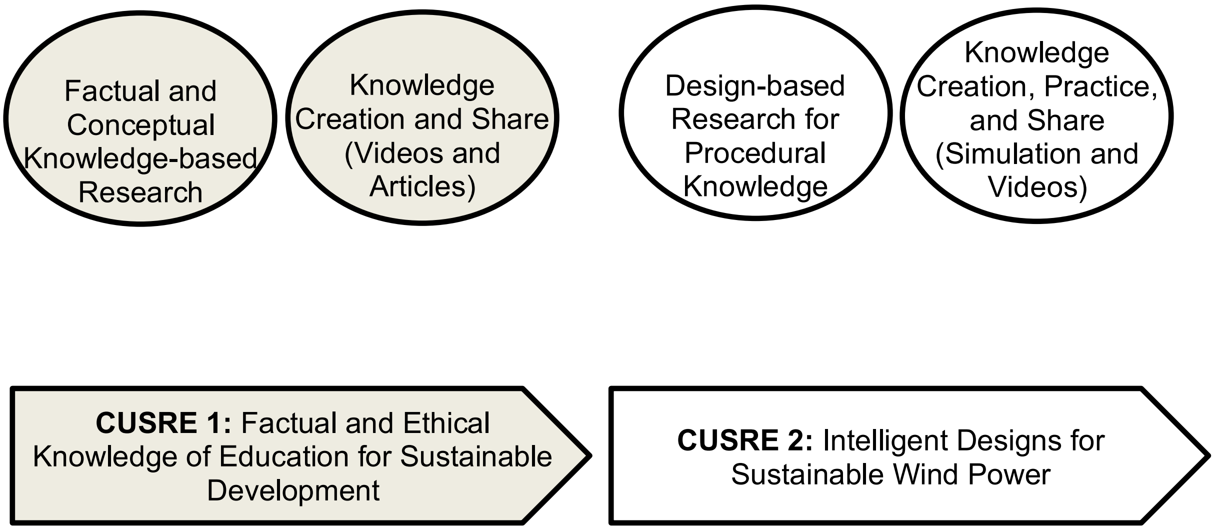

Fig. 2. Instructional design for the two CUSRE modules

In both courses, students work together in small groups to develop their research and design skills. This happens while conducting literature reviews, creating research tasks, and testing hypotheses using scientific methods and reflective problem-solving techniques. Additionally, they professionally present and share their findings through videos and articles, sometimes publishable.

Incorporating video creation, simulation, and article writing into the CUSRE modules can be a highly effective way of translating knowledge and engaging learners. In general, students exhibit value in both the creation of videos (implicit knowledge) and the subsequent simulation and article writing (explicit knowledge), which help them develop a deeper understanding of the subject matter (Habash and Abdulkadir 2023).

5 EVALUATION AND LEARNING EXPERIENCE

The intended learning objectives identified in this study are what the students are expected to learn in a course or teaching intervention. This includes the competencies the students should have acquired, or, in Bloom's terms, "what students should know or be able to do at the end of the course that they could not do before" (Bloom, 2001). The author, being the instructor, is deeply involved in the entire research-based curriculum and evaluation process. He collected empirical data through surveys and short interviews. The surveys had open-ended questions, aimed at gathering students' opinions on the courses. The students were interviewed in discussion circles and were asked questions about their thoughts and the inclusion of the CUSRE modules.

5.1 CUSRE 1: Knowledge-based Research

An anonymous survey of students of the second-year course on professional practice aimed to evaluate the effectiveness of learning materials and activities in an authentic learning environment. Data from the multiple-answer survey shows that 67% enjoyed the research cases compared to projects (40%) and tests (30%). The students preferred the CUSRE directly related to SD with 52% approval. 78% of students appreciated the opportunity to choose their topic within the CUSRE. 96% of the students valued the importance of professional social responsibilities in improving society, being active in the community, promoting racial understanding and helping others in need. For students who have been historically excluded from research experiences, there is a -11% equity gap between low-achieving and high-achieving students, but this gap is reduced to about –7%.

5.2 CUSRE 2: Design-based Research

An anonymous survey of students for the fourth-year course aimed to evaluate the effectiveness of the DBR and SBL as an approach for realizing real-life solutions that "by design" crisscross the sustainability practice space. 93% of the students were excited about the applied knowledge gained through DBR and SBL. Most of the students regarded the CUSRE as useful and successful in realizing the importance of engineering design for sustainability. 98% of the students "strongly agreed, just agreed, or slightly agreed" with the impact of the educational video creation and article writing exercise. Despite the satisfaction, this process might involve student uneasiness by being responsible for their learning tasks. For students who have been historically excluded from research experiences, there is a -9% equity gap between low-achieving and high-achieving students, but this gap is reduced to about –4%.

5.3 Feedback

An important aspect of the evaluation outcome is student fulfilment, which is correlated to but different from success as verified by student feedback and opinion about the learning experience:

"Engaging in course-based undergraduate sustainability research offers a dynamic approach to familiarize young students with contemporary engineering methodologies. The format I followed consisted of conducting a literature review, selecting a paper that aligns with the team's interests and strengths, replicating the results achieved in the paper, and finally presenting what we found to the rest of the class."

"Reflecting on this experience, I firmly believe to be a well-rounded engineer entering the workplace, you need the fundamental knowledge (math, physics, electronics, etc.) as well as perspective on research skills, sustainability, and contemporary learning methodologies."

6 Summary and Acknowledgment

One of the main challenges in engineering education has been the emphasis on the technical aspects of problem-solving and ignoring the socio-technical impact of the solutions. This requires changes in the education paradigm. However, the demanding academic plans of the technical content do not provide more room for supplementary content like sustainability. Therefore, the idea is to incorporate sustainability research in the curriculum interwoven or hidden within existing courses using methodologies like CBL, PBL, RBL, and SBL to adapt to diverse courses easily.

In this ongoing study, the classroom was viewed as a community of knowledge creation and practice where CUSRE plays an integral role in developing research competencies. It also demonstrates that incorporating research in the learning process promotes educational equity by engaging all students, irrespective of their social backgrounds and learning preferences. In addition, it reduces the performance gap between low-achieving and high-achieving students due to the compensatory effect caused by working in small groups to complete the learning tasks. Based on surveys, feedback from students, and observations of the instructor, it is recommended that classroom environments should promote social interaction and collaboration while emphasizing research skills. The curriculum structure should also strike a balance between KBR, DBR, and SBL by adopting CUSRE as a catalyst for sustainable curriculum transformation. This approach is crucial for bridging the classroom environment with professional practice to produce responsible socio-technical engineers who can resolve changing real-life problems.

Finally, the author thanks the numerous students who have taken the courses and participated in the survey and focus groups over the past year. The implementation of the CUSRE will be expanded to a third mechatronics course in the Fall of 2024.

REFERENCES

Afebisi, Y. A., “Undergraduate Students' Involvement in Research: Values, Benefits, Barriers and Recommendations,” *Annals of Medicine and Surgery* 81 (2022): 104384. doi: 10.1016/j.amsu.2022.104384

Arizona State University. *Teaching, The Sustainability Undergraduate Research Experience Program at Arizona State University*, 2024. https://schoolofsustainability.asu.edu/student-life/student-research/sure-program/

Armstrong, P. *Bloom’s Taxonomy, Vanderbilt University Center for Teaching*, 2024. https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy.

Auchincloss, L. C., S. L. Laursen, J. L. Branchaw, K.G.M. Eagan, D. L. Hanauer, G. Lawrie, C.M. McLinn, P. Pelaez, S. Rowland, M. Towns, N.M. Trautmann, P. Varma-Nelson, T. J. Weston, and E.L. Dolan, “Assessment of Course-based Undergraduate Research Experiences: A Meeting Report.” *CBE—Life Sciences Education* 13, no. 1 (2014): 29-40.

Bloom, B. S., P. Airasian, K. Cruikshank, R. Mayer, P. Pintrich, J. Raths, and M. Wittrock. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Longman, 2001.

Callard, A. *Aspiration: The Agency of Becoming*. Oxford, UK: Oxford University Press, 2018.

Carew, A. L., and C. A. Mitchell. "Teaching Sustainability as a Contested Concept: Capitalizing on Variation in Engineering Educators' Conceptions of Environmental, Social and Economic Sustainability," *Journal of Cleaner Production* 16, no.1 (2008): 105-115.

Cirkony, C., J. Kenny, and D. Zandvliet. "A Two-eyed Seeing Teaching and Learning Framework for Science Education." *Canadian Journal of Science, Mathematics, and Technology Education* 23 (July 2023): 340–364.

Cooper, K. M., J. N. Blattman, T. Hendrix, and S. E. Brownell. "The Impact of Broadly Relevant Novel Discoveries on Student Project Ownership in a Traditional Lab Course Turned CURE," *CBE—Life Science Education* 18, no. 4 (Winter 2019): 1-14.

Dadipoor, S., A. Ramezankhani, T. Aghamolaei, A. Safari-Moradabadi. "Barriers to Research Activities as Perceived by Medical University Students: A Cross-sectional Study," *Avicenna Journal of Medicine* 9, no. 1 (January-March 2019): 8–14.

Dekker, H., and S. W. Wolff. "Re-inventing Research-based Teaching and Learning," *European Forum for Enhanced Collaboration in Teaching of the European University Association*. Brussels, Belgium: Centre for Education and Learning, 2016.

García-Aranda, C., A. Molina García, J. Pérez Rodríguez, and J. Rodríguez-Chueca. Sustainability in Engineering Education. Experiences of Educational Innovation. In: Leal Filho, W., A. M. Azul, F. Doni, and A. L. Salvia (eds.) Handbook of Sustainability Science in the Future. Springer, Cham, 2023. https://doi.org/10.1007/978-3-030-68074-9_153-1

Habash, R. "Amalgamation of Research-, Case-, Project-, and Video-based Learning in Teaching Engineering and Computing Ethics," *International Journal of Engineering Education* 40, no. 3 (2024): 1-8.

Habash, R., and N. Abdulkadir. Video Creation as a Catalyst of Value Change in Engineering Education. In MIPRO 46th ICT and Electronics Convection, Opaticha, Croatia, May 22-26, 2023.

Hansel, N. H. *Course-based Undergraduate Research: Educational Equity and High-Impact Practice*, New York: Routledge, 2018.

Harrison, M., D. Dunbar, L. Ratmansky, K. Boyd, and D. Lopatto, "Classroom-based Science Research at the Introductory Level: Changes in Career Choices and Attitude," *CBE—Life Sciences Education* 10, no. 3 (Fall 2011): 279–286.

Healey, M., and A. Jenkins, *Developing Undergraduate Research and Inquiry*, York: Higher Education Academy, 2009.

Holmes, W., J. Persson, I. -A. Chounta, B. Wasson, and V. Dimitrova. Artificial Intelligence and Education: A Critical View through the Lens of Human Rights, Democracy, and the Rule of Law. Council of Europe, 2022.

https://democracy,t/artificial-intelligence-and-education-a-critical-view-through-the-lens/1680a886bd.

Hunter, A., S. Laursen, and E. Seymour, “Becoming a Scientist: The Role of Undergraduate Research in Students’ Cognitive, Personal, and Professional Development,” *CBE—Life Sciences Education* 91, no. 2 (December 2006): 36–74.
Kardash, C. M. “Evaluation of an Undergraduate Research Experience: Perceptions of Undergraduate Interns and their Faculty Mentors,” *Journal of Educational Psychology* 92, no. 1 (2000): 191–201.

Malmqvist, J., K. Edström, A. Rosen, R. Hugo, and D. Campbell. “Optional CDIO Standards: Sustainable Development, Simulation-based Mathematics, Engineering Entrepreneurship, Internationalization and Mobility,” In *Proceedings of the 16th International CDIO Conference*, vol. 1, Gothenburg, Sweden, pp. 48-59, 8-10 June 2020.

McLaughlin, J. S. and M. S. Coyle. “Increasing Authenticity and Inquiry in the Cell and Molecular Biology Laboratory,” *American Biology Teacher* 78, no. 6 (Fall 2016): 492-500.

McLaughlin, J. S., S. Jacqueline, E. David, E. Favre, S. E. Weinstein, and C. M. Goedhart. “The Impact of a Four-step Laboratory Pedagogical Framework on Biology Students’ Perceptions of Laboratory Skills, Knowledge, and Research Interest.” *Journal of College Science Teaching* 47, no. 1 (2017): 83-91.

Noguez, J., and L. Neri, “Research-based Learning: A Case Study for Engineering Students,” *The International Journal on Interactive Design and Manufacturing* 13 (May 2019): 1283-1295.

Olivares-Donoso, R., and C. González, “Undergraduate Research or Research-based Courses: Which is Most Beneficial for Science Students?” *Research in Science Education* 49, no. 1 (2019): 91–107. https://doi.org/10.1007/ s11165-017-9616-4

Sleeter, C. E. *Making Choices for Multicultural Education. Five Approaches to Race, Class, and Gender*, NJ, USA: John Wiley & Sons, Inc, 2007.

Stanford University. *Sustainability Undergraduate Research in Geoscience and Engineering Program*, 2024. https://sustainability.stanford.edu/our-community/dei/surge.

Taebi, B. “Bridging the Gap between Social Acceptance and Ethical Acceptability.” *Risk Analysis* 37, no. 10 (November 2016): 1817-1827.

Tormey, R., I. LeDuc, S. Issac, C. Hardebolle, and I. Vonèche Cardia. The Formal and Hidden Curricula of Ethics in Engineering Education. In *43rd Annual SEFI Conference* Orléans, France, June 29 -July 2, 2015.

UCLA. *Undergraduate Research Scholars Program*, 2024. https://sustainablela.ucla.edu/student-programming/ursp

Wessels, I., J. Rueß, C. Gess, W. Deicke, and M. Ziegler, “Is Research-based Learning Effective? Evidence from a Pre–post Analysis in the Social Sciences,” *Studies in Higher Education* 46, no. 12 (March 2021): 2595-2609.

NO TIME TO WASTE
A PLEA FOR IMMEDIATE IMPLEMENTATION OF SUSTAINABILITY IN ENGINEERING EDUCATION

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ABSTRACT

There are many ways of integrating sustainability into engineering education. While renewing the Bachelor's Programme in Architecture, Urbanism and Building Sciences at TU Delft, The Netherlands, we discovered that these ways can easily lead to a stalemate: while there is the forward thrust of a curriculum renewal with its strict deadlines, uncertainty about useable concepts to integrate sustainability can cause delays and the avoidance of fundamental decisions. In this practice paper we give a brief overview of the ways to integrate sustainability we have considered, and explain how we subsequently chose what to do first and why. After an inventory of UNESCO's Sustainable Development Goals (SDGs) in the current courses, we reasoned that our faculty themes on sustainability were not directive enough, and that sustainability frameworks were not fully developed yet. Therefore we adopted a twofold method, top-down and bottom-up: redesigning the curriculum based on a preliminary framework, and connecting it with the SDGs in all 24 courses. This new combination did not provide a 'finished' sustainable curriculum, but does allow for follow-up steps that will update it based on fully developed frameworks and sustainable competences in the learning objectives. Our conclusion is that any method of integration may work, but that change can only start by choosing a method and going with it. Our advice is therefore nothing less than a plea for a cultural shift: to break the stalemate by choosing any way of implementing sustainability as soon as possible, in order to gradually transform education *as* sustainability.

1 INTRODUCTION

1.1 TU Delft Context

The campus vision of Delft University of Technology (TU Delft), The Netherlands, approved by the Executive Board in January 2022, includes ambitious goals on sustainability: by 2030, TU Delft will be carbon neutral, climate adaptive, circular, contributing to liveability, and demonstrating its sustainability and excellence on the campus (Van den Dobbelsteen and Van Gameren 2022). Besides sustainable campus operation and becoming climate neutral and adaptive, sustainability in education is part of this transition. Also based on literature, it is imperative that we fully integrate sustainability into our education (Weiss et al. 2021a).

Back in the 1990s, efforts were already made to introduce sustainability in education at TU Delft, with a basic course and a certificate programme. The implementation was both add-on and integrated. Research on how to implement sustainability in education was done; a combination of top-down and bottom-up was suggested (Kamp 2006).

In the years that followed, sustainability and climate education was mainly implemented bottom-up in various courses. Graham indicates in her research that this is one of TU Delft's strengths (Graham 2018). A disadvantage of the bottom-up approach is the lack of an overall view on how the competences are implemented. As in TU's own research (Kamp 2006), in literature a combination of bottom-up and top-down is preferred (Weiss et al. 2021a; Weiss et al. 2021b; Reynante 2022).

1.2 Faculty Context

At the Faculty of Architecture and the Built Environment, pursuing a high level of sustainability in education fits within the faculty's broad approach towards sustainability. This approach has been formalized in the *Sustainability Action Plan*, which was set up in 2023 (Faculty of Architecture and the Built Environment 2023a). The plan describes the faculty's ambitions and goals for primary processes (research and education) and operational processes (building exploitation, energy use, etc.).

The need for a *Sustainability Action Plan* relates to the aforementioned campus vision. The sheer size of the university as an organization, and the many differences among its faculties and services, necessitated the development of local action plans tailored to each faculty and its curricula.

In terms of education, the faculty has interpreted the campus vision's ambitious goals as a responsibility to educate students who are able to contribute to a sustainable society in a responsible way, and who are able to critically address sustainability related issues. To us, the goals set out for the university stress that our education should be fully transitioned to a sustainable default by 2030 as well.

In parallel to the *Sustainability Action Plan*, the faculty has updated its *Vision on Education* in 2023, prescribing a strong emphasis on sustainability in the curricula (Faculty of Architecture and the Built Environment 2023b). It too describes the need to critically evaluate how to shape engineering education in a changing society.

The development of these plans has led us to question how the current curricula could be updated, adjusted and reformed, to accommodate a sustainable default for education. Both the faculty's ambitions and the campus vision evoke a sense of urgency in their commitment to sustainable reform, with many calls for immediate action. Often however, there is a multitude of possible approaches for achieving the set goals. This should not lead to indecision, because taking no action is the worst option of all. With no time to waste, we seized the planned Bachelor renewal as a benchmark opportunity to start a transition towards sustainability in education.

2 THE CASE OF THE BACHELOR RENEWAL

2.1 Reasons for the Bachelor Renewal

In 2022, the Faculty of Architecture and the Built Environment decided to update and renew its Bachelor's Programme in Architecture, Urbanism and Building Sciences, after ten years of intensive use. Our dean launched a project to design an improved curriculum, to be launched in the academic year 2024-2025. Since 2022, a large group of course coordinators, teachers and students is busy preparing this.

The ambition of the broad Bachelor's Programme was – and is – to educate students to become “skilled, academic and context-aware designers of the built environment”. However, major changes have occurred since the start of the present curriculum in 2013. In the social context, the climate crisis and the housing crisis have become much more urgent. Also, the speed of digitalisation is ever increasing. In academic research and teaching methods, innovations such as blended learning and open education have led to new forms of didactics, and more importance is being given to teaching interpersonal and intrapersonal skills. The architecture discipline itself has seen a shift towards interdisciplinarity and transdisciplinarity (respectively, collaborating with other disciplines, and with society). All of this necessitated a rethinking of our programme.

2.2 Aims of the Bachelor Renewal

Our aims for the renewed Bachelor's Programme were fourfold (Faculty of Architecture and the Built Environment 2022):

1. More 'breathing space'

Making courses and the curriculum less full, improving the 'study- and teachability'

2. More academic attitude

Strengthening scientific and critical reflection, increasing freedom of choice

3. Updated content

Integrating the current 'faculty themes', increasing digital and personal skills

4. Updated didactics

Renewing teaching methods

In the remainder of this paper, we focus on ways in which relevant aspects of sustainability could be structurally embedded in the new curriculum, in relation to these four goals.

2.3 Faculty Themes

In its *Multi-Annual Plan 2021-2025*, the faculty presented a number of strategic aims or "faculty themes", all of which directly or indirectly link to sustainability (Faculty of Architecture and the Built Environment 2021). In the document, the faculty identifies three societal challenges as a basis for further action: urban inequality, climate crisis and scarcity of resources. These are followed by three perspectives: on sustainable urbanization, healthy cities, and heritage futures. Finally, the document states three strategies to be developed further: digitalization and artificial intelligence, climate adaptation and energy transition, and circularity in the built environment.

2.4 Problem Statement

Whereas it is abundantly clear that sustainability is a central concept for the faculty, it was not so clear at the outset of the Bachelor renewal how to integrate these broad themes in the renewed programme. This can easily lead to a stalemate: on the one hand there is the forward thrust of the curriculum renewal process with its strict deadlines, on the other hand, uncertainty about useable concepts to integrate sustainability can lead to the desire to take it slow and avoid fundamental decisions affecting all of our teaching. The challenge in 2022 was how to bridge this gap.

3 OVERVIEW: SUSTAINABILITY IN CURRICULA

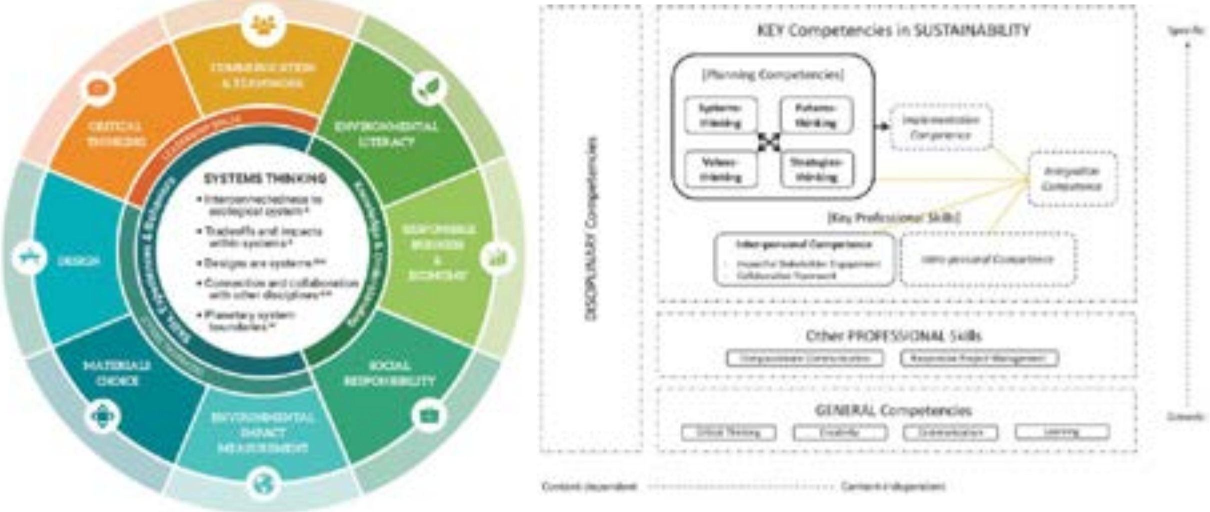
3.1 Frameworks

Twenty years ago, Sterling stated that "sustainability is not just another issue to be added to an overcrowded curriculum, but a gateway to a different view of curriculum, of pedagogy, of organisational change, of policy and particularly of ethos" (2004, 50). Sustainability can thus be implemented at different levels in education. When connecting to TU Delft's other transition goals, it is necessary to go for the highest level of implementation, redesign, education *as* sustainability, instead of education *about* sustainability, see Figure 1 (Weiss et al. 2021a).

Level		Type of ESD	Description	Pedagogical Approach
high/ very strong	redesign	education *as* sustainability	-holistic change and paradigm shift that places sustainability principles, ethics, and values at the core of the curriculum requiring the engagement of the whole person and institution -ESD is integrated into common core requirements and/or the vision of the HEI	emancipatory & transformative (third-order learning)
middle/ strong	'build-in'	education *for* sustainability	-significant changes to the curriculum by including a coherent coverage of content, values, and skills associated with sustainable development and a critical questioning of assumptions -sustainability is addressed in (interdisciplinary) programs/courses focusing on integrating sustainability issues -first linkages from ESD modules to other HEI areas such as operations/campus	
low/ weak	'bolt-on'	education *about* sustainability	-leaves current paradigm change unchallenged -sustainability concepts are added to specific disciplinary existing courses or programs (content based sustainability literacy) -minimal effort from the institution	instrumental & simplistic (first-order learning)
very weak	denial	no change	/	

Figure 1. Levels of implementing sustainability in curricula (Weiss et al. 2021a)

The usage of a framework for implementing Education for Sustainable Development (ESD) seems to be helpful (Wijnia, 2024). For our situation, we mainly looked at the Engineering for One Planet (EOP) framework and Wiek's framework, see Figure 2, left and right. Wiek's framework is the most frequently cited (Wiek and Redman 2022). This is a more general framework, with the disciplinary competencies placed next to the sustainability competencies. The Engineering for One Planet framework was developed specifically for engineering education (Anderson and Cooper 2022). It fulfils the Accreditation Board for Engineering and Technology (ABET) criteria, uses the United Nations Sustainable Development Goals (SDGs) and was prepared in collaboration with universities and industry. Knowledge on the specific implementation processes that lead to sustainable curricula still has to be developed (Weiss et al. 2021a). Wiek et al. (2011) indicate that it is more important to get started implementing ESD rather than developing the most ideal framework.



EOP framework	Wiek's framework
Model made for engineering education	General model
Disciplinary competences in the model	Competencies are largely independent of specific topics
2 levels: core and advanced	3 levels: novice, intermediate (BSc) and advanced (MSc)
Cross-referenced with engineering education and UN SDGs	Most cited research

Figure 2. Comparison of frameworks (Anderson and Cooper 2022; Wiek and Redman 2022)

3.2 Preliminary Adaptation

To fit in with TU Delft's education model, it was decided to use the EOP framework as a starting point. In 2023, a preliminary adaptation to our own educational situation has been made, see Figure 3. In the coming period, this will be further developed by a to be formed focus group. The ultimate goal is then to put this framework alongside new curricula and to see to what extent it is satisfying, can help curriculum development and needs to be updated. Educational redesign takes time to be implemented properly, and with our target there is time for improvement until 2030.

Figure 3. TU Delft Engineering for Sustainability (TUD ES) framework (own illustration based on EOP)

4 SUSTAINABILITY IN THE BACHELOR RENEWAL

4.1 Inventory

In order to check whether and where the faculty themes and sustainability could be implemented in the Bachelor renewal, an inventory of the current curriculum has been made. This started in 2022 with the report of GreenTU (GreenOffice TU Delft), in which all TU Delft education was examined and mainly looked at in outline terms, providing a general overview (GreenTU 2022). To get a better picture, research was conducted on the state of education in 2022-2023 by studying the publicly accessible information in the online Study guide. Keywords were examined and an inventory of the universally used SDGs was made using AI (see Figure 6 for all SDGs). The results were presented in the GreenDatabase. In the current Bachelor of Architecture, Urbanism and Building Sciences, a significant proportion of the courses was found to be dealing with sustainability: 10 out of 24 courses (42%), see Table 1. The courses were part of the so-called 'learning trajectories' 'Design' (ON), 'Technology' (TE) and 'Society' (MA), see Figure 4 for the curriculum.

Figure 4. Current Bachelor's Programme with 4 quarters per year (horizontal) in a 3-year curriculum (vertical) with 6 learning trajectories (see Table 1) (own illustration)

Table 1. Sustainability keywords and SDGs (for the numbers, see Figure 6) in the current programme, based on Study guide (GreenDatabase and own illustration)

Design ON (60 EC)	**Technology TE (25 EC)**	**Fundamentals GR (20 EC)**	**Representation and Form OV (15 EC)**	**Academic Skills AC (15 EC)**	**Society MA (15 EC)**
BK1ON1 11, 12, 13	BK1TE1 7, 9, 11, 13	BK1GR1	BK1OV1	BK2AC1	BK3MA1 11, 12
BK2ON2	BK1TE2	BK2GR2	BK2OV2	BK4AC2	BK4MA2 11
BK3ON3 11, 15	BK2TE3 7, 9, 11, 12	BK3GR3	BK3OV3	BK6AC3	BK6MA3 11, 12
BK4ON4 11	BK3TE4 11, 13	BK4GR4			
BK6ON5	BK4TE5 11, 12, 13				
BK6ON6 11, 12, 13, 15					
Contains 'sustainability'		Not sure		No 'sustainability'	

Next, in early 2023, the learning objectives of all courses were studied in detail by the programme coordinators. This confirmed the results of the GreenDatabase, with only one difference in the 10 courses dealing with sustainability: BK3ON3 instead of BK1ON1 in the 'Design' trajectory. However, most courses appeared to deal with sustainability only in a rather superficial way, e.g. in a subclause or as an 'add-on'.

4.2 Problems with the Faculty Themes and the TU Delft ES Framework

A major aim of the Bachelor renewal was to better embed and deepen sustainability in the programme, initially using the faculty themes. However, because these are quite abstract, thematically ordered and not linked to international examples, while the courses' learning objectives are specific and focused on assignments, the faculty themes proved difficult to use to give direction to the Bachelor renewal, in a way that is understandable also outside the faculty. Because the TUD ES framework was not fully developed during the renewal process but we did not want to delay, we adopted a twofold method, top-down and bottom-up: redesigning the curriculum based on the preliminary framework (Figure 3), and relating all courses to the SDGs.

4.3 Curriculum Redesign

First, during the first half of 2023, we redesigned the structure of the curriculum partly based on and incorporating the known knowledge, skills and attitudes from the preliminary TUD ES framework. This was one of the reasons for the fusion of the 'Academic Skills' (AC) and 'Representation and Form' (OV) trajectories into the new 'Science and Skills' (WV) trajectory, with more focus on critical thinking and personal skills, and for the introduction of the education-free and reflection-based Personal Development Week (P) twice a year (Bohm et al. 2023), see Figure 5. With these two innovations, the competences reflection & critical thinking, communication & teamwork, and social responsibility from Figure 3 are better incorporated.

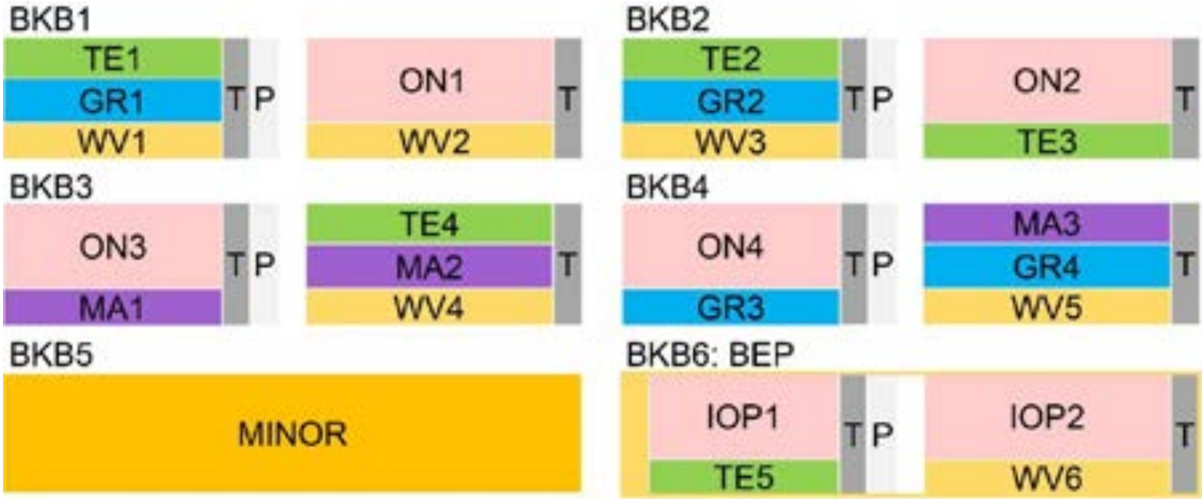


Figure 5. Renewed Bachelor's Programme starting in September 2024 (own illustration)

4.4 Sustainable Development Goals in all Renewed Trajectories and Courses

Second, we chose the SDGs as an extra framework (Beagon et al. 2022), and from summer 2023 asked all trajectory teams to what extent their renewed courses could be linked to them and steered by them. The initial question was to look at the primary (and possibly secondary) interfaces with the SDGs from the course description in development, and to interpret them broadly. For this we used the 'Wedding Cake

Model', in order to facilitate relating the SDGs to the natural and built environment, and its influencing contexts, see Figure 6 (Rockström and Sukhdev 2016).

Figure 6. SDGs Wedding Cake Model (Rockström and Sukhdev 2016)

It was explicitly not the ambition to cover all 17 SDGs with the 24 courses, as some SDGs are less related to the building domain in terms of content. Instead, the intention was to see where our programme is strongly or less connected, so an overall picture emerges.

In resolving duplications or omissions, UNESCO's publication *Education for Sustainable Development Goals* has been used (UNESCO 2017). This educational elaboration provides guidance on how to implement the SDGs in education, including suggestions for learning objectives. Besides learning objectives per SDG – subdivided into cognitive, socio-emotional and behavioural learning objectives – the publication also lists 8 generic key competences for sustainability: systems thinking, visualising multiple futures, using norms and values, strategic action, collaboration, critical thinking, self-awareness and integral problem solving. Using this, the trajectory teams started thinking about where in their courses (which) knowledge and skills about climate and sustainability could be conveyed, and how these could be captured in (assessable) learning objectives. For now, this has led to an updated version of Table 1, see Table 2, in which all courses now relate to one or more SDGs (with SDG 11 being present in 20 courses, and SDGs 1, 2 and 16 being absent).

In a future stage, the trajectory teams can fine-tune their course content as they continue to develop it during the 2024-2025 academic year, parallel to the further development of the TUD ES framework, and by using the European Commission's competence framework Greencomp (European Commission Joint Research Centre 2022). This contains 12 competences in four areas: sustainability values, complexity of sustainability, visualising a sustainable future, and pursuing sustainability.

Table 2. Sustainability keywords and SDGs (for the numbers, see Figure 6) in the renewed programme, according to the course coordinators (own illustration)

Design ON (60 EC)	Science and Skills WV (30 EC)	Technology TE (25 EC)	Fundamentals GR (20 EC)	Society MA (15 EC)
BKB1ON1 3, 6, 15	BKBWV1 4	BKB1TE1 4, 7, 13	BKB1GR1 11, 15	BKB3MA1 3, 10, 11, 13
BKB2ON2 7, 11, 12	BK1WV2 4	BKB2TE2 4, 11, 12, 13	BKB2GR2 11, 15	BKB3MA2 8, 11, 12, 17
BKB3ON3 11, 13, 15	BK2WV3 4, 11	BKB2TE3 3, 4, 6, 7, 11, 12, 13	BKB4GR3 11, 15	BKB4MA3 11, 12, 13, 17
BKB4ON4 3, 4, 5, 11	BKB3WV4 4, 11	BKB3TE4 3, 4, 7, 11, 13, 15	BKB4GR4 11,15	
BKB6IOP1 11, 17	BKB4WV5 7, 11, 14, 15	BKB6TE5 3, 4, 6, 9, 11, 12, 13, 15		
BKB6IOP2 6, 7, 11, 12	BKB6WV6 4, 11			

Contains 'sustainability'	Not sure	No 'sustainability'

5 Discussion

5.1 Conclusion

Looking back at the renewal process, and forward to the start of the renewed Bachelor's Programme in September 2024, we can conclude that our method did not provide a 'finished' sustainable curriculum at once. However, it has provided guidelines, also for other institutions, on how top-down and bottom-up approaches can be integrated: it did change the curriculum in a fundamental way, by a change of perspective on the design of a more sustainable curriculum, and on the courses' content with the SDGs; in line with the aforementioned quote of Sterling (2004).

Moreover, our method ensured that studyability (not adding more, but sometimes doing less) and teachability (a new curriculum demands a lot from staff) could receive a lot of attention. It also allows for follow-up steps from 2024-2025, that will update the curriculum in line with frameworks in development (including the TU Delft ES framework), and that will include sustainable competences in the learning objectives, while evaluating the courses and the needs of teachers and students. At the same time, our Bachelor renewal will serve as a pilot for other TU programmes.

With Wiek et al. (2011) and Weiss et al. (2021a), who indicate to get started with implementing sustainability rather than to wait for fully developed frameworks, our conclusion is that any method of integrating sustainability in engineering education may work, but that change can only start by daring to make a deliberate choice for a method and going with it. Given the implementation time, this is the first step in a process, and it will take several iterations to realise the highest level of integration.

5.2 Advice

Based on our case of the Bachelor renewal as well as on literature, our advice on integrating sustainability in engineering education is therefore nothing less than a plea for a cultural shift: to break the stalemate that may occur because of the many useable concepts, by choosing any way of implementing sustainability as soon as possible, in order to gradually transform engineering education *as* sustainability.

REFERENCES

Anderson, C., and C. Cooper (eds). *The Engineering for One Planet Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education*. Portland, OR: The Lemelson Foundation, 2022. https://engineeringforoneplanet.org/wp-content/uploads/EOP_Framework_2023.pdf

Beagon, U., K. Kövesi, B. Tabas, B. Nørgaard, R. Lehtinen, B. Bowe, C. Gillet, and C. Monrad Spliid. "Preparing engineering students for the challenges of the SDGs: what competences are required?" *European Journal of Engineering Education* 48 (2022), 1-23. https://doi.org/10.1080/03043797.2022.2033955

Bohm, N.L, M.J. Hoekstra, L.P.J. van den Burg, and M.M.O Reincke. "Who am I learning to become? Integrating personal development in curriculum design." In: *The 19th CDIO International Conference: Proceedings – Full Papers, Trondheim 2023*, 770-779. Trondheim: CDIO.

European Commission Joint Research Centre. *GreenComp: The European sustainability competence framework*. Luxembourg: Publications Office of the European Union, 2022. https://data.europa.eu/doi/10.2760/7670

Faculty of Architecture and the Built Environment. *Multi-Annual Plan: Bouwkunde 2021-2025*. Delft: Faculty of Architecture and the Built Environment, 2021.

Faculty of Architecture and the Built Environment. *Startdocument Vernieuwing Bachelor Bouwkunde.* Delft: Faculty of Architecture and the Built Environment, 2022.

Faculty of Architecture and the Built Environment. *Sustainability Action Plan*. Delft: Faculty of Architecture and the Built Environment, 2023a.

Faculty of Architecture and the Built Environment. *Durable Inspiration: Vision on Education BK 2023-2027*. Delft: Faculty of Architecture and the Built Environment, 2023b.

Graham, R. *The global state of the art in engineering education, March 2018*. Cambridge, MA: MIT, 2018.

GreenTU. *Vision on Sustainability: A Review and Strategy as of 2022*. Delft: TU Delft, 2022.

Kamp, L. "Engineering education in sustainable development at Delft University of Technology." *Journal of Cleaner Production* 14 (2006), 928-931. https://doi.org/10.1016/j.jclepro.2005.11.036

Reynante, B.M. *Engineering for One Planet Literature Review*. Portland, OR: EOP, 2022.

Rockström, J., and P. Sukhdev. *The SDGs Wedding Cake*. Stockholm: Stockholm Resilience Centre, 2016. https://www.stockholmresilience.org/research/research-news/2016-06-14-the-sdgs-wedding-cake.html

Sterling, S. "Higher Education, Sustainability, and the Role of Systemic Learning." In: P.B. Corcoran, and A.E.J. Wals (eds). *Higher Education and the Challenge of Sustainability*, 49-70. Kluwer: Dordrecht, 2004.

UNESCO. *Education for Sustainable Development Goals: Learning Objectives*. Paris: UNESCO, 2017. https://unesdoc.unesco.org/ark:/48223/pf0000247444

Van den Dobbelsteen, A., and D. van Gameren. *Sustainable TU Delft: Vision, Ambition and Action Plan for a Climate University*. Delft: TU Delft, 2022.

Weiss, M., M. Barth, A. Wiek, and H. von Wehrden. "Drivers and Barriers of Implementing Sustainability Curricula in Higher Education - Assumptions and Evidence." *Higher Education Studies* 11 (2021a): 42-64. https://doi.org/10.5539/hes.v11n2p42

Weiss, M., M. Barth, and H. von Wehrden. "The patterns of curriculum change processes that embed sustainability in higher education institutions." *Sustainability Science* 16 (2021b): 1579-1593. https://doi.org/10.1007/s11625-021-00984-1

Wiek, A., and A. Redman. "What Do Key Competencies in Sustainability Offer and How to Use Them." In: P. Vare, N. Lausselet, and M. Rieckmann (eds). *Competences in Education for Sustainable Development*, 27-34. Cham: Springer, 2022. https://doi.org/10.1007/978-3-030-91055-6_4

Wiek, A., L. Withycombe, and C.L. Redman. (2011). "Key competencies in sustainability: A reference framework for academic program development." *Sustainability Science* 6 (2011), 203-218. https://doi.org/10.1007/S11625-011-0132-6

Wijnia, P. *A systematic approach to implement education for sustainable development in applied science: A case-study of the TU Delft Applied Sciences Faculty*. Master Thesis. Delft: Faculty of Technology, Policy and Management, 2024. http://resolver.tudelft.nl/uuid:3a82e7c5-b7d4-435c-ab48-4949846a2ef8

https://www.tudelft.nl/en/greentu/greendatabase

More than ChatGPT – additional AI tools for different teaching-learning scenarios

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Conference Key Areas: *Digital tools and AI in engineering education, Diversity, equity and inclusion in our universities and in our teaching*
Keywords: *AI tools, teaching-learning scenarios, diversity*

ABSTRACT

Since the end of 2022, ChatGPT and other chatbots continue to revolutionise the way we work, and especially in scientific and academic fields, this is both an opportunity and a challenge for both students and lecturers. Custom chatbots can also be easily created to suit specific applications and purposes. In addition, there are many other AI tools, e.g., for image and video generation and manipulation, scientific work or presentations. This study evaluates some of these AI tools besides ChatGPT with regard to different applications for academic purposes, both from the students' and lecturers' point of view. As part of an interdisciplinary project, students, in collaboration with the lecturer, selected several AI tools based on possible application scenarios and investigated the basics and functionalities of the tools. In the next step, they analysed these tools with regard to possible teaching and learning scenarios. Based on these scenarios, they used the tools to develop detailed applications in different teaching-learning scenarios to check the suitability, effectiveness and correctness and to evaluate the results. Teaching material of a dedicated lecture, including presentations, videos, textbook and more was used as demonstrator for the different AI tools.

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1 INTRODUCTION

1.1 Generative AI and tools

Since end of 2022, ChatGPT and other chatbots are the most popular generative AI tools to generate and analyse text and support or even replace the writing process (Achiam 2023). These Large Language Models (LLM) were trained with an incredible amount of training data to be able to generate responses for queries, given as prompts to the tool by the user, in all kind of different domains (Chowdhury 2023). This capability of the chatbots, to generate answers based on large data sets, changes the way of writing text drastically as it reduces the creative writing process to dedicated and suitable prompting (Wu 2023). As the answers are generated by statistical processes of the LLM, the answer will not be checked for any kind of correctness and it might contain plausible yet incorrect or nonsensical information, known as hallucinations, a big challenge for the user of the tool, also in academic area, where both students and academics use chatbots to generate their text for research proposals, thesis or any other kind of documentation (Sok 2023). In academic education, generative AI can be used for active learning environments (Elsayary 2024). Besides chatbots like ChatGPT, there are many other AI tools for other purposes, like generation of images, video or presentations, scientific work, collaboration and project work and others (Bankar 2023). In addition to ChatGPT, these tools also enter the academic world and can be used by students as well as lecturers (Lee 2023, Cao 2023). In particular lecturers have to be aware of these AI tools to uses the tools themselves in a responsible and adequate manner, to be able to support students on proper use on the one hand, and to be able to check any inadequate and unallowed use on the other hand (Ghimire 2024).. Therefore, a rough knowledge and understanding of the tools is essential for lecturers as well as students.

1.2 Learning and teaching scenarios

Like chatbots (Labadze 2023, Bewersdorff 2024), other AI tools can also be used by students and lecturers to support and improve both teaching and learning and to create new learning-teaching scenarios. Always keeping in mind, that the tools might suffer from hallucinations, emphasising the importance of guided use and background knowledge about the topics. Possible application areas are listed in Tab. 1.

Table 1. Application areas for AI tools

Lecturer	Student
L1: Additional and better learning material	S1: Support in scientific work
L2: Better visualization	S2: Self-generation of questions of understanding for exam preparation
L3: Support in generation of exams	S3: Generation of presentations and material
L4: Better and more individual evaluation of learning progress of the students	S4: Summarizing learning material for exam preparation

L5: More flexibility	S5: Support in creative processes
L6: Better accessibility of learning material	

2 METHODOLOGY

2.1 Experimental setup

To take both the lecturers' and the students' point of view into account, the evaluation of AI tools for teaching-learning scenarios was done in an Interdisciplinary Project (IP). IPs with students of different bachelor and master study programs (Electrical Engineering (EE), Information Technology (IT), Multimedia and Communication for Digital Business (MCD) and Information Systems (IS)) are essential parts of the curricula of these study programs at the department of Electrical Engineering and Information Technology (FB5) at University of Applied Science Aachen. The integration of an interdisciplinary teaching approach offers dedicated advantages for the students, like better preparation for today's jobs and challenges, critical thinking about the own discipline, enhanced communication skills with other disciplines and more (Woods 2007). In addition, the combination of interdisciplinarity with project-based learning extends the competences of the students during the interdisciplinary project with regard to increased autonomy, self-management, problem analysis and communication (González-Carrasco 2016, Haack 2013). With regard to these studies, the interdisciplinarity also introduces other benefits, like different prior knowledge of the students, different expertise and technical socialization. During winter term 2023/2024 in total 25 students participated in an IP called "ChatGPT & Co – Possible applications in teaching at FB5", both bachelor and master level. After a short introduction to the topic, the students researched different AI application areas and tools that could be suitable for an analysis with regard to teaching and learning. Finally, 6 application areas were selected by the students and 6 groups were formed. During the project time, these groups worked in a self-organized way with bi-weekly status meetings with all groups and the lecturer. The tasks for the groups were:

- Analyse the technical background of the tools
- Get familiar with the tool
- Identify possible applications for teaching and learning
- Develop real scenarios, e.g. for a dedicated module
- Evaluate and rate the results

2.2 Selected tools

In total, more than 10 different AI application areas were found by the students to be interesting for teaching or learning. Out of these, 6 were selected for detailed analysis in 6 groups. Due to limited space, this paper focusses on two AI application areas – PDF chatbots and image and video generation – and on the results of the analysis with regard to teaching and learning. The complete results of all 6 groups, including generation of presentations, scientific work and research and project management, can be requested from the author.

3 RESULTS

3.1 PDF chatbots

PDF chatbots are AI tools similar to ChatGPT to directly interact or chat with dedicated pdf documents to provide pdf processing capabilities including summarization, generation of question and answers, citing sources from the pdf.

Unlike chatbots like ChatGPT, they act on the pdf documents provided by the user instead on their own database. There are many different PDF chatbots available, commercial tools like ChatPDF or pdf.ai, open source tools, or you can create your own pdf chatbot. As most teaching material is provided and is available in form of pdf documents, PDF chatbots and their capabilities will be an important tool for academic use. Typical uses cases for students and lecturers are listed in Tab. 2.

Table 2. Uses cases for PDF chatbots

Lecturer	**Student**
Create questions & answers	Summarize learning material
Create exercises and labs	Generate questions & answers
Summarize books and scientific texts	Solve exercises and labs
Check answers and solutions	Get feedback for own work
Understand use of chatbots by students	Support with language problems
Create exams	Prepare for exam
Create feedback	

As clearly visible in Tab. 2, PDF chatbots change the way of interaction with the learning material, both for lecturers and students. For lecturers, PDF chatbots can improve the quality and the quantity of learning material, e.g., by providing focussed summaries, and increase the variety and flexibility of training material like exercises.

For students, PDF chatbots can be positive and negative with regard to their own learning success. In best case, the PDF chatbot can act as a training partner for better understanding of the teaching material, e.g., by asking dedicated questions for unclear topics, generating executive summaries, or even generate additional questions for better understanding. Also, the preparation for exams can be improved. On the other hand, PDF chatbots can tempt students to neglect real understanding and instead rely solely on the chatbot's answers without engaging intensively with the material. This topic is difficult in two ways: the students miss real understanding, and, in case of wrong answers, e.g., due to hallucination of the PDF chatbot or bad prompting, learn false facts.

To analyse the student's use cases, the complete teaching material of a dedicated module – sensors and actuators – was used, a complete set of presentations (about 500 slides), a textbook (about 200 pages), data sheets, exercises and lab material. The analysis used several different PDF chatbots – ChatPDF, Bingchat, PDFgear and pdf.ai – and covered uses cases like questions of understanding, generation of exercises and solutions, searching for details in data sheets, explanations, and more. The generated material was checked afterwards by the lecturer with regard to correctness and completeness.

As a result, questions of understanding were answered correctly by the PDF chatbots in most cases, just minor errors were introduced. Solutions to exercises, in particular for calculation tasks, were sometimes correct, but mostly incorrect. Either the equations used were wrong, or the calculating path, or the calculation itself. Students should therefor refrain from using PDF chatbots for calculations and solving exercises, at least they should be aware that the solution might be wrong and should be just a first hint for an own solution. The capability to summarize pdfs differ between the tools under investigation. The quality of the summary depends on proper and detailed prompting, and the length of the summary. the more detailed the summary should be, the shorter the input should be. Again, the student should be able to judge the quality of the summary. PDF chatbots can generate questions very well, the corresponding answers are, like for the first point, mostly correct for questions of understanding and often wring for calculations. Fig. 1 summarizes the results in form of a SWOT analysis.

Fig. 1. SWOT analysis of PDF chatbots

3.2 Image & video tools

Image and video processing tools are important and powerful AI tools in general (Singh 2023). Based on proper prompting, they can generate images and videos in different styles, manipulate and edit images and videos, convert text to image/video and vice versa, or video to video. For teaching and learning scenarios, these capabilities offer a wider range of applications for image and video processing tools like synthesia or runwayml, e.g., generation of dedicated images for visualization, increase the creativity and the variety of learning material, add subtitles to videos or generate explanatory videos. Form these applications, two were selected for more detailed analysis with regard to teaching and learning, creation of an explanatory video, and adding subtitle to an existing video.

For generating subtitles for an existing video, the AI tool reduces the noise of the video to increase the quality of the sound and performs an acoustic modelling to understand connections between phonemes heard. Afterwards a language modelling understands the text and in a final step, this text is reworked and corrected. To generate the subtitles in another language, e.g., for foreign students, the text can be downloaded in an .srt-file with timestamps. Afterwards it can be translated using ChatGPT for example and reinserted into the .srt-fil, which can be imported by a video player in the end resulting in a video with multilingual subtitles. These steps were done using the existing videos of the module sensors and actuators. After getting used to the AI video processing tool, the effort to generate subtitles is very low and it just takes about two minutes to generate subtitles in German for one of the videos of the modul of about 25 minutes. To generate multilingual subtitles, the extra steps for translation are currently manual and take some time, but still the effort is rather low. In future, these steps can be automated using an API instead. A screenshot of the video with English subtitles is depicted in Fig. 2. Due to the simplicity and speed of generation it can be done by either the lecturer, or by the students for individual settings and languages.

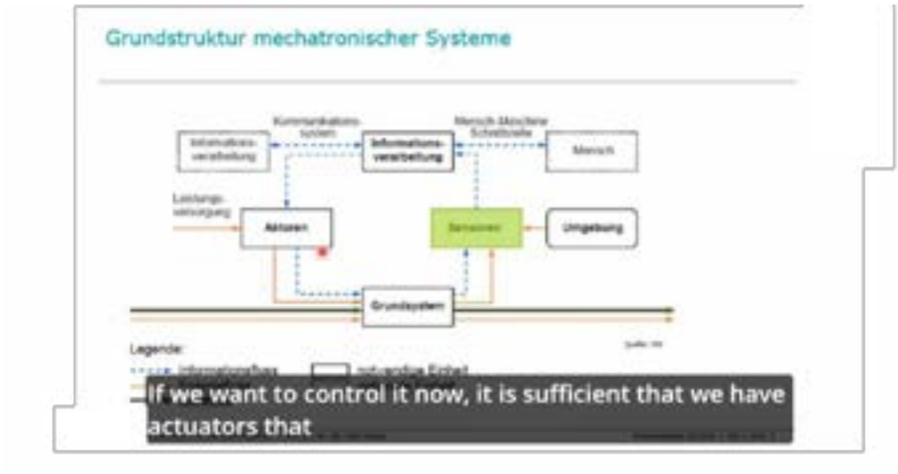

Fig. 2. English subtitles for a German video

The possibility of adding (multilingual) subtitles to videos increases the accessibility for several groups of students significantly. For foreign students, the translation of the subtitles to their mother tongue keeping the original language of the slides and the speech, can support their technical learning outcome as well as their understanding of the original teaching language. For students with hearing impairment subtitles will significantly increase the possibility for understanding the teaching material and improve their learning outcome. Or they can use the generated text instead.

Another application area of image and video AI tools is the creating of additional teaching material, e.g., in form of explanatory videos using avatars. Starting point for generation of explanatory videos is a script that should be presented in the video. This script is analysed by the AI tool to understand the context and to determine semantics and pronunciation. In the following prosody modelling step the AI tool understands the intonation and rhythm of the text and uses it to model pitches and durations. In the speech synthesis step, a trained neural network finally generates the actual speech based on the speech patterns and modelling.

As an application example, the written installation instructions for a lab were converted into an explanatory video using the tool synthesia. In a first step, the written instruction was converted to a script on different slides within synthesia. Afterwards, the features of the video can be adapted to the requirements, e.g., the animation style, language, avatar and gestures, speech. In Fig.3 a screenshot of the generated explanatory video is shown. The effort for the generation of the videos is rather low. Main task is to generate the script in the first step. The selection of the video features is a matter of training and doesn't need much time. The generation of the video itself is rather time consuming, for a video of about 30 s it took roughly 8 minutes to generate the video.

Explanatory videos increase the variety of learning material and provide an additional approach for the students as they can enable an easier access to dedicated topics. Hence, these explanatory videos don't require much effort for the lecturer, but can support and relieve the professor with simple descriptions and explanations.

Fig. 3. Screenshot of explanatory video

3.3 Evaluation of PDF chatbots and image & video tools

The results of the analysis above can be mapped to the application areas of Tab. 1, as depicted in Tab. 3. Even just two types of AI tools, PDF chatbots and image & video tools, can significantly contribute to the improvement of the teaching and learning material, increase the accessibility of the material, promote more inclusive engineering curricula and provide a higher degree of flexibility and individualization, simplifying the work for both lecturers as well as students and increasing the individual learning outcome of the students.

Table 3. Mapping of results to application areas

Group	**PDF chatbots**	**Image & video tools**
Lecturer	L1, L3, L4, L5	L1, L2, L4, L5, L6
Students	S1, S2, S4	S3, S5

4 SUMMARY AND ACKNOWLEDGEMENTS

This paper summarizes some of the results of an Interdisciplinary Project with regard to AI tools for teaching and learning, focussing on two AI applications. Both AI applications, PDF chatbots and video generation, were shortly introduced and important results were presented. PDF chatbots can support lecturers to improve their teaching material. For students, the use of PDF chatbot has some pros and cons and students should be aware of these to use the PDF chatbots sensibly, purposefully and correctly. Video generation tools can significantly improve the teaching and learning material and can be very helpful in terms of accessibility for foreign students and students with disabilities.

The careful use of AI tools is highly recommended, and in particular lecturers have to have a profound knowledge of these tools and their application.

The author would like to thank the students of the IP for their creativity and excellent cooperation. The complete results of the project can be requested by the author.

REFERENCES

Achiam, J., Adler, S., Agarwal, S., Ahmad, L., Akkaya, I., Aleman, F. L., McGrew, B. “Gpt-4 technical report”. (2023) arXiv preprint arXiv:2303.08774.

Bankar, R.S., Lihitkar, S.R. “Artificial Intelligence-Based Utility Tools for Research Communication: A Brief Overview.” *Proceedings of National Conference-2023*, 251 - 262. Shivaji University, Kolhapur: Prarup Publication.

Bewersdorff, A., Hartmann, C., Hornberger, M., Seßler, K., Bannert, M., Kasneci, E., Nerdel, C. “Taking the Next Step with Generative Artificial Intelligence: The Transformative Role of Multimodal Large Language Models in Science Education.” 2024 *arXiv preprint arXiv:2401.00832*.

Cao, C., Ding, Z., Lee, G. G., Jiao, J., Lin, J., Zhai, X. “Elucidating STEM concepts through generative AI: A multi-modal exploration of analogical reasoning.“ 2023 arXiv preprint arXiv:2308.10454.

Chowdhury, M. N.-U.-R. and Haque, A., “ChatGPT: Its Applications and Limitations.” *2023 3rd International Conference on Intelligent Technologies (CONIT)*, Hubli, India, 2023, pp. 1-7, doi: 10.1109/CONIT59222.2023.10205621

Elsayary, A., “Integrating Generative AI in Active Learning Environments: Enhancing Metacognition and Technological Skills.” In N. Callaos, S. Hashimoto, N. Lace, B. Sánchez, M. Savoie (Eds.), *Proceedings of the 15th International Multi-Conference on Complexity, Informatics and Cybernetics: IMCIC* 2024, pp. 135-138. International Institute of Informatics and Cybernetics. https://doi.org/10.54808/IMCIC2024.01.135

Ghimire, A., Prather, J., Edwards, J., “Generative AI in Education: A Study of Educators' Awareness, Sentiments, and Influencing Factors.” 2024 arXiv preprint arXiv:2403.15586

González-Carrasco, M., Ortega, J. F., de Castro Vila, R., Vivas, M. C., San Molina, J., Bonmati, J. M., “The development of professional competences using the interdisciplinary project approach with university students.” *Journal of Technology and Science Education*, vol. 6, no. 2, pp. 121–134, June 2016, http://dx.doi.org/10.3926/jotse.196

Haack, C., Lüthi, E., Janssen, V., “A student’s interdisciplinary product development project in engineering design education*.” International conference on engineering and product design education*, Dublin Institute of Technology, Dublin Ireland, September 2013

Labadze, L., Grigolia, M. and Machaidze, L. “Role of AI chatbots in education: systematic literature review.” *Int J Educ Technol High Educ* **20**, 56 (2023). https://doi.org/10.1186/s41239-023-00426-1

Lee, U., Han, A., Lee, J., Lee, E., Kim, J., Kim, H., Lim, C., “Prompt Aloud!: Incorporating image-generative AI into STEAM class with learning analytics using prompt data.” *Education and Information Technologies*. 1-31. 10.1007/s10639-023-12150-4. (2023)

Singh, A.," A Survey of AI Text-to-Image and AI Text-to-Video Generators. "*2023 4th International Conference on Artificial Intelligence, Robotics and Control (AIRC)*. IEEE, 2023.

Sok, S. and Heng, K., "ChatGPT for Education and Research: A Review of Benefits and Risks" 2023. http://dx.doi.org/10.2139/ssrn.4378735

Woods, C., "Researching and developing interdisciplinary teaching: Towards a conceptual framework for classroom communication." *Higher Education*, 54, pp. 853–866, 2007, doi: 10.1007/s10734-006-9027-3

Wu, T and Zhang, S, "Applications and implication of Generative AI in Non-STEM disciplines in Higher Education." *International Conference on AI-generated Content*, Singapore: Springer Nature Singapore, 2023

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THE STRAIGHT POOP: HOW SERVICE DESIGN AND TEACHING PARTNERSHIPS MITIGATE OVER-ENGINEERING AND PROMOTE SUSTAINABILITY

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ABSTRACT

In response to students' over-engineered designs in a biological engineering capstone course, the authors formulated a teaching partnership among communication, engineering, and library science instructors. We outline service design methodology as the framework for a teaching intervention in our partnered courses and then provide examples of instruction stemming from our respective areas of expertise. Our goal is to show how our multidisciplinary teaching collaboration improves the engineering curriculum while intersecting several ABET student learning outcomes. This teaching team was particularly attentive to centering people or users to educate engineers in a way that deters user dissatisfaction and environmental waste. We include one team's coursework as a case study for how this unique pedagogical framework improves student learning and simultaneously forwards their awareness of sustainability in engineering.

1 INTRODUCTION: PROBLEM & TEACHING INTERVENTION OVERVIEW

Picture a table-sized mobile phone charger whose surface automatically detects the device's location and charges it. Although this technology is fairly innovative, it lacks purpose for users. Outlet-based chargers are the norm, and while this technology design removes a user's need to be close to an outlet, it's unclear why a user would purchase a large, expensive charger over a readily available, less expensive one. A design like this one suffers from *over-engineering*, a process by which engineers design a product that is "unnecessarily complicated" ("Over-Engineered" 2024).

Over-engineered designs fail to prompt social and environmental sustainability. One example comes from a prominent German automotive manufacturer, who added 78 optional extras over 20 years, despite that "the number of customers purchasing these add-on components remained steady at only one in six for the same time period" (Bryant and Wrigley 2014, 78). Likewise, engineering designs that do not meet user needs also fail to meet sustainability goals, such as "the presence of high occupancy vehicle (HOV) lanes in Atlanta, Georgia for two decades has had little noticeable effect on congestion and driver behavior, particularly on willingness to carpool" (Guerra and Shealy 2018). Because the problem of over-engineering begins partially in the undergraduate engineering curriculum and sustainability is one way of contending with it, we argue for educating engineers to learn concepts and practices that deter such dissatisfaction and waste.

Therefore, our teaching team included service design methodology as a pedagogical framework for improving the learning outcomes in a senior biological engineering capstone course where students prototype and test physical designs. Five years ago, our multidisciplinary teaching team began a collaborative curriculum approach, combining communication and biological engineering expertise. Our instruction approach *authentically integrates* communication in the engineering curriculum (Reave 2004) with the goal of providing students with a situated learning experience (Artemeva, Logie, and St-Martin 1999) through a hands-on engineering design project. We accomplished this by adding a new engineering communication course, ENGRC 4590, to the curriculum that is partnered with BEE 4590: Physical Design in Biological Engineering. Two years ago, Christina Sheley, a library scientist, joined our team to provide information literacy instruction in the communication course to improve students' research skills so they could better define their problem, user, technology, and broader contexts before and during the design process.

First, we describe the current state of engineering design education, and second, we define service design methodology as the framework for a teaching intervention in our partnered courses. From there, we summarize the engineering student outcomes supported by our collaborative teaching partnership and offer examples from each respective instructor's area of expertise. Throughout we include a case study of one team's coursework as an illustration of how this unique pedagogical framework improves student learning and simultaneously forwards their awareness of sustainability in engineering. Upon examining the students' projects from 2023, we observed their heightened understanding of user needs which ultimately led to more sustainably conscientious and usable designs.

1.1 Engineering Design Curriculum Structure

In traditional engineering curricula, senior design or capstone courses emphasize structured design processes aimed at "the application of scientific and technical knowledge" (Atman et al. 2014, 210), mainly from textbook-based knowledge (Qattawi et al. 2021). These courses often follow one of two formats: students are either directed by one or two instructors who propose specific ideas for student exploration, or students are guided by academic faculty members who, while advising students, also derive benefits from the faculty's own research projects, treating student contributions as a form of free labor. These approaches raise ethical concerns/questions about effectiveness in enhancing students' design capabilities, especially because design problems are pre-defined. In contrast, we believe the primary objective of these courses should be to develop students' abilities to tackle real-world engineering problems through design for the benefit of people. Like Miska et al. (2022), our teaching team endorses "expand[ing] the curriculum beyond the theoretical and technical core concepts to an application-focused, holistic approach" (618) that fuses students' technical and professional skills in an effort to close a gap between academia and industry.

1.2 Student Outcomes Fostered by Multidisciplinary Teaching Team

Our goal in describing each instructor's service design teaching intervention is to outline how we fostered the Accreditation Board for Engineering and Technology (ABET) student outcomes by weaving together our multidisciplinary expertise. For the purposes of this paper, we limit attention to the broader ABET student outcomes, but each of our courses identifies more specific student learning outcomes that align with ABET. We provided instruction stemming from our respective areas of expertise to enable student teams to ideate, prototype, and iterate upon designs that more closely matched user needs. Here we endeavor to show how the engineering curriculum can be improved by a multidisciplinary teaching collaboration such as ours that intersects multiple ABET student outcomes.

ABET requires engineering programs to meet educational objectives that include seven student outcomes (SO), and we argue that our partnered courses, BEE and ENGRC 4590, achieve all seven. Briefly, ABET outcomes that prepare "graduates to enter the professional practice of engineering" include the abilities to:

1. solve complex engineering problems
2. apply engineering design

3. communicate effectively
4. recognize ethical and professional responsibilities
5. function effectively on a team
6. develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. acquire and apply new knowledge ("Criteria for Accrediting Engineering Programs, 2024 - 2025," n.d.)

In particular, SO 4 relates to environmental contexts, which we focused on more in the most recent semester by directing the physical design toward the Environmental Protection Agency's People, Prosperity and the Planet (P3) Student Design Competition. The EPA P3 grant offers funding to "benefit people, promote prosperity and protect the planet by designing environmental solutions that move us toward a sustainable future" (US EPA 2015).

When the teaching partnership between the Biological Engineering Department and the Engineering Communications Program first began, student teams documented their physical design project by writing a patent. The United States Patent and Trademark Office's stringency and highly complex requirements are perhaps well-known, and students often struggled to meet both technical writing and engineering design aspects of patent documents. The anecdote in the introduction also signaled to us that wastefulness and sustainability needed to figure more prominently in the curriculum. Therefore, in 2023, our teaching team discussed another, more suitable lens for the physical design project, and the student teams instead wrote design proposals targeted toward the EPA P3 grant.

2 SERVICE DESIGN AS A CURRICULAR INTERVENTION

After hearing multiple instances of over-engineered designs, Allison Hutchison, the communication instructor, applied her research experience with service design methodology by revising course materials to introduce students to concepts and tools that connect design more carefully to users and their needs, not just technological innovation. We draw upon Polaine, Løvlie, and Reason's definition of service design as a methodology that "is about designing *with* people and not just *for* them" (2013, 41). Service design "is commonly used in the service economy, such as restaurants and hotels, in order to design or redesign services" (Hutchison 2019, ii), but its applicability to engineering design has been treated nominally. According to Kaner and Karni, service design and service engineering hold similar practices (2007). While user-centered design (UCD) or user experience (UX) might be thought of as umbrella terms, service design differs in that it incorporates research to identify service interactions, allowing the researcher to "experience things for themselves that may be hard for someone to describe to them" (Polaine, Løvlie, and Reason 2013, 57). All three methodologies employ research methods such as interviews, surveys, and observations, but service design frames its approach around three main areas: *props, processes*, and *people*. Props consist of any physical or digital artifacts needed to execute the service, processes refer to "Workflows, procedures, or rules needed to perform the service successfully," and people include anyone involved in or affected by the service (Gibbons 2017).

2.1 Communication Instruction

Students in ENGRC 4950 created service blueprints that visualized the props, processes, and people involved in their proposed physical design, as well as a user persona for whom the design was created. Student teams first incorporated their service blueprint in a design proposal. The instructions stated, “The service blueprint shows your persona's user journey, including what is frontstage (what the user interacts with) and what is backstage (what goes on behind the scenes). Consider people, processes, and props in this service blueprint.” For instance, a team who dubbed themselves the Manure Buddies mapped out the user journey of an “environmentally conscious farmer” who “wishes to better understand their manure storage’s volume and environmental impact” (see Figure 1). They identified applicable props, processes, and people in their proposed design to “construct a camera-based device for measuring depth” of manure storage on a dairy farm, including:

- **Props:** manure, livestock, manure storage, camera-based device
- **Processes:** install device in manure storage system, obtain accurate storage volume measurement, obtain emissions estimate
- **People:** dairy farmers, agricultural scientists, agricultural researchers

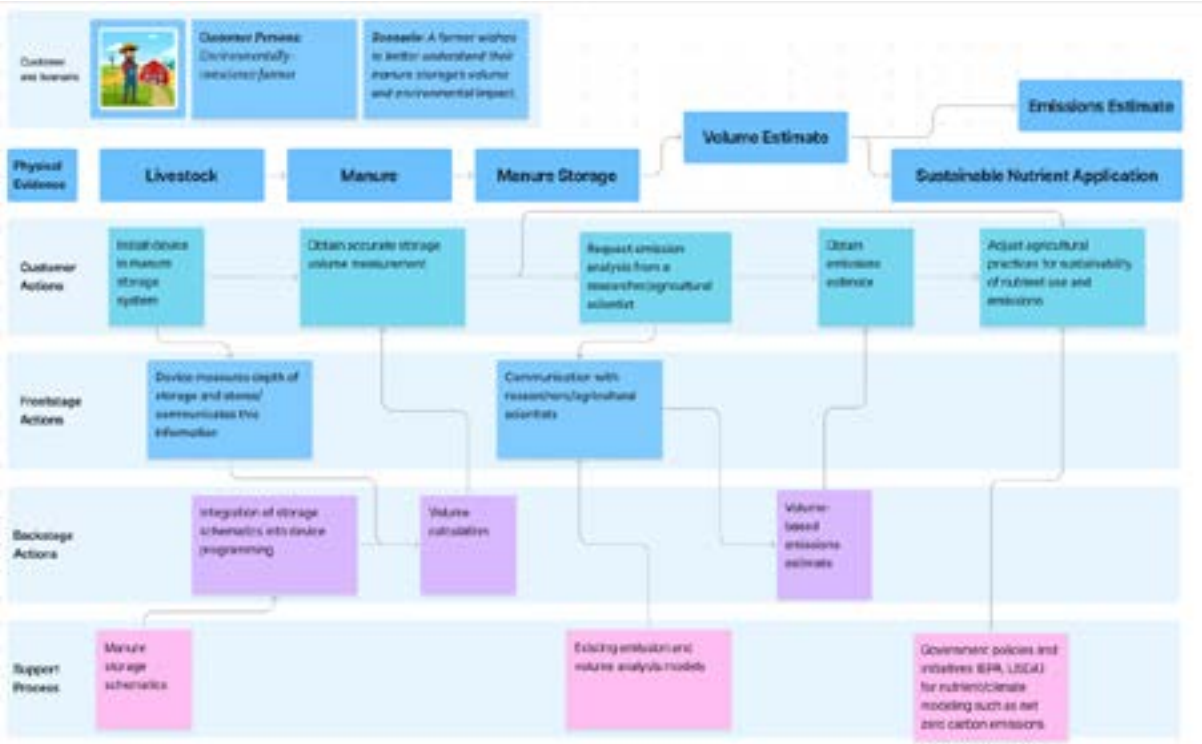

Fig. 1. The Manure Buddies’ Service Blueprint for a Manure Storage Measuring Device. Net zero carbon emissions appear as a support process (bottom right corner, in pink).

Not only did the service blueprint serve as a communication deliverable, evidencing SO 3, but it also showed how the students planned to solve the problem of safely measuring manure storage (SO 1); visualized how they applied engineering design principles through frontstage, backstage, and support processes (SO 2); and incorporated their recognition of the design’s attention to reducing harmful emissions

(SO 4). The team researched several processes in their proposals that particularly relate to sustainability (SO 4), described in more detail in the next section.

2.2 Information Literacy Instruction

The information literacy component was introduced into the BEE/ENGRC 4590 course in 2021 and has progressively increased from research consultations in the library to embedded instructional support to Hutchison by co-teaching the communication course. Initially, Sheley conducted research appointments so students could better understand how to integrate secondary sources that "positioned" their evolving designs in the marketplace, explored features appropriate for particular user groups and environments, and identified similar, existing technologies. However, during our conversations, it became clear that students also needed to stretch their understanding of the real-world contextual factors that could impact their thinking and approach. For example, Sheley prompted discussion about geopolitical factors, data collection methods and evaluation, and potential ethical and moral implications of an engineer's design (SO 1, 4, 7).

To embed information literacy instruction in the communication course, Sheley developed learning outcomes focused on the iterative nature of research and the contextual evaluation of information (SO 7). To achieve these outcomes, they gave lectures on the real-world factors mentioned in the above paragraph and demonstrations on researching the problem central to the design and end user. Additionally, they attended every class to support each phase of the research process, particularly after students were given feedback from course instructors. When students gave presentations about various aspects of their technologies to the class, the assessment rubric included a scoring area focused on using evidence to support their claims, thereby signaling how important research and information were to their design process.

One pain point at this time was the students' tendency to focus heavily on the technology and design, while excluding the problem and the user. Course instructors repeatedly brought those elements frontstage, so Sheley suggested adding user personas to the communications component. Personas are typically defined as "fictional, detailed archetypical characters that represent distinct groupings of behaviors, goals, and motivations" (Calde, Goodwin, and Reimann 2002), and act as stand-ins for real users to help guide decisions about functionality and design (Robertson 2024). They are often used when designers cannot engage directly with end users, due to time, money, or other project constraints (Marshall et al. 2015) and are based on knowledge of real users garnered from user research that identifies customer motivations, expectations, and goals about the target product segment (Bryant and Wrigley 2014, 76). Additionally, personas bring empathy into the design process because engineers focus on the intricacies of a user's journey and behavior (SO 1, 4). One class period was dedicated to introducing this concept and providing suggestions on secondary sources that provided demographic, behavioral, and psychographic information for generating a persona.

As Sheley moved into a co-instructor role, the communication course retained the previously introduced information literacy instruction and research support; however, additional emphasis was placed on user personas to address the *people* element of the service design framework. We also embedded this concept in several places across the course to ensure the user stayed central and to provide scaffolding for the storyboard and video assignments. Each team produced a user persona based on initial research using the secondary sources outlined above. For example, the Manure Buddies team initially identified two users: farmers and researchers. Many teams then talked to a user about their projects and specific needs. This generated new information that was then used to refine their persona and overall design.

We incorporated in-class activities that scaffolded teamwork (SO 5), such as the one depicted in Figure 2, where the Manure Buddies teammates individually sketched storyboard drafts. The goal here was to give all teammates a chance to convey their ideas about the design project to one another, as well as support a subsequent video assignment for the design course. The team then turned these individual storyboards into a unified storyboard that outlined their video. The video demonstrated how their proposed design would allow their intended user persona to measure the volume of a manure storage more safely and, consequently, support more accurate calculations of methane emissions.

Fig. 2. The Manure Buddies Team Drawing Storyboards During ENGRC 4590.

The Manure Buddies' awareness of the effect of methane emissions on climate change increased as the semester progressed. By examining props, processes, and people relevant to their proposed design, they more intentionally matched their design to a user persona and offered an innovative, sustainable solution. The team's initial design proposal stated that their device "would help agricultural researchers reliably estimate CH_4 emissions and see how they change annually," but how gathering more accurate manure measurements could lead to reducing greenhouse gas emissions was unclear. Later, in their EPA P3 proposal, the team expanded their literature review to connect the larger problem of greenhouse gas emissions to the more localized problem of underestimated methane emissions from livestock manure. In that way, gaining a greater understanding of two *processes* (gathering measurements and estimating emissions) allowed them to better situate how their *prop* (an autonomous stereo camera-based device) works for specific *people* (dairy farmers and agricultural researchers). In their words, they developed a "device that can autonomously, continuously, and accurately measure manure storage volumes," fostering cooperation among two groups of people with different areas of expertise to reduce methane emissions that contribute to global warming.

2.3 Biological Engineering Instruction

In the design capstone course, Sunghwan Jung extended invitations to researchers affiliated with the university’s Cooperative Extension. These extensions bridge communities with the university's research, enhancing and empowering neighbors, local businesses, and urban and rural areas. While academic faculty members have proposed various design project ideas in recent years, Jung noted these projects often stem from faculty's own curiosity or research interests, rather than focusing on specific user needs. In contrast, extension researchers have consistently informed design challenges to students, which are directly relevant to agricultural fields and environmental contexts, informed by feedback from farmers, environmental activists, and governments. By consulting with Jason Oliver, PhD, Senior Extension Associate, students gained access to practical knowledge and real-world challenges that are related to community needs and environmental considerations. Therefore, the project they worked on became not only technically viable (SO 1) but also socially relevant and impactful to communities (SO 4).

Adhering to Oliver’s advice, the Manure Buddies implemented service design’s concentration on *people*. The extension researcher’s advisory role significantly informed the Manure Buddies’ development of a user persona for the design and centered the user’s perspective. During Oliver’s initial conversation with the Manure Buddies, the team thought their design would be “just a researcher tool,” so Oliver sought to increase their appreciation of the reality of weekly, state-required manure storage measurements (Jason Oliver, phone call to Hutchison, April 1, 2024). Therefore, in addition to showing the Manure Buddies the manure storage facility on campus, Oliver also connected them to “a farmer with a couple thousand cows to bounce ideas off of” because he “wanted them to have a genuine conversation.” According to Oliver, visiting the campus farm and speaking to a New York dairy farmer “helped students *see* the system and understand the context of why farms invest in manure storages.” This combination of activities enacted service design methodology in that students got their hands (a little) dirty and experienced the problem beyond Oliver’s explanations (cf. Polaine, Løvlie, and Reason 2013, 57).

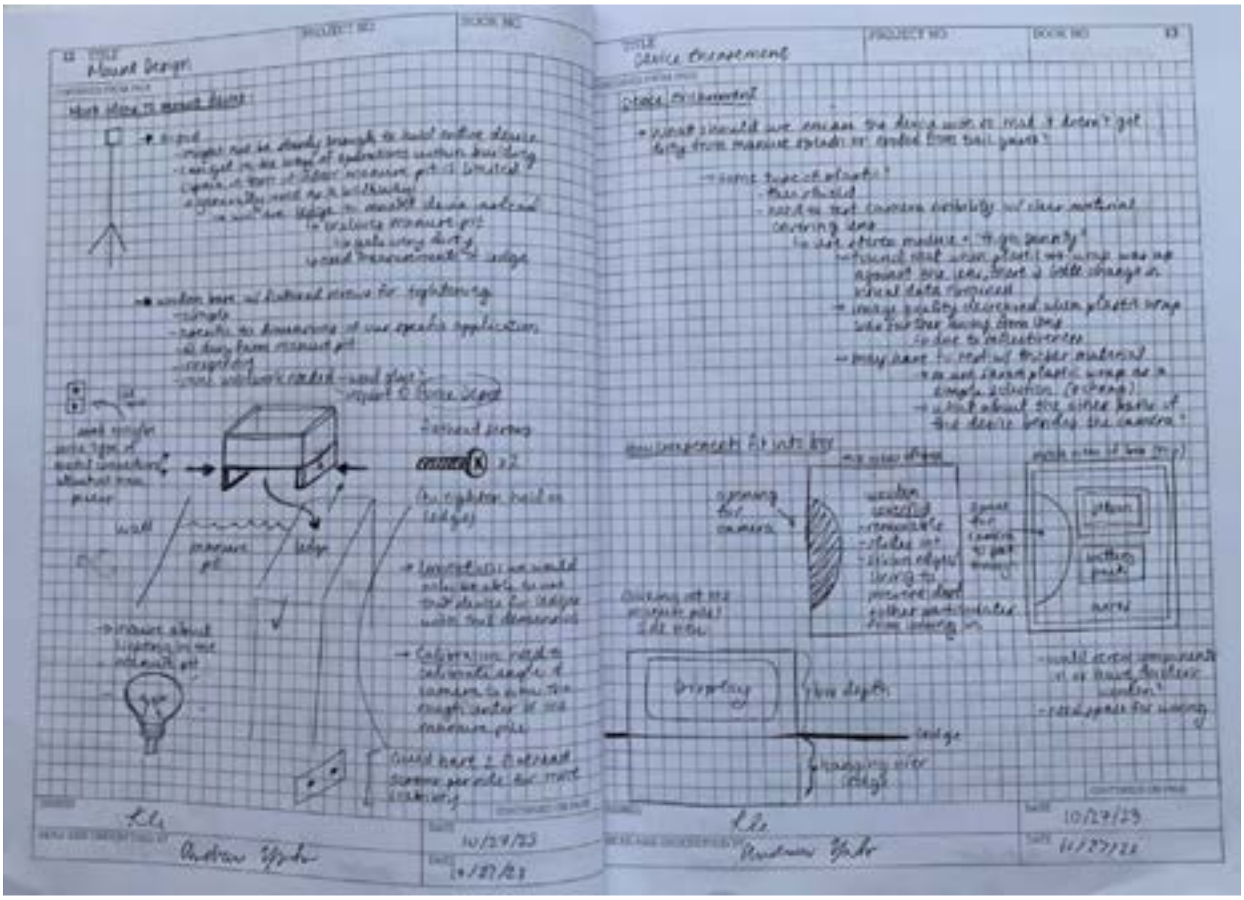

Fig. 3. A Page from Kathy Le's Lab Notebook. It showcases the student's critical analysis and thinking of potential issues (such as sturdiness) related to a simple design (a stereo camera on a tripod) that the Manure Buddies team initially drafted.

Our course emphasizes the maintenance and significance of student laboratory notebooks (see Figure 3). Each student kept an individual notebook and recorded their weekly work along with their team members. After completing their write-ups, peers reviewed and validated the content by signing the bottom of each page. This process allowed students to summarize collaborative work to ensure alignment with their teammates' work. In addition, students documented their data collection and analysis methods, recorded discussions with teammates, advisors, and users, and outlined next steps or potential solutions using their engineering knowledge (SO 6). Instructors examined these notebooks to check students' thought processes during the design phase and practical application of their engineering knowledge (SO 2).

3 COLLABORATIVE TEACHING REFLECTIONS

For undergraduate biological engineering majors to solve complex engineering problems (SO 1) and apply engineering design (SO 2), our experience has shown that embedding communication and information literacy instruction in the curriculum enhances opportunities for students to practice communication (SO 3) and teamwork (SO 5) within the situated context of a hands-on learning environment. We forward this model to improve the engineering curriculum by better responding to growing concerns about sustainability and preparing engineering students to take increased responsibility for socially and environmentally informed designs. An area of future research for our teaching team is seeking student responses to this intervention, such as how service design might impact their work as professional engineers. On the communication course's evaluations, one student shared, "There was a strong emphasis on inventing for a user group, which I found very useful." Another student wrote, "I think that this course is strong in guiding engineers to start with the user in mind rather than simply finding a problem to solve. I liked that the emphasis was creating something useful, rather than just inventing for the sake of inventing."

Finally, we conclude by offering steps for the next partner course design iteration.

Throughout a twelve-year period of teaching the capstone design course at two US-based universities along with instructors in engineering communication programs at both institutions, the biological engineering instructor has modified and advanced the course, transitioning from solely academic, research-driven projects to user-centric projects. This transition reflects the need to develop the course to educate students to address real-world problems and to ensure students not only acquire technical skills but also develop user awareness. With instructors in two engineering communication programs, the design instructor's development and modification of the course will continue to help students to be ready to face and solve the complexities of modern engineering challenges.

Because the focus of the biological engineering design course is moving from research-driven to more user-centered projects, the information literacy component will continue to lean heavily on the user persona within the service design framework. Future instruction will address how to conduct primary, user research (both qualitative and quantitative) to outline a user's nuanced journey. Additional exploration here adds to the information students receive in class and from outside advisors/stakeholders and can be consulted during the design prototyping and testing phases. Furthermore, additional instruction on searching for prior art to identify a wider variety of possible solutions that meet user needs before picking a particular direction will be given. Ideally, this work also supports a more sustainable engineering design process, as students will identify gaps in the marketplace and/or flaws in existing designs earlier and not replicate what is currently available.

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REFERENCES

Artemeva, Natasha, Susan Logie, and Jennie St-Martin. 1999. "From Page to Stage: How Theories of Genre and Situated Learning Help Introduce Engineering Students to Discipline-specific Communication." *Technical Communication Quarterly* 8 (3): 301–16. https://doi.org/10.1080/10572259909364670.

Atman, Cynthia J., Ozgur Eris, Janet McDonnell, Monica E. Cardella, and Jim L. Borgford-Parnell. 2014. "Engineering Design Education: Research, Practice, and Examples That Link the Two." In *Cambridge Handbook of Engineering Education Research*, edited by Aditya Johri and Barbara M. Olds, 201–26.

Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139013451.015.

Bryant, Scott, and Cara Wrigley. 2014. “Driving toward User-centered Engineering in Automotive Design.” *Design Management Journal* 9 (1): 74–84.

Calde, Steve, Kim Goodwin, and Robert Reimann. 2002. “SHS Orcas: The First Integrated Information System for Long-Term Healthcare Facility Management.” In *Case Studies of the CHI2002|AIGA Experience Design FORUM*, 2–16. CHI ’02. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/507752.507753.

“Criteria for Accrediting Engineering Programs, 2024 - 2025.” n.d. *ABET* (blog). Accessed January 8, 2024. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2024-2025/.

Gibbons, Sarah. 2017. “Service Design 101.” Nielsen Norman Group. July 9, 2017. https://www.nngroup.com/articles/service-design-101/.

Guerra, Miguelandres, and Tripp Shealy. 2018. “Teaching User-Centered Design for More Sustainable Infrastructure through Role-Play and Experiential Learning.” *Journal of Professional Issues in Engineering Education and Practice* 144 (4). https://doi.org/10.1061/(ASCE)EI.1943-5541.0000385.

Hutchison, Allison. 2019. “Assessing the Feasibility of Online Writing Support for Technical Writing Students.” Dissertation, Blacksburg, VA: Virginia Tech. https://vtechworks.lib.vt.edu/handle/10919/90375.

Kaner, Maya, and Reuven Karni. 2007. “Engineering Design of a Service System: An Empirical Study: Information Knowledge Systems Management.” *Information Knowledge Systems Management* 6 (3): 235–63.

Marshall, Russell, Sharon Cook, Val Mitchell, Steve Summerskill, Victoria Haines, Martin Maguire, Ruth Sims, Diane Gyi, and Keith Case. 2015. “Design and Evaluation: End Users, User Datasets and Personas.” *Applied Ergonomics*, Special Issue: Inclusive Design, 46 (January): 311–17. https://doi.org/10.1016/j.apergo.2013.03.008.

Miska, Jacob W., Laura Mathews, Jessica Driscoll, Steven Hoffenson, Sarah Crimmins, Alejandro Espera Jr., and Nicole Pitterson. 2022. “How Do Undergraduate Engineering Students Conceptualize Product Design? An Analysis of Two Third-Year Design Courses.” *Journal of Engineering Education* 111 (3): 616–41. https://doi.org/10.1002/jee.20468.

“Over-Engineered.” 2024. Collins English Dictionary. Definition in American English. February 16, 2024. https://www.collinsdictionary.com/us/dictionary/english/over-engineered.

Polaine, Andrew, Lavrans Løvlie, and Ben Reason. 2013. *Service Design: From Insight to Implementation*. Brooklyn, NY: Rosenfeld Media.

Qattawi, Ala, Ala’aldin Alafaghani, Muhammad Ali Ablat, and Md Shah Jaman. 2021. “A Multidisciplinary Engineering Capstone Design Course: A Case Study for Design-Based Approach.” *International Journal of Mechanical Engineering Education* 49 (3): 223–41. https://doi.org/10.1177/0306419019882622.

Reave, Laura. 2004. “Technical Communication Instruction in Engineering Schools: A Survey of Top-Ranked U.S. and Canadian Programs.” *Journal of Business and Technical Communication* 18 (4): 452–90. https://doi.org/10.1177/1050651904267068.

Robertson, James. 2024. “Employee Personas and How to Create Them.” *Step Two* (blog). 2024. https://www.steptwo.com.au/papers/kmc_personas/.

US EPA, ORD. 2015. “Learn About P3 Program.” Overviews and Factsheets. May 19, 2015. https://www.epa.gov/P3/learn-about-p3-program.

MICRO-CREDENTIAL ARCHITECTURE THAT HIERARCHICALLY STRUCTURES EDUCATIONAL SYSTEMS AND INFORMATION TECHNOLOGIES

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ABSTRACT

Micro-credentials offer flexible and targeted approaches to skill development. However, their international exchange and utilization are hindered by a lack of standardization. Herein, we propose a hierarchical architecture and reference framework for Micro-credentials. The hierarchical architecture integrates educational systems with information technology for secure storage, issuance, and exchange of learning records. The framework establishes a common definition of Micro-credentials, reference descriptors for describing them, and quality assurance guidelines. By standardizing these elements, the framework enables learners to compare credentials, employers to evaluate skills, and institutions to design high-quality Micro-credentials. This comprehensive approach paves the way for a global learning ecosystem in which Micro-credentials empower lifelong learning and workforce mobility.

1 INTRODUCTION

1.1 Background

To develop human resources who can respond to rapid changes in industrial structures and promote digital transformation (DX) and green transformation (GX), learning must continue beyond the knowledge acquired in the university. There is a need for reskilling to acquire knowledge and skills in different fields and upskilling to enhance competence in one’s area of expertise.

Micro-credentials have attracted attention in many countries as complementary education to master’s and bachelor’s degree programs, in which students acquire skills in a specific study area in a relatively short period with certified results. Flexible teaching methods, such as online or blended teaching, are employed (OECD2021).

Micro-credentials comprise an educational system, which assures the quality of education, and information technology, which allows learners to securely store and share their learning history. These are interrelated but are considered by different organizations. Educational systems are first developed at the national or regional level (Australia 2021) (European Union 2022) (MQA 2020) (JMOOC 2023), and international mutual recognition can be included. Information technology for the digital issuance of academic records is developed by international standard organizations, such as 1EdTech Consortium (1EdTech 2024).

To design Micro-credentials, share and stack them locally and internationally, and implement their operation with digital data, the roles of educational systems and information technology, as well as their interdependencies, must be well defined.

Herein, we define the structure of an educational system and information technology and propose a system architecture for hierarchically structured Micro-credentials to ensure that Micro-credentials acquired by learners are internationally recognized and used.

1.2 Definition of Micro-credential

A Micro-credential comprises two aspects: the educational program and a proof of its academic record. The definition of Micro-credential varies among countries and regions. Based on the various definitions in various countries, UNESCO reported the following (UNESCO 2022):

(1) A Micro-credential is a record of focused learning achievement verifying what the learner knows, understands or can do.

(2) It includes assessment based on clearly defined standards and is awarded by a trusted provider.

(3) It has standalone value and may also contribute to or complement other micro-credentials or macro-credentials, including through recognition of prior learning.

(4) It meets the standards required by relevant quality assurance.

1.3 Micro-credential architecture that hierarchically structures educational systems and information technology

Micro-credentials comprise educational systems and information technologies that allow learners to securely store and share their academic history.

Herein, we propose an overall system comprising three layers of educational systems (Layers 1–3 on the top) and three layers of information technologies (Layers 4–6 on the bottom). These layers are as follows:

Layer 1: Individual Micro-credentials

Layer 2: National Qualifications Framework and Skill Standards

Layer 3: Micro-credential framework

Layer 4: Interface between the Micro-credential framework and digital certificate issuance technology

Layer 5: Digital certificate. Technology for digital issuance of academic records

Layer 6: Digital format for exchanging academic records. Comprehensive storage and international exchange of academic records.

The rest of this paper is organized as follows; Chapter 2 presents the framework of the Micro-credential (Layer 3), Chapter 3 presents the technical layer of issuing digital certificates (Layer 5), and Chapter 4 describes the details of the Micro-credential architecture.

2 MICRO-CREDENTIAL FRAMEWORK

2.1 Micro-credential framework and the current state of the world

A framework is required to enable learners to compare Micro-credentials issued by various institutions and make appropriate choices, employers to appropriately evaluate Micro-credentials, and guide the design of issuing institutions.

The framework provides a common set of Micro-credential guidelines for learners who want to decide what to study, organizations and institutions issuing and accrediting Micro-credentials, and employers and professional organizations seeking to understand the learning outcomes and competency of their learners and employees. The framework facilitates the development, acquisition, and use of high-quality Micro-credentials.

The standard elements used to objectively and clearly describe various Micro-credentials are called descriptors. Descriptors are the basic building blocks of a Micro-credential framework. Table 1 compares the major international Micro-credential descriptors. The bolded and red items are required descriptors and must be included when describing a Micro-credential. The title of the Micro-credential, awarding body, and learning outcomes and their assessment (type of assessment) are defined, the teaching method (form of participation) and the amount of learning (Total learning time) (Learner Effort). These are prerequisites for a Micro-credential. The rest are recommended descriptors, and their inclusion is optional.

Descriptors in each country are similar but expressed differently. Therefore, translation between descriptors is necessary for the international use of Micro-credentials.

2.2 Proposed Micro-credential reference framework

To facilitate the international exchange of Micro-credentials, we propose a reference framework for Micro-credentials. The reference framework comprises (1) the definition of a Micro-credential, (2) reference descriptors for expressing a Micro-credential, and (3) quality assurance guidelines. Reference descriptors are included in Table 1 to clarify the correspondence between Micro-credential descriptors in each country. The reference descriptors allow for international comparison and reference of Micro-credentials and promote their use across countries by developing a reference framework for collaboration among countries.

Table 1. Proposed reference descriptors for micro-credentials

Proposed reference descriptors	**EU**	**Australia**	**Malaysia**
Identification of the learner	**Identification of the learner**	-	Name NRIC
Date of issuing	**Date of issuing**	-	Date of award
Title of the micro-credential	**Title of the micro-credential**	**Title**	Name of course
Awarding body	**Awarding body**	**Provider**	Awarding institution
Country/Region of the issuer	**Country/Region of the issuer**	-	-
Content/ Description	-	**Content/ Description**	-
Learning outcomes	**Learning outcomes**	**Learning Outcomes**	Learning Outcomes
Form of participation	**Form of participation**	**Delivery Mode**	Mode of delivery Method of learning and teaching
Language	-	**Language**	Language

Learner effort	Notional workload (in ECTS credits, wherever possible)	Learner Effort	Student learning time
Credit/ Other recognition		Credit/ Other Recognition	Credit hours/ equivalent
Type of assessment	Type of assessment	Assessment	Assessment
Type of quality assurance	Type of quality assurance	Quality Assurance	Quality Assurance
Level	Level of the learning experience (EQF)	-	Level of the course
Certification	-	Certification	-
Prerequisites needed to enroll	Prerequisites needed to enroll	Prerequisite/s	Enrolment Requirements
Stackability	Integration/stackability	Stackability	-

(Australia 2021) (European Union 2022) (MQA 2020) (MCJWG 2024)

3 Technology for the Digital Issuance of Academic Records

This chapter describes the relationship between Micro-credentials as a system of education and information technology that issues academic records.

Academic credentials include traditional degrees, such as bachelor's and master's degrees, and nonformal credentials, such as Micro-credentials. Education can be recorded and certified using both paper-based and digital certificates. Figure 1 shows the relationship between these types of certificates.

Digital certificates can be issued as electronic files (e.g., PDF) or digital badges. Digital certificates issued as PDF files with digital signatures are commonly issued for bachelor's, master's, and other degrees. A digital badge is issued for a visual record of knowledge, skills, or experience that can be visually communicated. Digital badges are a popular digital proof of academic achievement, such as Micro-credentials, but they can also be used for participation in events, awards, skills, credentials, and other noneducational applications. An international standard for digital badges developed by the 1EdTech Consortium, an international association, is Open Badges.

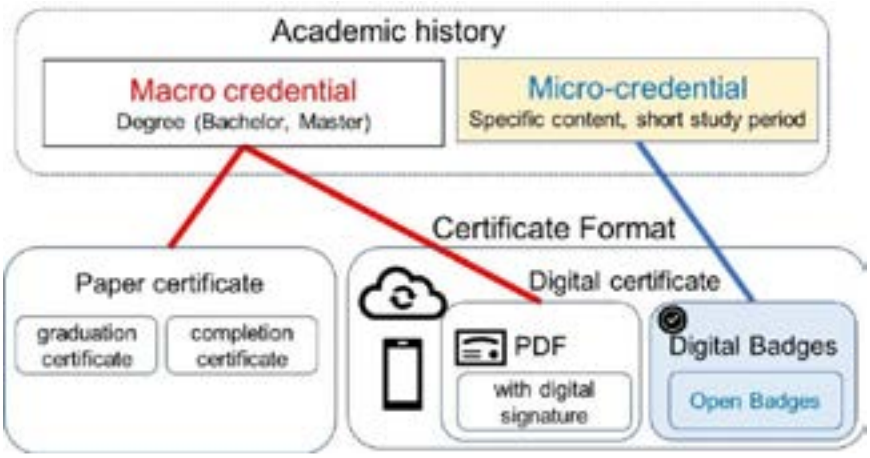


Fig. 1. Relationship between academic history and its means of certification

4 Proposed Micro-credential Architecture

Micro-credentials comprise a mechanism for quality assurance of education and information technology for learners to securely store and share their academic history. To share and accumulate micro-credential internationally and implement its operation with digital data, it is necessary to define the roles of education systems and information technology and design and collaborate internationally on the architecture.

Herein, we propose a hierarchical architecture comprising three layers of educational systems (Layers 1–3) and three layers of information technologies (Layers 4–6), as shown in Figure 2. The following sections describe the layers.

Layer 1: Individual Micro-credentials. Systematically designed individual Micro-credentials are deployed.

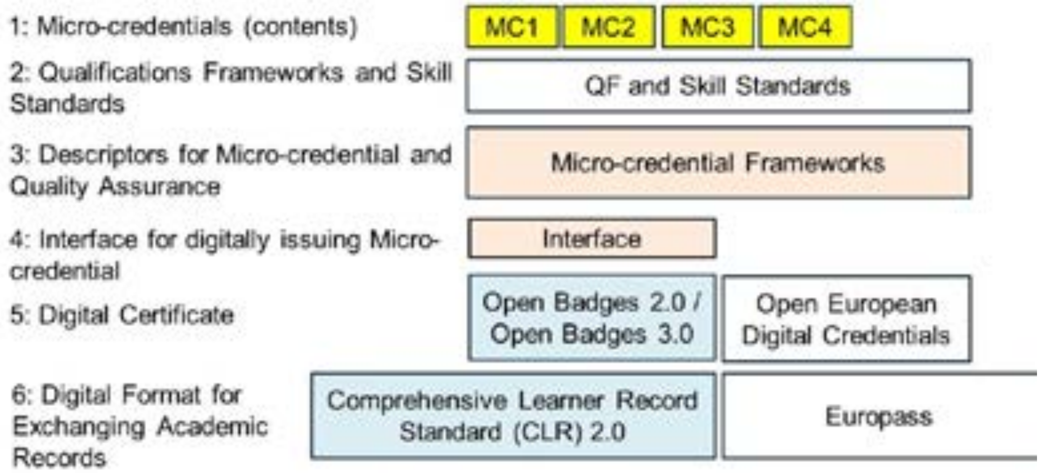
Layer 2: National Qualifications Framework and Skill Standards. The levels of Micro-credentials are defined according to the national qualifications framework and contrasted with the skill standards for each discipline. In addition, the size of Micro-credentials (scope of study) is systematically defined so that Micro-credentials issued by different institutions can be combined and studied without duplication or omission.

Layer 3: A framework for Micro-credentials

Layer 4: Interface layer for issuing digital Micro-credentials. This interface layer inserts the standard descriptors of Micro-credentials (Layer 3) into the metadata of digital technology (Layer 5).

Layer 5: Digital certificate. This is the layer of technologies for digital issuance of academic credentials. Examples include The 1EdTech Consortium's specification, Open Badges, and the European specification, Open European Digital Credential.

Layer 6: Digital format for exchanging academic records. This layer indicates comprehensive learner records, including Micro-credentials and degrees, such as bachelor's and master's degrees. This layer enables comprehensive academic records to be stored and used internationally.



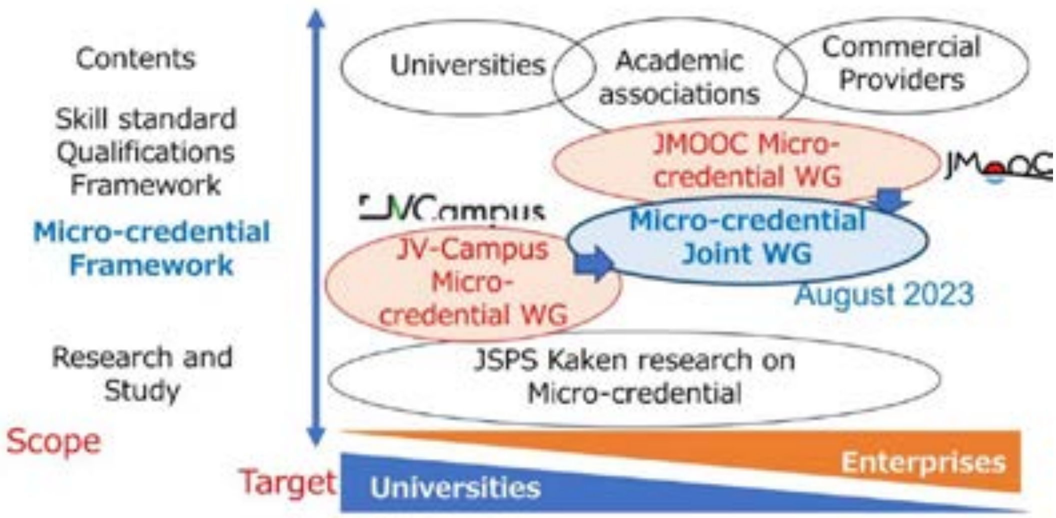
(1EdTech 2023) (1EdTech 2024a) (JMOOC 2023) (MCJWG 2024) (Noda 2023)

Fig. 2. Micro-credential architecture with a hierarchical structure of educational systems and information technology

5 MICRO-CREDENTIALING INITIATIVES IN JAPAN AND INTERNATIONAL COLLABORATION

In 2007, Japan approved the "certificate of completion program" to certify the completion of educational programs that aim at the acquisition of systematic knowledge and skills with a duration of 120 h or more, which is shorter than the time required for a degree. In 2019, the requirement for certification programs was reduced from 120 to 60 h, and universities can now recognize the completion of certification programs as credits toward a degree.

Figure 3 shows the current Micro-credentialing efforts in Japan. The Japan Virtual (JV) Campus, a project subsidized by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), established the Badge and Credential Subcommittee in April 2022, and the Japan Council for Open Online Education (JMOOC) established the Micro-credential Working Group in June 2023. The subcommittee of JV-Campus and the JMOOC working group formed a Micro-credential joint working group in August 2023 (JV-Campus 2023) and published "Micro-credential Framework" and "Guidelines for Issuing Micro-credentials Digitally" (JMOOC 2023) (MCJWG 2024).

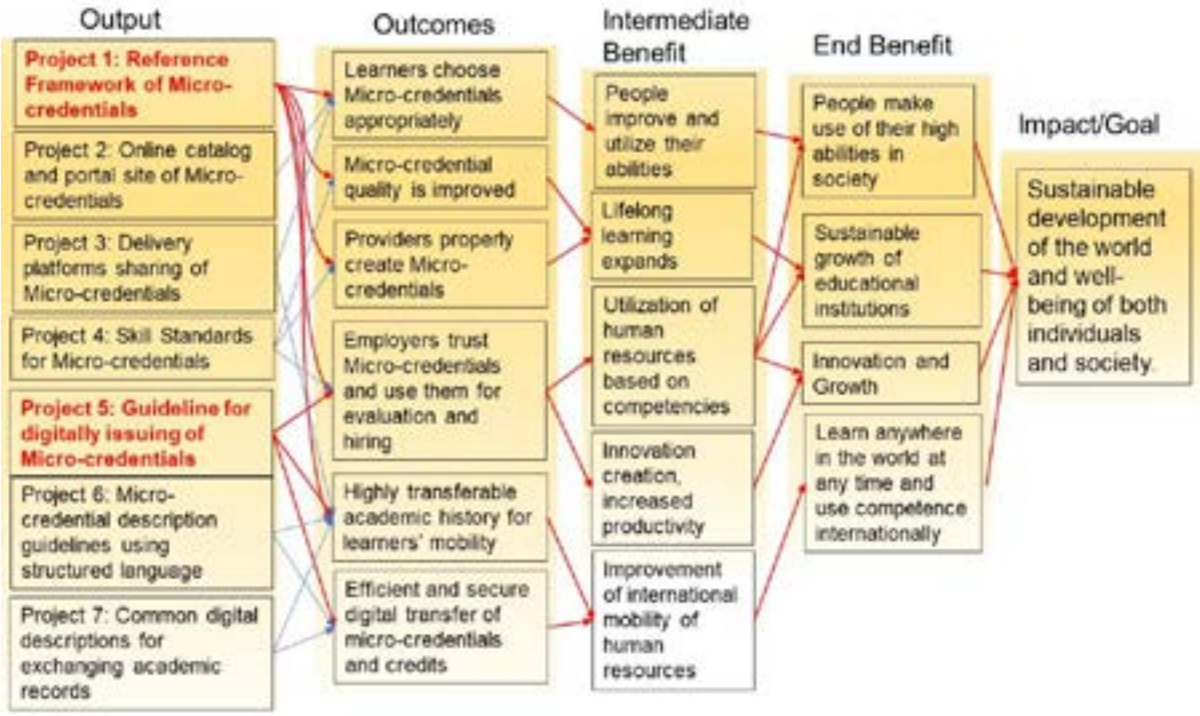


(JMOOC 2023) (JV-Campus 2023) (MCJWG 2024)

Fig. 3. Current Micro-credentialing initiatives in Japan

6 DISCUSSION

6.1 Value and Impact of Micro-credentials and their Architecture



(1EdTech 2024a) (JMOOC 2023) (MCJWG 2024)

Fig. 4 Value and Impact of Micro-credentials and their Architecture

Figure 4 shows the impact of promoting Micro-credential projects along the proposed architecture and reference framework. Projects 1 and 5 are promoted by the JV-Campus/JMOOC Micro-credential joint working group, and the results was made public in April 2024. They also promote international collaborative activities. Micro-credentials and their architectures promote global sustainable development and the well-being of both individuals and society.

6.2 Structuring educational systems and information technologies

To structure educational and information systems and evaluate the adequacy of their architecture, conditions and cases that affect the architecture are investigated, and the responses of to such cases are elucidated. Several cases are presented and discussed below.

(1) Cases in which information technologies differ by country or region

The U.S. and Japan use 1Edtech's Open Badges as their information technology, whereas Europe uses the Open European Digital Credentials.

If micro-credentials are built on equivalent educational systems and have equivalent descriptor schemes, then micro-credentials can be shared and transferred. However, because of differences in information technology standards, digital data differs between the U.S./Japan and Europe. There are two responses to this case. (a) The international postal and mail model: In this model a micro-credential is relayed as a payload to different information technology standards. In this case, each user only needs to support the local technology standard. (b) The Internet model: On the Internet, users use multiple applications such as e-mail and social networking services. In this case, the user simultaneously has multiple information technology standards to handle micro-credentials. A user's wallet contains multiple micro-credentials, which use multiple information technology standards.

(2) Cases where the framework differs by country or region

Micro-credentials are translated using a reference framework. Each country has a different framework. When transferring micro-credentials across national borders, the originating side sends data that is converted using a reference descriptor. The receiving side receives the data with the reference descriptor and converts it into the home country's descriptor if required.

7 Conclusion

The proposed architecture establishes a hierarchical structure with three educational system layers and three information technology layers. The educational system layers define individual Micro-credentials, ensure alignment with national qualifications frameworks and skill standards, and establish a Micro-credential framework. The information technology layers address the digital issuance and exchange of learning records. This design facilitates the international recognition and use of Micro-credentials.

To promote global adoption, we propose a Micro-credential reference framework comprising a common definition of Micro-credentials, standardized descriptors for describing them, and quality assurance guidelines. This standardization enables learners to effectively compare credentials, employers to accurately evaluate skills, and institutions to design high-quality Micro-credentials.

By integrating these educational systems and technologies, the proposed architecture would pave the way for a global ecosystem for effective lifelong learning. Micro-credentials issued under this framework can empower individuals to continuously develop their skillsets, remain competitive in the workforce, and pursue their learning goals throughout their lives.

REFERENCES

1EdTech. “Comprehensive Learner Record Standard, Candidate Final Public, Spec Version 2.0.” January 26, 2023. https://www.1edtech.org/standards/clr.

1EdTech. “Open Badges Specification Final Release Spec Version 3.0.” May 27, 2024a. https://www.imsglobal.org/spec/ob/v3p0/.

1EdTech. “Competencies and Academic Standards Exchange (CASE).” Accessed March 31, 2024b. https://www.imsglobal.org/activity/case#Public.

Australia. “National Microcredentials Framework.” Department of Education, Skills and Employment, Australia, November 2021. https://www.dese.gov.au/higher-education-publications/resources/national-microcredentials-framework.

European Union. “European Digital Credentials Infrastructure (EDCI).” European Union. 2021.

European Union. “Proposal for a Council Recommendation on a European approach to micro-credentials for lifelong learning and employability- Adoption.” European Union. 2022.

Inoue, M., Tsunoda, K., Nagahara, Y., Yaegashi, R., Ishizaki, H., Tsujino, K., Maruyama, T., and Ashizawa, S. “Digital Transformation of Engineering Education and Initiatives of Micro-credential.” *Japanese Journal of Engineering Education.* Vol.1, No.4, pp. 4_7-4_12, 2023. https://doi.org/10.4307/jsee.71.4_7.

JMOOC. “Draft framework and guidelines for micro-credentials.” October 5, 2023. https://www.jmooc.jp/20231005_announcement/.

JV-Campus. “Regarding the establishment of the Micro-credential Joint Working Group.” August 18, 2023. https://www.jv-campus.org/en/newslist/353314/.

MCJWG. “Micro-credential Joint Working Group.” Accessed Juen 8, 2024. https://www.micro-credential-jwg.org.

MQA. “GUIDELINES TO GOOD PRACTICES: MICRO-CREDENTIALS,” Malaysian Qualifications Agency, 2020.

Noda, A. “Exploring the possibilities and challenges in developing the Japanese qualifications framework.” *Higher Education Evaluation and Development*, 17(2):82-95, 2023.

OECD. “Micro-credential innovations in higher education Who, What and Why?.” OECD Education Policy Perspectives, 39(22), 2021.

UNESCO, “Towards a common definition of micro-credentials.” 2022. https://unesdoc.unesco.org/ark:/48223/pf0000381668.

INTEGRATING ETHICS OF CARE INTO ENGINEERING EDUCATION

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ABSTRACT

We introduced Care Ethics to enhance empathy and perspective taking in a second-year Engineering and Society course. Care is a practice and a mindset, so we guide students to move from self interest to caring: identifying the need for care, taking responsibility for care, developing competence to care, and receiving and assessing care (from Tronto, 1998). Situating care ethics in discussion of artificial intelligence (AI) opens concepts of moral distance and interconnectedness, while examining care ethics in the context of sustainability allows students to consider the extension of care to more-than-human actors. Activities help students consider perspectives including the environment or most vulnerable.

Our experience suggests (1) starting from an interest enhances engagement and uptake. (2) Students struggle to enact care because they see it as just "something you do". (3) Empathy and care require emphasis to enable students to permit themselves to enact empathy and care in professional work.

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Although activities in a course are distinct from developed ethical practice, we create the potential for moral and ethical growth. Helping students to integrate empathy into their ethical reflexes can help develop a mindset of care.

1 INTRODUCTION

While care is embedded formally in professions such as medicine and nursing, it has received less explicit emphasis in engineering, despite the relationship between engineering work and critical social issues (Campbell et al, 2012). This paper explores our experience integrating care ethics into a mandatory second-year course about Engineering and Society at a large North American university. The course serves as students' first experience with social sciences in their engineering education through an in-depth consideration of the impact of technology on society and the environment. It also builds on their first-year experience in engineering design. We have situated care ethics in discussions of ethics in Artificial Intelligence due to interest in the field and the future career paths of students in the class, and in discussions of sustainability given the critical nature of the climate crisis and our collective responsibility to consider it. The goal of the paper is to explain how learning outcomes are being achieved thereby improving our ability to support students in developing into caring engineers.

The course involves lectures, readings, and weekly small-group discussion seminars. For the past eight years, we have incorporated ethical reasoning into the course as part of the over-arching conceptual structure that gets enacted throughout the course, i.e. it is not just taught and dropped, but becomes central to our examination of all sociotechnical issues. Our motivation to build the ethical framework in the course derives from an understanding that "effective ethical reasoning requires both some specific knowledge of morality and ethical frameworks as well as some reasoning skills" (Beever and Brightman, 2016: p.278). This pedagogical underpinning requires reaching past ethics education as case-based, code-based, or theory-based. Students need to develop a character of ethical awareness and understanding; that is, they require virtue with its emphasis on the character of the decision maker.

Care has emerged more recently in engineering education because it seems well situated to enhance empathy and perspective taking to address ethical concerns in design (Pantazidou and Nair, 1999). In practice, human-centred design approaches entail empathetic perspective taking through listening, identifying underlying causes of needs, and increasing resources and opportunities for those in need (Leydens et al, 2014), so virtue and care ethics offer appropriate means to develop necessary engineering attributes.

2 DEFINING ETHICS OF CARE

Care ethics is related to virtue ethics in that both are concerned with character. "A care ethic emphasizes the importance of responsibility, concern, and relationship over consequences or rules" (Nair and Bulleit, 2020: 78). Essentially, virtuous relations guide right action, rather than right action demonstrating virtuous character. Care ethics received its first unique articulation by Carol Gilligan (1982) as a feminist response to the unempathetic, utilitarian, analytical reasoning in favour at the time.

Tronto (1998) has offered a usable articulation of care ethics, as evidenced by its relevance across a range of engineering contexts including teaching design and problem-solving methodologies (Pantazidou and Nair, 1999), sustainability (Campbell 2013), and as a critical component of professional practice (Kardon 2005). Further, the application of care ethics to engineering provides an opportunity to reinforce a motivation towards equity, and to broaden interest in participating in engineering if it is framed as a caring profession (Campbell, 2013).

Tronto articulates four moral elements of care – attentiveness, responsibility, competence and responsiveness – which correspond to four phases of a practice of care, noting the development and deepening of commitment to community that they entail:

- recognizing the need for care. At this point, empathy shapes the caring act as the individual sees an opportunity to care: "They need help/care."
- taking responsibility for care. The second stage becomes more personal as the individual takes ownership of the care: "I need to provide care."
- having competence to care. This level is the most challenging aspect because the individual must assess their own assets and abilities to help (and not harm) in a situation: "I can provide care."
- receiving care. Here, the caregiving individual can assess the efficacy of the care as received. In relationship with the party receiving care, they can ask questions: "Is this helpful? Does the nature of care need to change?

Care starts in character but is embodied in praxis. The caring mindset involves recognizing one's place in a network of actors and developing an orientation toward responsiveness that moves beyond rules or calculated outcomes to consider the vulnerable and the voiceless (Villegas-Galaviz & Martin, 2023). Further, Tronto (1998) suggests an integration of phases to deepen the practice of care and working through the possibility of conflicts unique to the context.

3. OUR APPROACH

Developing care through a balance of theory and application should bolster students' ability to begin to make ethical judgments. We begin with ethical reasoning to ground our approach to ethics. Then, we define care ethics simply "an act is right if it promotes deeper attentiveness to each other and the community" including the environment (Whyte & Cuomo, 2015). Using Tronto's framing and specific examples ranging from micro to macro ethics, we seek to build an understanding of care ethics in our students and given them an ability to enact care in their ethical reasoning process.

3.1. Building Care Ethics from Ethical Reasoning

Our commitment to ethical reasoning led us to adopt Beever and Brightman's 'reflexive principlism' (2016). The approach comes from applied medical ethics and specifies a limited set of virtues (principles), which allow for focused reasoning. The iterative aspect is aimed specifically at engineering. Stated briefly, reflexive principlism offers structured ethical reasoning using four principles:

- respect for autonomy, upholding the rights and the dignity of individuals,
- beneficence, actually doing good,

- justice, ensuring an appropriate sharing of risks and benefits across the actors in the ethical situation, and
- non-maleficence, avoiding doing harms.

From these principles, reasoning involves specification and balancing. Specification is the process of moving from the abstract to more determinate understanding of the principle in each situation. Balancing, in turn, is a process of adjudicating conflicts between principles as they have gained power through specification (Beever and Brightman, 2016). We have found that, through reading Beever and Brightman's paper and classroom discussion, students easily grasp the four principles and see their reasoning power in action. They are less able to reach to the stage of balancing between conflicts—a factor that could result from students' lack of ethical commitments or the limitations of the classroom (including time, subject knowledge, and our teaching of the concept).

We began to incorporate care ethics into our discussion for three main reasons: first, we saw it as a way to expand students' awareness of justice beyond the obvious actors in a network. Second, we sought to use it to engage the students with other voices particularly Indigenous ways of knowing. Third, we saw care as complementary to reflexive principlism, encouraging specific types of balancing to help the students consider the process of ethical action-taking as a human activity requiring care within relations.

Since engineering remains a largely analytical field, we looked for means to allow students to develop care, including permission to feel. Indigenous writer, Kyle Whyte notes that: "Feminist and indigenous conceptions of care ethics offer a range of ideas and tools for environmental ethics that are helpful for unearthing deep connections and moral commitments, and for guiding environmental decision making" (Whyte and Cuomo, 2015, p.243). Since the environment and sustainability are already well-integrated into the course, we saw this as a meaningful point of connection. More recently, we have extended the incorporation of care to concerns about AI.

3.2. Introducing Care Ethics to Students

After students are introduced to ethics and ethical reasoning, including virtue ethics and reflexive principlism, we commence a week of study on the concept of care ethics. In lectures, key concepts are introduced, alongside examples so students can start to apply these concepts.

To support our discussion of care ethics, we recently added the reading, "Moral distance, AI, and the Ethics of Care" by Villegas-Galaviz and Martin (2023) to connect care ethics to computational technologies and artificial intelligence, which are areas of interest to many of our students. The article wrestles with the concept of moral distance with respect to AI, something the students see as worthwhile and important. So, it creates buy-in to the concept of care. Additionally, it provides a specific orientation to ethical reasoning that links our interconnectedness with the need to attend to the vulnerable and voiceless. Then, as we begin to explore sustainability, students read an article that raises the concern of care for more-than-human actors through the lens of Indigenous ways of knowing (Todd, 2017). These two readings in particular offer an overview of care as a concept and expand student understanding of to what and whom care should be extended.

In the first seminar on care ethics, we use a sequence of cases that allow students to move outwards from their immediate circle to understand the nature, benefits and limits of care. Students were encouraged to use the framing of care ethics from Villegas-Galaviz and Martin (2023), which draws from Tronto's elements and phases of care, to consider care in the cases. For each of Villegas-Galaviz and Martin's four framings, we developed a set of questions to prompt student thinking and discussion, and to scaffold a 'way of being' that can be difficult to articulate.

- Interdependent Relationships: who or what is in the context (or web of relations), and what are the key relations? Who needs to be considered? How can we act in a way that is responsive to the needs of others?
- Context and circumstances: What is unique about the context/circumstances that requires care? How might another circumstance require a different response? How do we need to be responsive to the needs of "particular" others?
- Vulnerability: Who is vulnerable in the context/circumstance? What are the risks to those who are vulnerable? How can those risks be mitigated?
- Voice: who or what needs to be given a voice? How can we give voice to every affected part of this context/circumstance? How do we engage in the relational act of listening and bringing close?

In seminar, we start our exploration of care with a microethics case relevant to their own life as an engineering student:

> *Your friend in (your program) is having a rough go of things – they are dealing with some major family challenges and trying to balance the tough workload of (the program) with a part-time job. It's week 4 of the semester and suddenly, things have gotten really busy. They ask you to copy your thermodynamics problem set, which your professor has asked you to complete independently.*

After considering a 20 second "gut decision", students are asked to map out the actors in the network and consider the prompting questions noted above, giving them scaffolding to articulate how they have considered care in their decision-making. After this, students are invited to participate in a brainstorm to share the ways they "show care" in their lives: as a person and as an engineer-in-training. These warm-up activities provide an opportunity for students to connect care to familiar experiences. The brainstorm exposes how care is something we consider more easily for those in "close proximity" to us, drawing from the concept of moral distance in the reading. In these activities, students value the opportunity to share their own notions of care and how they extend care to those around them.

Next, we move to a case beyond their own sphere of direct experience, using a classic robotics ethical dilemma (Open Roboethics Institute, 2015):

Emma is a 68-year-old woman and an alcoholic. Due to her age and poor health, she is unable to perform everyday tasks such as fetching objects or cooking for herself. Therefore, she purchased a care robot. Her doctor advises her to quit drinking to avoid worsening her condition. When Emma commands the robot to fetch her an alcoholic drink, should the care robot fetch the drink for her? (A second version of the case has the robot provided to Emma through a funded healthcare program).

Students are initially introduced to this case in lecture while discussing reflexive principlism, which elucidates interesting perspectives around the principles of justice and autonomy. In re-examining this case, students are encouraged to consider whether a specific attention to care ethics changes their approach, and what actions might lead to a caring/ethical result. It's worth noting that as students examine this case, they don't necessarily change their response to the question of whether the robot should fetch the drink but do generate new considerations about how to approach this challenge in a way that demonstrates care, for example: programming the robot to respond in a way that demonstrates care, re-considering the relationship between the robot, Emma and her care team, or generating new ideas on the resources Emma may need to live a healthy life.

Finally, students are re-introduced to macroethics case studies that were shared in the previous week: one exploring the use of AI to create "griefbots" based on the personalities and communication patterns of the deceased, and one on use of AI in recidivism. However, this time, rather than consider care ethics as an alternative to reflexive principlism, we encouraged students to consider how reflexive principles and care ethics can be brought together in service of the development of responsible AI, giving them the scenario that they are hired by a large AI firm to head up the "responsible AI" initiative at the company, and are responsible for creating a set of guidelines for company management on how to encourage ethical thinking.

As students move further away from their personal sphere of "care", they are more challenged to apply the concept. However, the concept of moral distance helps them to make sense of this, acknowledging that as we find ourselves further removed, through distance, time, bureaucracy or otherwise, we struggle to understand the reciprocity that exists between, for example, those who design an algorithm or a care robot, and those who implement that robot in the field.

3.3 Application through the Course

Early in our discussion of sustainability, we engage in a critical examination of the role of oil and gas in our sociotechnical world. To provide immediacy to the discussion—and create a context in which care becomes important—we introduce the students to the case of the Coastal Gaslink (CGL) Pipeline Project, a recent and contentious oil and gas project in Western Canada. The multi-billion-dollar project involves construction of a pipeline to transport fracked and liquified natural gas (LNG) from a gas field in northeastern British Columbia, Canada, to the small coastal city of Kitimat, BC. From there, LNG is shipped to international destinations. The pipeline is contentious because it traverses land claimed by indigenous peoples. Most significantly, it crosses the land of the Wet'suwet'en people. This land was never ceded to Canada under any treaty and remains the subject of land claim disputes in Canadian courts. Indigenous protesters have resisted and blocked the pipeline construction. In turn, they have been arrested and subjected to police violence and intimidation. In working through the case in lectures, we provide detailed background on numerous stakeholders—the company, elected and the hereditary Wet'suwet'en chiefs, local, provincial and federal politicians, and various environmental systems.

We also look at the conflict within Wet'suwet'en society with its elected and hereditary chief structures (the former a fixture of colonialism, the latter traditional self-government). Whereas the elected chiefs have approved the pipeline seeing employment opportunities and financial benefits, the hereditary chiefs have opposed the pipeline because it violates sacred lands and relationships with more-than-human actors.

In the seminars, we have a set of activities for the students. In groups of two, they are assigned to examine the case using either reflexive principlism or ethics of care. They try to determine the key ethical considerations by either approach. Then, paired with a team using the other approach they look for commonalities and differences in findings. The students are prompted with questions to deepen their thinking:

- What challenges came up in balancing dimensions of the case?
- Can care be applied across all actors? Did you find yourself prioritizing care for a particular group or need?
- Do we need to consider the possibility that coercion is used to greenlight projects like this? How does this differ from consent?
- Several more-than-human (environmental) actors were included in the network. How far are you willing to spread inclusion of other species?

In the process of these discussions, students begin to confront their own limits of care, as many prioritize LNG extraction over the environment and struggle to accept the idea that more-than-human actors have any standing in ethical considerations. Students want to claim that they care for the vulnerable, but when confronted by the moral distance of a different species (plants, animals) or remote people (the Wet'suwet'en) they struggle to care. The mere fact of this struggle reveals the students' ethical commitments to petro-capitalism rather than (broadly speaking) environmental care. Of course, some students do incorporate care for others and other species into their ethical reasoning, and in doing so they become advocates for care, and exemplars of a deeper care ethic.

As a second example, later in the course, we explore technological unemployment as a byproduct of the pace of technological development. Through examining case studies of technological job loss due to automated manufacturing or self-driving cars, students are encouraged to apply care ethics to investigate particular dimensions of the cases; for example, what roles/functions should be automated and what should remain the work of humans? How should we best support people whose work is displaced through technological unemployment? And should we mitigate economic inequality and labour disruption caused by technological development? Our impression is that framing ethical thinking as "care" helps learners broaden their thinking about what and who to attend to in such circumstances. It has particular salience for students to conceive of their own work as displacing others.

Throughout the course, we encourage students to broaden their perspective and to see the "particular other" (Schmidt, 2014), who needs care for reasons of vulnerability or lack of voice. By opening students to building their basis for empathy, we hope to engender (or more often legitimize pre-existing) compassion that can be enacted as caregiving when the situation is appropriate.

4 OUTCOMES AND REFLECTIONS

We acknowledge that activities in a course are a long way from an embodied mindset lived out in praxis. Empathy and care are learnable but require development. Our activities help students build a process to actualize care. They consider other perspectives and discuss the challenges in the perspective of the "particular other"—the person, group, or entity (including the environment) most vulnerable in any situation. While taking such perspectives may be new, it encourages students to understand the situation more holistically.

Our experience suggests three insights. The first should probably have occurred to us before we started with care ethics, as it is a truism of teaching. It is this: rooting the concept in an area of known interest to students deepens engagement. Specifically, placing care ethics in questions around AI enhanced interest and willingness to reason through a "care lens". Initially, we only considered care ethics in terms of the environment, but we found the students less disposed to engage in the personal challenge of considering others in need of compassionate care. By reframing the questions to focus first on AI using the reading from Villegas-Galaviz and Martin, we have found students more open to asking questions and considering their own ethical positions. Given that care ethics involves developing a mindset, openness is critical to engagement.

Second, even when willing, students struggle to apply care to engineering work, in part due to an implicit belief that care is just "something you do". As such, it does not feel as rigorous as a code that can be assiduously applied or a theory that can be referenced. Ironically, this "caring" thing we just do, asks more of us because it asks us to be particular kinds of people with particular ethical commitments. Developing such commitments as an undergraduate student takes time and awareness. We can only begin to help students along that process.

Finally, unlike other concepts, care seems to require emphasis to validate it with students—and often the question is how to permit themselves to bring their empathy and care into the professional sphere. Schmidt (2014) offers strong grounding for doing so as he focuses on the aspirational goal of engineering as being contributing to everyone's "material well-being." Framing that as the goal of engineering creates an opening for students to examine what ethical character such an objective requires.

Because care ethics emphasizes attentiveness to the various actors requiring care, we argue it helps students to cast a wider net in understanding who must be considered. This is especially important in complex systems like the environment or artificial intelligence with various actors and relations to consider, widely variable moral distance, and ethical decisions being made in significant uncertainty and ambiguity.

5 CONCLUSIONS

Activities in a course are distinct from developed ethical practice; however, by providing an opening to explore and enact care ethics, we create the potential for moral and ethical growth. Helping students to integrate care into their ethical reflexes can help them to acknowledge the moral distance and seek to minimize it through empathy and care.

Validating care is an ongoing challenge. So much of engineering education is concerned with analytical "doing", while care ethics asks students to develop ways of "being"—that alone makes ethical development uncomfortable and unfamiliar to students. We have sketched several different ways of framing care ethics (Tronto, Villegas-Galaviz and Martin, Whyte and Cuomo), but we continue to struggle to reconcile the different framings and guide students into a coherent means to deepen their sense of care. Even so, we can see it infiltrate students' ethical reasoning processes through assignments, through course discussion, and even through their design work in a subsequent design course.

We need further interrogation how to connect care to other approaches to engineering ethics, how to bring it into engineering work. We trust that if you hold care and consider others with care you are doing something important, worthwhile and relevant to engineering. Like Carol Gilligan, we are attempting to give language and conceptual richness to something that is taken for granted by, but little embodied in students. By seeking to elevate a different voice—many different voices—we aim to encourage students to hear the vulnerable and pay attention to the voiceless in the pursuit of the highest aspirations of engineering as a noble profession.

REFERENCES

Beever, J. and A. Brightman, "Reflexive Principlism as an Effective Approach for Developing Ethical Reasoning in Engineering." *Sci Eng Ethics* 22, (2016): 275–291. DOI https://doi.org/10.1007/s11948-015-9633-5

Campbell, R.C. "How can engineering students learn to care? How can Engineering faculty teach to care?" *Engineering education for social justice: Critical explorations and opportunities* (2013): 111-131. https://doi.org/10.1007/978-94-007-6350-0_6

Campbell, R. C., K. Yasuhara, & D. Wilson. "Care ethics in engineering education: Undergraduate student perceptions of responsibility". *Frontiers in Education Conference Proceedings*, (2012): 1–6. https://doi.org/10.1109/FIE.2012.6462370

Gilligan, C. *In a Different Voice: Psychological Theory and Women's Development*. Harvard UP, 1982.

Kardon, J.B. "Concept of "care" in engineering." *Journal of Performance of Constructed Facilities* 19, no. 3 (2005): 256-260. https://doi.org/10.1061/(ASCE)0887-3828(2005)19:3(256)

Leydens, J., J.C. Lucena, and D. Nieusma. "What is design for social justice?" *2014 ASEE Annual Conference & Exposition Conference Proceedings*, (2014): 24-1368.

Nair, I. and W.M. Bulleit. "Pragmatism and care in engineering ethics." *Science and engineering ethics* 26 (2020): 65-87. https://doi.org/10.1007/s11948-018-0080-y

Open Robotics Institute, https://openroboethics.org/results-should-a-carebot-bring-an-alcoholic-a-drink-poll-says-it-depends-on-who-owns-the-robot/

Pantazidou, M. and I. Nair. "Ethic of care: Guiding principles for engineering teaching & practice." *Journal of Engineering Education* 88, no. 2 (1999): 205-212. https://doi.org/10.1002/j.2168-9830.1999.tb00436.x

Schmidt, J.A. "Changing the Paradigm for Engineering Ethics." *Science and Engineering Ethics,* 20, (2014): 985–1010. DOI https://dio.org/10.1007/s11948-013-9491-y

Todd, Z. "Fish, kin and hope: Tending to water violations in Amiskwaciwâskahikan and Treaty Six Territory." *Afterall: A Journal of Art, Context and Enquiry* 43, no. 1 (2017): 102-107. https://doi.org/10.1086/692559

Tronto, J.C. “An Ethic of Care.” *Generations: Journal of the American Society on Aging,* 22. no. 3 (1998):15-20.

Villegas-Galaviz, C. and Martin, K. “Moral distance, AI, and the ethics of care.” *AI & Soc* (2023): 1-12. https://doi.org/10.1007/s00146-023-01642-z .

Whyte, K. and Cuomo, C. “Ethics of Caring in Environmental Ethics: Indigenous and Feminist Philosophies” In S. Gardiner, (Ed) *The Oxford handbook of environmental ethics.* pp. 234-245. Oxford UP, 2015.
https://doi.org/10.1093/oxfordhb/9780199941339.013.22

Project-Based Learning Approach for an Engineering Course: Challenges and Learnings of Teaching Transversal Skills

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ABSTRACT

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Project-based learning (PBL), as one of the effective teaching and learning approaches in engineering education, can create opportunities for students to address problems with real-world applications, integrate and apply knowledge, and practice and develop transversal competencies such as teamwork and communication. However, with the common emphasis on final products and a lack of explicit attention to transversal competencies in designing and teaching PBL courses, the benefit of PBL in facilitating the development of transversal skills is under question. In this paper, we use a critical lens to examine a project-based course offered at a polytechnic university in Switzerland, EPFL, and explore structural elements that are important in facilitating the development of transversal competencies. We describe the structure of the PBL course, Mechanical Product Design and Development, that was recently conceived and received positive feedback from students, report on ways transversal competencies were addressed, and reflect on lessons that can be learned from the praxis, informed by the literature, to avoid missing opportunities to support students in developing transversal competencies.

1 INTRODUCTION

Within the last three decades, there has been growing attention to the importance of effective teaching and learning approaches to help engineering students develop the competencies required to address problems in work settings and live in today's world. Initially, in response to outcome-based education and later with the increasing evidence from learning sciences as well as funding opportunities for engineering education research, students' learning became the center of attention in pedagogical design and development, and incorporating student-centered approaches became common within engineering curricula. Project-based learning (PBL) is one such approach that has been frequently used, especially in the context of first-year engineering courses and capstone design. In this practice paper, we focus on a project-based course offered at EPFL, discuss how the course provides opportunities for enhancing transversal competencies, and reflect on limitations and possible improvements for incorporating PBL in engineering curricula, more specifically concerning transversal skills.

PBL is centered around a project that students need to address through collaborative work by applying and integrating knowledge and skills to arrive at final products (or artifacts). The project has two major components: a question or problem that organizes a set of activities and those activities that will lead to the creation/construction of final products (Blumenfeld et al. 1991). Learning is relevant and engaging as students face problems similar to real world settings that are open-ended, complex, ambiguous, and ill-structured, often with conflicting goals (Jonassen et al. 2006). The appropriate driving question then needs to inspire and motivate students, which will help them to better understand and monitor what they are learning (Barron et al. 2014). Among the major features of PBL are "learning by doing", students' agency, teamwork, opportunities for assessment and revision, and the creation of artifacts (Barron et al., 2014; Chen and Yang, 2019; Guo et al., 2020).

Conceptually supported by constructivism, PBL involves students, actively, in the process of learning by creating mental models and constructing and reconstructing knowledge through which they understand what they experience (Prince and Felder, 2006; Lattuca and Stark, 2006). Proper implementation of PBL that provides a connection with students' prior knowledge and gives them agency in the process of learning with opportunities for reflection improves metacognition, which facilitates the transfer of learning to new settings (Barron et al. 2014; NRC, 2005; Prince and Felder, 2006). From another perspective, inspired by the design profession and ways by which designers think and work, the practice of PBL is in line with design thinking discourses where there is an emphasis on the creation of artifacts, reflection, and problem-solving (Johansson-Sköldberg et al. 2013). PBL courses very often provide structure for students to move through the major steps of design (engineering design) by emphasizing elements of problem definition, ideation, prototyping, and testing (Dym et al., 2005; Seidel and Fixson, 2013). More recently, several studies illustrated the integration of PBL and design thinking in designing and teaching project-oriented courses (Jiang and Pang, 2023; Kuo et al. 2021).

Prior literature emphasized the benefits of PBL in relation to persistence and improving students' performance in subsequent courses (Nguyen et al. 2020), improving students' motivation (de Graaff and Kolmos, 2003; Prince and Felder, 2006), and creating opportunity for learning transversal competencies including teamwork and collaboration (Boelt et al. 2022; de Graaff and Kolmos, 2003; Guo et al. 2020; Llorens et al. 2017; Miranda et al. 2020; Uotila et al. 2023). While it is challenging to pinpoint a specific list of skills/sub-skills, PBL learning environments provide potential settings for enhancing students' transversal competencies. Within the engineering education literature, PBL has been portrayed as an effective approach to help students develop transversal competencies (Boelt et al. 2022; Uotila et al. 2023; Vogler et al. 2018). That is why it is not surprising that the benefits of PBL courses in developing professional skills have been taken for granted in the majority of case studies and examples of PBL demonstrated in the literature. The underlying assumption is that creating opportunities for teamwork or presentation of the project outcomes, for instance, facilitates the development of corresponding competencies. But, can we make a conclusive argument about the impact through mere exposure of students to such opportunities? In this paper, we grapple with this question and address some structural elements necessary for promoting transversal competencies.

In a recent review of students' perceptions of the development of generic/transversal competencies in PBL and problem-based learning environments, Boelt et al. (2022) argued that research should uncover how alignment and scaffolding of different activities contribute to intended learning outcomes concerning transversal competencies. Considering the importance of explicit instruction in addressing transversal competencies (Isaac et al. 2023; Picard et al. 2023) on one hand and considerable time and efforts in implementing PBL (Chen et al. 2021; Chen and Yang, 2019) on the other hand, it is less clear how educators prioritize and operationalize opportunities to help students develop professional skills. Among a few studies that explicitly addressed the development of transversal competencies in PBL, we can highlight the following strategies discussed: regular supervision of the groups (MacLeod and van der Veen, 2020); lectures on professional skills (Uotila et al. 2023); opportunities for feedback from different stakeholders including industrial partners (Shekar, 2007; Uotila et al. 2023); and the integration of learning contracts (Llorens et al. 2017). In general, there is an underrepresentation of studies examining practices in PBL environments to facilitate students' development of transversal competencies.

In what follows, we briefly describe the structure of a PBL course that was recently conceived and received positive feedback from students, report on ways transversal competencies were addressed, and finally reflect on challenges and limitations and provide ideas for improvement applicable in similar settings.

2 SETTING: MECHANICAL PRODUCT DESIGN AND DEVELOPMENT

2.1 Overall structure of the course

The course is a five-credit elective course (3 hours of contact hours that are a mix of lectures, exercises, and project sessions) offered by the Mechanical Engineering Department. The course was originally developed by one of the authors of this paper with the major goal of immersing students in “A to Z” product development. While there may seem to be similar existing courses in other departments and other universities, often as a Capstone project, there are two distinctive characteristics of this class worth noting: 1) the curriculum ensures to stretch the engineering mind without only relying on the intuitions, 2) it requires the students to building a truly a full robotic system.

Concerning the first characteristic, sharpening engineering minds, the curriculum and the project deliverables focus on students to question their intuitions and create concrete reasonings for their design choices. Not only that, they are asked to create measurable and quantitative benchmarks to which they compare their designs. This means that it cannot be based on aesthetics, popular opinions, or even SWAT tables. While still important, the students were asked to focus on the mechanical and physical functionalities of the design and their reproducible results that can be quantified. Regarding the second characteristic, a comprehensive system development of a working robotic prototype, while building a new robotic platform in a class is not new, building a brand-new prototype with specific metrics to achieve and deliver a working prototype during a period less than 14 weeks has novelty. The fast-paced nature of the program encouraged students to make hard choices during the first 3 weeks of their design and that point on, focus on the “transferable knowledge” of the sub-components of their design (i.e., control architecture, working principles, motor and sensor characterizations). What these “transferable knowledge” packages allow students to gain was not the time, but any learnings that they have accumulated could be maintained even if they were to change some aspects of the product design such as dimensions, materials, and even applications.

Each year, up to 30 students from different engineering disciplines (Master students in mechanical engineering, electrical engineering, computer science, and micro-engineering) enroll in the course, where they work in groups of 4-5 to conduct an in-depth analysis of the operation principles and apply knowledge on advanced meso-scale technologies (kinematics, structural design, mechatronics, sensors and actuators, etc). The theme of the problem given to students is wearable technology and related mechatronic components and systems. Consistent with the PBL approach, a high emphasis is given to creative solutions, working concepts, and functioning prototypes. Students’ assessment is based on the final project outcomes (70%), including final report, final presentation, and working prototype, designed over 12 weeks, and weekly presentation and participation (30%). Following the recommendations by Helle et al. (2006) on the necessity of addressing the details of project-based courses, it is worth noting that each group has 2 teaching assistants

(TAs) who follow their work throughout the semester. A budget of about 500 CHF (fluctuated due to annual institutional budget) is given to each group on top of a starting kit that includes a microprocessor kit, basic mechanical hand tools and electronic components. They have access to mechanical and additive manufacturing ateliers (workshops) where they can create/ machine their own components or have it machined by the mechanics.

2.2 Course design and implementation

A comprehensive robotic platform development in under 14 weeks requires a clear outline of deliverables. Normally these are courses offered for over 30-week classes with a larger group of student teams. What has been unique in creating the class and keeping it within such a tight running schedule is to put the emphasis in the 1) concrete decision making processes based on quantifiable measurements - not based on surveys nor opinions 2) giving weekly feedback on the set of specific questions and deliverables that are pertinent to keeping i) the manufacturing feasible, ii) control algorithm relevant, and iii) prototyping and assembly to function. These questions and comments were streamlined using the accumulated FAQs from the previous years as well. What made these FAQ more reliable was that the “transferable knowledge” was clearly defined and communicated every session for each group.

The course facilitates the iterative process of engineering design where students need to develop a new robotic product (robot - as it is defined by having a motor, sensor and a microcontroller to control the movement), where in the process they choose methods and tools for the development, modeling and simulation, and the analysis of alternatives in designing the chosen functional product. They are expected to refine and update their motivations, understanding of the problem, and the state-of-the-art. As such, there are several points throughout the course that students need to reflect on their decision making. With the emphasis on planning earlier in the semester, students are given opportunities to reflect on what they do, reconstruct knowledge, and adjust their future decisions and actions (Helle et al. 2006; Miranda et al. 2020). In terms of student weekly presentations, they were presenting based on the given format (form and contents) that followed defining/redefining the problem statement, product specification, concept generation, concept selection, simulation, experiment design for validation, prototyping, and testing. From a technical standpoint, products developed by teams should include i) actuators (any type of motors, i.e. smart materials, electro/ magnetic/ electric/ ultrasonic/pneumatic/ etc); ii) structures (origami, cable-pulled underactuated system, 3D printed modular blocks); iii) model (analytical, numerical, simulation tool based); iv) working prototype (benchtop prototype, scaled version, or a display of a working principle. Therefore, students need to apply knowledge, concepts and principles related to mechanics, electronics, robotics, advanced manufacturing, sensors, motors, and programming into a real-world problem. Among examples of final prototypes/artifacts developed by student teams we can refer to are post-surgical scar rehab massager, zero-shock baby carrier, auto-launching cleats, automatic bicycle transmission, rowing synchronizer, automated contractor knee-pad, auto-compensating foot orthosis, free-hug squeeze doll for the stressed, auto focusing lens for surgeons, noise-limiting device, and haptic mouse (Figure 1).

Fig. 1. Two examples of artifacts produced by students

Students are given the theme of the project in the first class - it needs to be an active wearable / portable device that must contain at least one motor and a sensor to be controlled by a microcontroller. Students brainstorm product ideas and form groups based on the common project idea. Each team is required to define their own specific scenarios with existing problems and challenges that in turn translate into a clear purpose and desired functions. In other words, considering the categorization of de Graaff and Kolmos (2003), the type of project is the discipline project where the instructor provides some degree of planning and direction in terms of required design iterations (functionality design, mechanical design, mechatronics design, and program design), while at the same time, students have the autonomy to identify and define specific problems in line with the theme that is given. Within the first few weeks of the semester, students are given a tour of the university infrastructure supporting PBL, which provides access to tools, machines, and space for prototyping. The overall structure of the course is presented in Table 1.

Students' feedback about the course has been really encouraging. For instance, in Spring 2023, 19 students (out of 29) completed the final course evaluation where all of the respondents strongly agreed to the statement "I find this course interesting." and 18/19 strongly agreed that "In my opinion, the project complements and adds value to the theoretical knowledge of the course."

Table 1. Overall structure of the course

	Week	Topics	Student tasks and deliverables
Theory and application	1	Introduction to the course and project: general wearable tech; product development, fabrication methods, project brainstorming.	› Forming groups. › Think of 3 product ideas.
	2	Core components for wearable tech: electronics	› Choose 3 potential solutions. For each, define functionality of product, quantifiable metrics, motor, and sensor choices.
	3	Performance & Challenges for wearable tech: core challenges and performance metrics (qualitative and quantitative measures). Motors; actuators and sensors.	› Revisit state-of-the-art and choose the final design. › Compare 3 solutions: calculations / metrics. › Choose a motor. › Sketch of the product
	4	Functionality considerations of wearable tech: choices of design and performance; evaluation metrics; cost estimation.	› Improve the functionality/engineering specification of one of the parameters in the chosen solution.
	5	Considerations for prototyping and demos: core components of automated product functionality	› Test actuator and sensor solutions. › Plan the demo.
Refining prototypes	6	Weekly feedback and comments to the progress of the project.	› Controller for sensor and actuator
	7		› Finalize platform design
	8		› Finalize the solution presentation – metric performance
	9		› Polish the demo scenario
	10		› Flyer, poster, presentation, and report
	11		› Finish the project and communication formats
Final deliverables	12	Presentation of the project and prototype to the wide public	
	13	Presentation of the project and prototype to all the class and teaching team (graded).	
	14	Recap and feedback to all projects, presentations, and prototypes.	

3 TRANSVERSAL SKILLS

In this section, we summarize the elements and practices that have been integrated into the course design and implementation to address specific transversal skills.

3.1 Communication

Recognizing the importance of students' ability to communicate with different stakeholders, the course provides a structure for practicing communication in different formats and at different times. Students are required to have a weekly presentation where they provide systematic and intermediate updates about their progress with their project and how they applied what they have learned conceptually, for instance, on product specification or functionality. Among the major aspects, students need to address motivation, the latest updates, and proof of working principle. The last aspect is emphasized later in the semester when students made progress with conceptual and detailed design and incorporated demo presentations. At the end of the semester, student teams need to prepare presentations in three different formats: poster presentation, final in-class presentation, and public presentation with live function demonstrations. The first two formats follow academic guidelines in which students address elements such as motivation, state-of-the-art, design process, performance and results, and future direction. Students' audience is their peers, TAs, and instructor. As such, the instructor expects students to use i) technical details, ii) precise scientific language, and iii) quantified data. For the public presentation, students are required to focus on prototype demos using real prototypes, highlighting the need and application. Students are instructed to use i) accessible language, ii) accessible plots, and iii) qualitative representations of results.

3.2 Feedback

Continuous stream of feedback is crucial for every project. One of the distinct elements of the course is weekly presentations. Every class opens up with the teacher recapping the structure and progress of the project: the lecture always ends with summary slides "by this week, your group should have completed 1,2,3.." and "this week, your group should aim to achieve…". The contents reflect the general outcome of the week before but is adjusted to the fixed demo day schedule and the syllabus. With these slides, all the groups are reminded of their pace and progress. Based on the given slides, each group also presents their weekly progress to the whole class (3 slides under 5 minutes). This is when formal feedback takes place. Students have the opportunity to both provide and receive feedback from their peers, the teacher, and TAs. The continual aspect of weekly presentations creates a learning environment where the emphasis is on process rather than the final product. Through exchanges about the evolution of the project, students receive input and suggestions on their choices and decisions. As such, this process allows students to i) learn and reflect on what other groups are progressing; ii) make decisions that may not be the "ideal" and have some space for failure; and iii) incorporate the feedback received in improving their work. Among different means incorporated to encourage feedback, peer-feedback was fruitful when it was in a verbal form, but also the instructor witnessed its longer effect: it was apparent from the follow-up questions and slide updates that students made auto-corrections based on watching their peers presenting. The aspect of active and continuous feedback continues between the TAs and the teacher as well. After each class, the round-table discussion with the TAs allows the instruction team to share the common challenges both TAs and students face and solutions and strategies to communicate approaches.

Students value these interactions and opportunities for feedback, as we can observe in the data collected at the survey at the end of the semester, where 90% of the students agree or strongly agree with the statement, “I could get advice and useful feedback on my work during the semester.” However, while integrating arrangements for seeking and providing feedback is a unique and valuable component of the course, we cannot make a conclusive argument about how students used the opportunities, what the perceived benefits are, and whether there has been an impact on students' capacity to appreciate feedback, making judgment, managing affect, and taking action as major components of feedback literacy (Carless and Boud, 2018). How can educators systematically rely on peer feedback that is beyond impressions and curiosity-driven comments to a more educational and thought-through practice? Considering the possible benefits of repeated exposure to peer feedback on teamwork skills and confidence in evaluating and communicating about other performances (Donia and O'Neill, 2018), creating a more formal and standardized structure for feedback may contribute to team effectiveness and the development of transversal skills.

It is also worth noting that student teams start prototyping during the first few weeks of the semester. In other words, they are encouraged to use the opportunity as a springboard for communication and feedback. The use of tangibles, in general, and prototyping, in particular, facilitates visualizing and materializing ideas that can help students in improving and refining the concepts (Jalali et al. 2023; Stigliani and Ravasi, 2012).

3.3 Teamwork and collaboration

One major feature of PBL approach is the emphasis on teamwork and collaboration. In the context of this course, student teams are formed at the beginning of the semester based on their initial interest and field of study. The instructor of the course is intentional in creating teams with multiple disciplinary backgrounds so that students have the opportunity to collaborate across different boundaries. Prior literature on teamwork highlights the benefits of diversity in skills and expertise (Williams and O'Reilly, 1998). In addition, the fact that students share an interest in a given project aligns with the documented benefit of deep-level diversity in work teams that has been highlighted in social psychology literature (Harrison et al. 1998). In other words, in terms of structural elements, teams have the potential to flourish and function effectively. Further, considering teamwork processes, course activities, and assignments facilitate team communication and coordination. With the need for weekly interactions and discussions in advancing product design and preparing presentation materials, and the accountability of individual students in presenting and prototyping, there are more opportunities for informal discussion, cohesion, and integration within the group to improve.

It is also inevitable when working in groups, there are discrepancies in the division of the workload. While monitoring the team dynamics every week helped minimizing catastrophes (disappeared member, declaration of alienating a single member, etc), what made it more concrete was making an official disclaimer to the groups in the beginning of the semester. The teacher dedicated the time to explain the importance of having a “functional group” - it is not the excellence of individuals that make a strong group, but it is the teamwork that builds a group. Therefore, the teacher put the responsibility to every member for creating a working relationship: if there is a problem, it was their responsibility to seek help immediately. Whether students acquire specific teamwork competencies that they could apply in different settings is subject to speculation. For instance, members within a team may be exposed to disagreements and conflict; how they navigate and resolve the issues is critical to the team's effectiveness and performance; importantly, as it relates to the focus of our discussion, a question should be asked: Do students learn teamwork competencies from the experience?

4 DISCUSSION AND CONCLUSION

In this paper, we described a novel PBL course focusing on product design and development and explained how the course provides opportunities for students to practice and develop transversal competencies. One of the central themes in students' comments to open-ended questions on the course evaluation questionnaire has been on learning “doing a project.” By going through different stages of design process and acquiring and applying knowledge into practice, students indeed, first and foremost, enhance their problem-solving skills.

Instructor’s attempts to facilitate appropriate collaboration and teamwork (Chen and Yang, 2019) and deliberate integration of opportunities for giving/receiving feedback and presentation are essential features of this course regarding transversal competencies. Students can diagnose and correct errors in their project work process (Blumenfeld et al. 1991) in formal and informal interactions with their peers and instructor teams. Importantly, they need to frequently reflect on their design choices, where they are, and what they have learned to formulate and discuss their progress weekly. They also need to reflect on their experience with the exchanges to adjust future decisions and actions and comparing to the accumulated FAQ lists. This reflective process is an important feature of PBL (Barron et al. 2014; Miranda et al. 2020), and the course uses creative ways to operationalize it. Do all students take these chances seriously and learn from the overall process? In contemplating this question, we shall recognize the need for more explicit attention to reflection. For students to learn with understanding and be able to transfer what they have learned to new settings, there should be opportunities for thinking about the goals, where they are in the process of learning, and how they should make adjustments (Barron et al. 2014). A potential advancement to the course is to incorporate explicit prompts or opportunities for self-assessment/reflection linked with discussion within the group (team, with the instructor, or with the whole class). What is critical is to unfold the meaning process of reflection by expressing it to others; in other words, it needs to happen in a community and interact with others (Rodgers, 2004).

Moving from reflection that is applicable to learning in general to more specific skills and competencies highlighted in this paper, communication, feedback (literacy), and teamwork, what can we learn? First, as briefly addressed earlier, the course may benefit from explicit instruction on specific skills. Time and resources are a major challenge in ensuring that students learn new competencies. Prior literature highlighted the significant investment for students in PBLs (Du et al, 2021; Guo et al. 2020; Miranda et al. 2020) and closely related demands on facilitators/instructors to properly help students to navigate the complexities and uncertainties in the process (Du et al. 2021; Bissett-Johnson and Radcliffe, 2021; Guo et al. 2020; Miranda et al. 2020). Adding new elements to existing courses might be challenging, but it can be really rewarding. Now, the question is whether we should expect instructors in PBL courses to lead the designing and implementing new modules and materials on transversal competencies. In fact, one of the fruitful outcomes of the collaboration of the authors of this paper is unfolding the potential of the course in addressing transversal competencies and envisioning potential interventions where students can first appreciate the importance of specific skills, gain conceptual knowledge and understanding about frameworks underlying specific skills, practice in applying those skills in a meaningful way, and reflect on their experience to develop an awareness of their abilities and what needs to be improved.

A closely related issue to what has been discussed is difficulties with assessment in PBLs in general (Miranda et al. 2020), and more specifically related to transversal competencies. To examine students' learning and/or the influence of particular interventions addressing specific transversal competencies, it is critical to take advantage of different tools and measures. For instance, designing and integrating rubrics for presentation skills is a mainstream educational practice; evaluating teamwork skills, on the other hand, is more challenging considering a variety of factors that may influence the dynamics and the process of collaboration and complexities in unfolding behavioral components of teamwork skills. In this case, for instance, educators can benefit from incorporating peer evaluation or assessing students' self-efficacy beliefs. As a measure of learning, students' beliefs about their abilities may demonstrate their tendency to apply what they have learned to the new settings.

Reflecting on what has been discussed on explicit integration of transversal competencies, while enhancement in design and delivery of the course is desired, we should acknowledge once again the amount of investment and efforts instructors of PBLs need to make despite major institutional challenges in recognition of such courses, including financial support (Chen et al. 2021). As such, instructors often have to deal with broader contextual and structural issues when offering such courses. Nevertheless, as illustrated in this paper, lessons can be learned from the praxis to avoid missing opportunities to support students in developing transversal competencies.

REFERENCES

Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (2014). Doing with understanding: Lessons from research on problem-and project-based learning. In *Learning through problem solving* (pp. 271-311). Psychology Press.

Bissett-Johnson, K., & Radcliffe, D. F. (2021). Engaging engineering students in socially responsible design using global projects. *European Journal of Engineering Education*, *46*(1), 4-26.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist*, *26*(3-4), 369-398.

Boelt, A. M., Kolmos, A., & Holgaard, J. E. (2022). Literature review of students' perceptions of generic competence development in problem-based learning in engineering education. *European Journal of Engineering Education*, *47*(6), 1399-1420.

Carless, D., & Boud, D. (2018). The development of student feedback literacy: enabling uptake of feedback. *Assessment & Evaluation in Higher Education*, *43*(8), 1315-1325.

Chen, C. H., & Yang, Y. C. (2019). Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. *Educational Research Review*, *26*, 71-81.

Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: a review of literature. *European Journal of Engineering Education*, *46*(1), 90-115.

de Graaff, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International journal of engineering education*, *19*(5), 657-662.

Donia, M. B., O'Neill, T. A., & Brutus, S. (2018). The longitudinal effects of peer feedback in the development and transfer of student teamwork skills. *Learning and Individual Differences*, *61*, 87-98.

Du, X., Lundberg, A., Ayari, M. A., Naji, K. K., & Hawari, A. (2021). Examining engineering students' perceptions of learner agency enactment in problem- and project-based learning using Q methodology. *Journal of Engineering Education*, *111*(1), 111-136.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of engineering education*, *94*(1), 103-120.

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International journal of educational research*, *102*, 101586.

Harrison, D. A., Price, K. H., & Bell, M. P. (1998). Beyond relational demography: Time and the effects of surface-and deep-level diversity on work group cohesion. *Academy of management journal*, *41*(1), 96-107.

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education–theory, practice and rubber sling shots. *Higher education*, *51*, 287-314.

Isaac, S., Jalali, Y., Petringa, N., Tormey, R., & Dehler Zufferey, J. (2023). Are engineering teachers ready to leverage the power of play to teach transversal skills? European Society for Engineering Education (SEFI) Conference.

Jalali, Y., Bürer, M. J., Petringa, N., & Zufferey, J. D. (2023, October). What Role Do Tangibles Play in Fostering Design Thinking Skills? An Exploratory Study. *2023 IEEE Frontiers in Education Conference (FIE)* (pp. 1-9). IEEE.

Jiang, C., & Pang, Y. (2023). Enhancing design thinking in engineering students with project-based learning. *Computer Applications in Engineering Education*, *31*(4), 814-830.

Johansson-Sköldberg, U., Woodilla, J., & Çetinkaya, M. (2013). Design thinking: Past, present and possible futures. *Creativity and innovation management*, *22*(2), 121-146.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of engineering education*, *95*(2), 139-151.

Kuo, H. C., Yang, Y. T. C., Chen, J. S., Hou, T. W., & Ho, M. T. (2021). The impact of design thinking PBL robot course on college students' learning motivation and creative thinking. *IEEE Transactions on Education*, *65*(2), 124-131.

Lattuca, L. R., & Stark, J. S. (2009). *Shaping the college curriculum: Academic plans in context*. John Wiley & Sons.

Llorens, A., Berbegal-Mirabent, J., & Llinàs-Audet, X. (2017). Aligning professional skills and active learning methods: an application for information and communications technology engineering. *European Journal of Engineering Education*, *42*(4), 382-395.

MacLeod, M., & van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. *European journal of engineering education*, *45*(3), 363-377.

Miranda, M., Saiz-Linares, Á., da Costa, A., & Castro, J. (2020). Active, experiential and reflective training in civil engineering: evaluation of a project-based learning proposal. *European Journal of Engineering Education*, *45*(6), 937-956.

National Research Council [NRC] (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. National Academies Press.

Nguyen, H., Wu, L., Fischer, C., Washington, G., & Warschauer, M. (2020). Increasing success in college: Examining the impact of a project-based introductory engineering course. *Journal of Engineering Education*, *109*(3), 384-401.

Picard, C., Hardebolle, C., Tormey, R., & Schiffmann, J. (2022). Which professional skills do students learn in engineering team-based projects?. *European Journal of Engineering Education*, *47*(2), 314-332.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of engineering education*, *95*(2), 123-138.

Rodgers, C. (2002). Defining reflection: Another look at John Dewey and reflective thinking. *Teachers college record*, *104*(4), 842-866.

Seidel, V. P., & Fixson, S. K. (2013). Adopting design thinking in novice multidisciplinary teams: The application and limits of design methods and reflexive practices. *Journal of Product Innovation Management*, *30*, 19-33.

Shekar, A. (2007). Active learning and reflection in product development engineering education. *European Journal of Engineering Education*, *32*(2), 125-133.

Stigliani, I., & Ravasi, D. (2012). Organizing thoughts and connecting brains: Material practices and the transition from individual to group-level prospective sensemaking. *Academy of Management journal*, *55*(5), 1232-1259.

Uotila, U., Keskiniva, K., Junnonen, J. M., & Saari, A. (2023). Developing engineering students' generic and professional skills through a consultative approach to project-based learning. *European Journal of Engineering Education*, 1-16.

Vogler, J. S., Thompson, P., Davis, D. W., Mayfield, B. E., Finley, P. M., & Yasseri, D. (2018). The hard work of soft skills: augmenting the project-based learning experience with interdisciplinary teamwork. *Instructional Science*, *46*, 457-488.

Williams, K. Y., & O'Reilly III, C. A. (1998). Demography and diversity in organizations: A review of 40 years of research. *Research in organizational behavior*, *20*, 77-140.

UNLOCKING NEW POSSIBILITIES IN BIO EDUCATION AND RESEARCH: THE FIBER - FLEXIBLE INTERACTIVE BIOREACTOR

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***Conference Key Areas**: 3. Teaching technical knowledge in and across engineering disciplines; 11. Engineering skills, professional skills, and transversal skills*

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ABSTRACT

FIBER (Flexible Interactive Bioreactor for Experimentation and Research), a novel bioreactor platform designed to bridge the gap between theoretical understanding and practical application in bioengineering education. Bioreactors are fundamental technologies in various fields, but their inherent practical nature can make theoretical introduction challenging for students. FIBER tackles this issue by fostering active learning experiences through modular and adaptable design. The platform's modular components allow students to conduct multiple experiments simultaneously and tailor FIBER to fit specific experimental requirements. Affordability is a key consideration, with FIBER utilising readily available materials and 3D-printed parts, making it accessible for educational institutions with budgetary constraints. Additionally, FIBER boasts a compact design with a base station smaller than 10x10 cm for convenient benchtop operation. FIBER is further enhanced by interactive software that facilitates real-time monitoring and control of experiments. Students can use this software to compare different bioreactor operating modes, customize and investigate how various parameters influence cell growth. For increased versatility, FIBER integrates sensor slots for bacterial growth measurement. The design includes attachments for simple integration of Optical Density (OD) and fluorescence sensors, allowing for adaptation to diverse experimental needs. While the primary focus of FIBER lies in its educational applications, its ability to run multiple simultaneous experiments with its modular and cost-effective design holds potential for researchers as well. FIBER promotes active learning and responsible research practices by educating students to build socially and environmentally sustainable society.

1 INTRODUCTION

Bioreactors are cornerstone technologies across diverse industries, enabling the production of enzymes, proteins, microbial biomass, vaccines, biofuels such as ethanol, biodiesel and much more (Regonesi, 2023). This widespread use necessitates a well-equipped and educated engineering workforce. However, the inherently practical nature of bioreactors can pose a challenge in traditional, theory-heavy educational settings. This practice paper introduces FIBER (Flexible Interactive Bioreactor for Experimentation and Research), a novel device designed to bridge this gap and enhance bioengineering education. FIBER fosters active learning by providing a hands-on platform for students to apply theoretical concepts in a practical environment. They can explore different bioreactor operating modes, investigate the impact of parameters like temperature on bacterial growth, and gain a deeper understanding of the many disciplines that are integrated in bioreactors design and experiments such as fluid mechanics, biology and chemistry. This approach aims to assist in the education of students to build a more socially and environmentally sustainable society.

Recent research offers some promising avenues for bioreactor development. A morbidostat bioreactor was developed to continuously monitor bacterial growth and drug resistance of these bacteria (Toprak et al. 2013). Another example is the creation of a low-cost, customisable, turbidostat for use in the characterisation of synthetic circuits (Takahashi et al. 2015). This device proposed a system that could measure Optical Density (OD) and Fluorescence in alternating times. A more complex solution that makes use of a modular reactor with a microfluidic plate is the eVOLVER (Wong et al. 2018). A more comprehensive view on miniature size bioreactors can be seen in the review by Betts and Baganz (Betts and Baganz 2006. In education, bioreactors have been incorporated to provide students with an introduction to bioreactors and its uses, the EVE (Evolutionary Bioreactor, Gopalakrishnan et al. 2022) is a device proposed to be a low-cost morbidostat used in educational settings to demonstrate real-time examples of bacterial evolution. However, the most common solution to teaching students about operational modes of bioreactors is through virtual labs due to the high cost of equipment (Martín-Lara and Ronda 2020, Seidel, Eibl-Schindler, and Eibl 2022). Hence, by introducing FIBER, we present a solution to some of the issues of bioengineering education such as the high costs of bioreactors and the extensive training that usually is required to operate them (Seidel, Eibl-Schindler, and Eibl 2022). FIBER's strength lies in its user-friendly, affordable, and modular platform with multiple cells. This innovative design empowers students to delve into the fascinating world of bioreactors and explore diverse bioprocesses. Unlike traditional bioreactor setups FIBER allows exploration in novel settings fostering a deeper understanding and opening doors to exciting discoveries.

2 FIBER'S UNIQUE FEATURES

Traditionally, grasping bioreactor concepts can be challenging for students due to the inherent complexity of these systems. FIBER addresses this issue by focusing on a student-centered design. The platform tackles these challenges by prioritising features that enhance learning, such as modularity for flexibility in experimentation and affordability to make it accessible for educational institutions. FIBER user-friendly, small-scale, and modular platform empowers students to directly interact and experiment, fostering a deeper understanding of bioprocesses. This hands-on approach lets them design and test experiments for optimal growth conditions, building not only bioreactor knowledge but also valuable experimental skills. Ultimately, FIBER bridges the theory-practice gap crucial for industry, where diverse biological needs demand precise optimization (Enes Kadic and Heindel, 2014).

2.1 Modular and Compact

Ensuring student collaboration in labs with limited space is a key consideration for FIBER's design. With an entire setup occupying less than 50 x 10 cm for four bioreactor cells, multiple FIBER units can be simultaneously used on a standard lab bench with a base station measuring under 10 x 10 cm. In addition, FIBER is designed so that by adding or removing individual bioreactors cells from the base station, students can run multiple experiments simultaneously to gather data under various conditions. This focus on modularity and compactness saves not only valuable lab space and time, but also allows for more efficient data collection and analysis of different experimental conditions.

2.2 Affordability and Accessibility

Ensuring widespread adoption in educational settings was a core principle behind FIBER's design. Affordability was paramount, with a focus on readily available components that can be purchased in bulk for cost-effectiveness. 3D printing forms the backbone of FIBER, allowing for easy replication of parts and construction at any location. This not only makes FIBER accessible to institutions with varying budgets, but also empowers them to customize and adapt the platform for specific educational needs. The final design for FIBER aims to be at least 25% cheaper than any current market alternatives when two experimental cells are considered. This difference further increases with a higher number of cells to run parallel experiments, with FIBER being at least 40% and 50% cheaper for 3 and 4 cells respectively, with an increase in functionality.

2.3 Adaptable

FIBER prioritises user-friendliness and adaptability for both educational and research applications. The intuitive software offers presets for fundamental bioreactor control systems, including turbidostats, batch-fed, chemostats, and retentostats. These form the foundation for more complex systems like luminostats and morbidostats. While these advanced systems are not currently supported, FIBER's source code allows users to customize the software for their specific needs. Furthermore, the platform's adaptability extends to sensor selection. Users can modify sensor components, such as the LED for fluorescence experiments, to align with the specific wavelength of interest. This allows FIBER to accommodate diverse educational curriculums and research projects, empowering both students and researchers.

3 THE BIOREACTOR

It's important to acknowledge that FIBER is a continuously evolving platform. While this practice paper details its current design and functionalities, ongoing development efforts may introduce refinements in the future. This transparency allows for open discussion and potential collaboration as FIBER's capabilities continue to expand.

3.1 The design

FIBER's core design philosophy prioritises user flexibility. To facilitate a wide range of experiments, the platform is divided into two key components: a base station and interchangeable experimental cells. The base station acts as the central control hub, managing data collection, fluid distribution, and communication with connected cells. Each base station, also referred to as a feeding station, can support up to four experimental cells simultaneously. These cells connect to the base station for data exchange and power supply.

Figure 1 illustrates the current FIBER design. Figure 1a) shows the 3D-printed components of the current prototype, with the blue part in Figure 1b) corresponding to the base station. This section, covered in detail later (section 3.2), manages the flow of fluids to individual experimental cells. The red components in Figure 1b) represent the experimental cells, currently under development (section 3.3). These cells, where microorganisms will be grown, connect and communicate with the base station. This modular design allows users to tailor FIBER to their specific needs by easily adding or removing experimental cells for parallel experiments.

FIBER's impact extends beyond the hardware. We have developed an open-source software that empowers students to tailor experiments by adjusting parameters and visualizing data with automatic growth calculations. Researchers can access raw sensor data and write custom scripts. This opens doors for a wider range of modifications, ensuring FIBER adapts to the specific needs of each experiment.

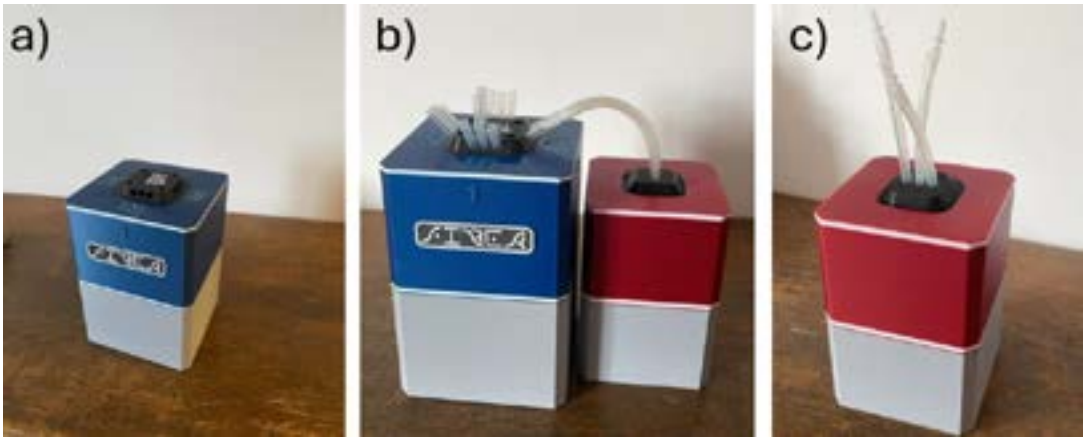

Fig 1. Images of the prototype of FIBER. a) is a picture of the 3D-printed base station of the system without the tubing attached. b) is a picture of FIBER. In blue is the base station, with the tubing leaving through the top. The tubing will be connected to each one of the experimental cells (red) which are shown in c).

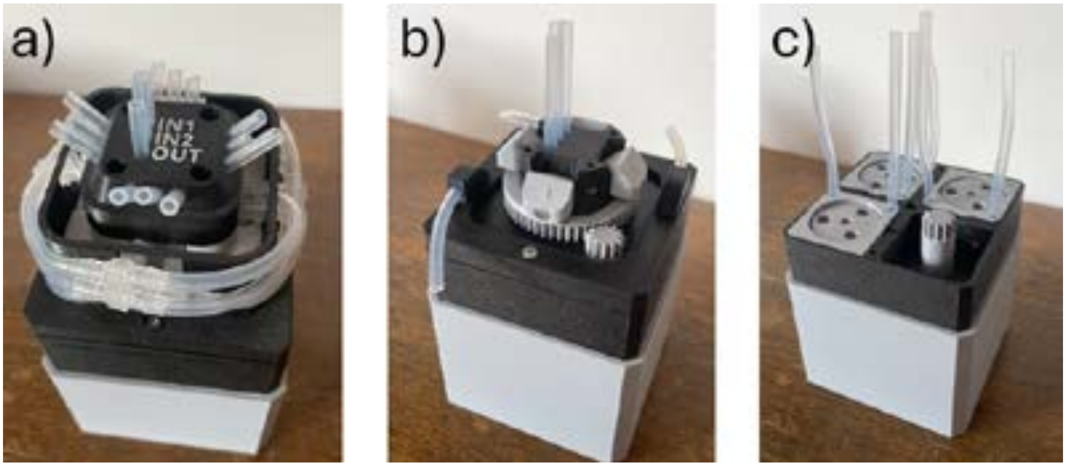

Fig 2. Pictures of the base station. All images correspond to sections of the base station, a) shows the tubing of the pinch valve that controls the amount of fluid distributed to the cells. b) shows a clearer picture of the pinch valve mechanism that distributes fluids to the cells. c) shows the stepper motors that control the pinch valve and the peristaltic pumps. The part presented in c) is on the bottom of the tubing shown in a) and b).

3.2 Base station

As the central control unit, the base station plays a critical role in coordinating and managing experiments. It houses a powerful microcontroller for advanced regulation and user-defined calculations. However, the core functionality lies in its sophisticated fluidic control system. Equipped with four stepper motors, the base station operates peristaltic pumps and a fluid pinch valve to precisely regulate the flow of fluids to each connected experimental cell. Figures 2a and 2b illustrate the pinch valve system. By compressing or relaxing tubing wrapped around the base, the valve controls fluid flow based on requests from the experimental cells. The remaining three stepper motors drive the peristaltic pumps. One pump acts as an output, removing fluids from the cells, while the other two function as inputs, allowing for the introduction of two distinct fluids into the same experiment. This configuration, depicted in Figure 2c, empowers students and researchers to investigate various scenarios, such as how different substrate concentrations impact cell growth. A picture of this system is shown in Fig. 2c), where there are three peristaltic pumps and a stepper motor that controls the pinch valve. This robust fluidic control system empowers FIBER to conduct diverse and controlled experiments.

3.3 Experimental cell

The experimental cell, arguably the heart of FIBER where experiments take place, is meticulously designed for flexibility and user customisation. Currently, the Team's focus is on integrating core sensors like the Optical Density (OD) sensor for measuring total cell concentration. A dedicated slot is planned for a future fluorescence sensor, though not currently prioritised due to the complexity of fluorescence-based measurements. Additionally, an infrared temperature sensor slot will be included for precise temperature control within the cell. However, true to FIBER's modular philosophy, users can modify the cells to add, remove, or adjust sensors to suit specific experimental needs. As the OD sensor relies on light intensity reaching a photodetector, external light can impact readings. To minimise this background error for light-based sensors, the cell will be equipped with a removable lid (the red compartment in Figure 1c). This lid not only protects against light interference but also allows for easy access for adjustments to LEDs or other experimental configurations. This combination of core sensors and user-customisable options empowers students and researchers to conduct a wide range of experiments within the FIBER platform.

4 RESULTS

While FIBER's development is ongoing, an initial experiment has yielded promising results for the sensor design. This preliminary test aimed to evaluate the functionality of the fluorescence sensor alongside the Optical Density (OD) sensor. *Escherichia coli* (*E. coli*) bacteria engineered with Green Fluorescent Protein (GFP) were used in the experiment (Figure 3).

The data collected indicates that the sensor placement and design function are as expected. The figure shows variations in light intensity measured by the phototransistor, corresponding to bacterial growth. The OD (red line), measured using a red LED, exhibits an exponential increase until approximately 10 hours into the experiment, when it reaches its stationary phase of growth. Similarly, the blue line, representing the fluorescence intensity, shows an exponential increase until the 10-hour mark, signifying stable bacterial growth.

The agreement between OD and fluorescence readings suggests that growth stabilises after 10 hours, which is a strong indication of successful sensor design for FIBER. These encouraging initial results pave the way for further development and testing of FIBER's functionalities. The results displayed have been confirmed by multiple experiments developed, thus further increasing the viability of the sensor design.

FIBER is currently undergoing testing and refinements. Following completion of testing, we will gather feedback from researchers and conduct student learning sessions to evaluate FIBER's educational potential after the ethical approval for student trials is granted. We anticipate FIBER's evolving capabilities hold immense promise for future collaborations.

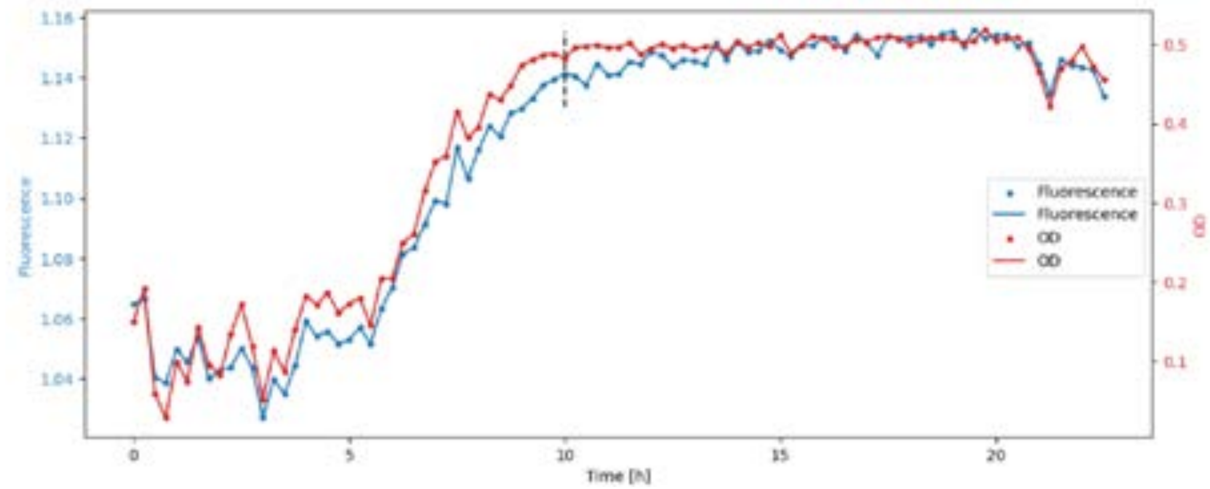

Fig 3. Data collected during preliminary tests of the OD and fluorescence sensors for FIBER. The graph presents the readings for the light intensity registered by the photodetector for OD (red) and fluorescence (blue). Both the OD and Fluorescence data show exponential growth until around t = 10h. After t = 10h, both measurements present stability and no significant relevant variations.

5 APPLICATIONS OF FIBER

FIBER's impact transcends the realm of education, offering valuable applications for research as well. The platform's modular design and ability to run multiple experiments simultaneously make it a cost-effective tool for students and researchers. This translates to several benefits: increased experimental throughput through faster data collection and analysis, optimised culture conditions by allowing researchers to efficiently explore various parameters for maximising cell growth or product yield, and the flexibility to tailor FIBER to specific research questions through its modular design. These functionalities, coupled with its primary focus on enhancing bioengineering education, solidify FIBER as a versatile and valuable tool for both learning and scientific exploration.

5.1 Educational Institutions

FIBER is designed to revolutionise bioengineering education at various levels. For university students, particularly those in Chemical and Biological Engineering disciplines, FIBER offers a hands-on platform to apply theoretical concepts in cell manipulation and production, crucial aspects of these fields. Research has been conducted on how to incorporate bioreactors in education and it was suggested to use of virtual bioreactors as opposed to their physical counterparts due to the high cost of equipment (Martín-Lara and Ronda 2020, Seidel, Eibl-Schindler, and Eibl 2022). Meanwhile (Gopalakrishnan et al. 2022) present a new bioreactor that focuses on helping biologists to understand bacterial evolution using a Morbidostat. FIBER attempts to innovate on the principles presented by helping students to gain a deeper understanding of complex bioreactor control systems by conducting experiments that compare different operating modes for an affordable price.

Additionally, FIBER allows them to investigate how various variables, like temperature or nutrient concentration, impact the growth of living cells. At the school secondary level, FIBER can be introduced as a captivating lab experiment exploring bacterial growth. This could spark student interest in biotechnology and potentially steer them towards STEM careers. Furthermore, FIBER can be seamlessly integrated into various curriculum topics, providing students with the opportunity to practice scientific investigation and visually understand concepts related to bacterial growth. Its adaptability also extends to higher education institutions beyond engineering, empowering undergraduate students in other disciplines to develop research skills and conduct their investigations. By fostering active learning across multiple educational levels, FIBER bridges the gap between theory and practice, fostering a deeper understanding of bioengineering principles which could facilitate the transitions of students from university to industrial settings where complex bioreactors are used.

5.2 Research

While education remains our primary focus, FIBER's potential extends to aiding researchers in diverse biological fields. The platform's key strengths - user-friendliness and adaptability - make it a valuable tool for biologists of varying experience levels to conduct simultaneous experiments. This adaptability goes beyond hardware; the customisable control system opens doors for exciting applications like developing an algorithm for simultaneous growth characterisation of different bacterial strains. FIBER's cost-effectiveness positions it as an attractive option for researchers with budgetary constraints. Additionally, researchers with some understanding of control systems engineering could further tailor FIBER to their specific needs. In fact, discussions with PhD students at the University revealed their enthusiasm for FIBER's potential to automate the creation of growth curves for microorganisms - a task currently performed manually. In addition to the feedback provided by the PhD students, mini bioreactors, the category where FIBER lies, are needed to be adaptable due to the large range of conditions required by different biological species (Betts and Baganz 2006). Therefore, as one of FIBER’s focus is its adaptability, it can be used in a variety of situations in research without the requirement of expensive purchases for simple tests. The points raised underscores FIBER's ability to streamline research processes and enhance efficiency for biologists beyond the educational realm.

6 SUMMARY AND ACKNOWLEDGEMENTS

FIBER addresses the critical need for a user-friendly and affordable bioreactor platform to bridge the gap between theory and practice in bioengineering education. This modular system prioritises affordability through readily available materials and 3D printing, making it accessible for institutions with varying budgets. The compact design ensures efficient use of lab space, while the interactive software empowers students to actively participate in experiments, monitor parameters in real-time, and analyse the impact of different variables on cell growth. Sensor integration with options for customisation further enhances FIBER's adaptability to diverse experimental needs. Beyond education, FIBER's potential extends to research, offering researchers the ability to run multiple simultaneous experiments, optimize culture conditions, and tailor the platform to address specific research questions. This versatility, coupled with its focus on active learning, positions FIBER as a valuable tool for both bioengineering education and research. FIBER is not just a bioreactor, it is an educational bridge to empowers students to explore bioprocesses through hands-on experimentation, fostering a generation equipped to tackle future ethical and sustainability challenges.

REFERENCES

Betts, Jonathan I, and Frank Baganz. 2006. "Miniature Bioreactors: Current Practices and Future Opportunities." Microbial Cell Factories 5 (1): 21. https://doi.org/10.1186/1475-2859-5-21.

Enes Kadic, and Theodore J Heindel. 2014. An Introduction to Bioreactor Hydrodynamics and Gas-Liquid Mass Transfer. Hoboken, New Jersey: Wiley.

Gopalakrishnan, Vishhvaan, Dena Crozier, Kyle J Card, Lacy D Chick, Nikhil P Krishnan, Erin McClure, Julia Pelesko, et al. 2022. "Science Forum: A Low-Cost, Open-Source Evolutionary Bioreactor and Its Educational Use." Edited by Peter Rodgers. *ELife* 11: e83067. https://doi.org/10.7554/eLife.83067.

Martín-Lara, M. Ángeles, and Alicia Ronda. 2020. "Implementation of Modeling Tools for Teaching Biorefinery (Focused on Bioethanol Production) in Biochemical Engineering Courses: Dynamic Modeling of Batch, Semi-Batch, and Continuous Well-Stirred Bioreactors." Energies 13 (21): 5772. https://doi.org/10.3390/en13215772.

Regonesi, Giuliano. 2023. "BIOREACTORS : A Complete Review," August. https://doi.org/10.13140/RG.2.2.11630.79685.

Seidel, Stefan, Regine Eibl-Schindler, and Dieter Eibl. 2022. "Laboratory-Independent Exploration of Stirred Bioreactors and Their Fluid Dynamics." Education for Chemical Engineers 42 (December): 80–87. https://doi.org/10.1016/j.ece.2022.10.001.

Takahashi, Chris N, Aaron W Miller, Felix Ekness, Maitreya J Dunham, and Eric Klavins. 2015. "A Low Cost, Customizable Turbidostat for Use in Synthetic Circuit Characterization." *ACS Synth. Biol.* 4 (1): 32–38. https://doi.org/10.1021/sb500165g.

Toprak, Erdal, Adrian Veres, Sadik Yildiz, Juan M Pedraza, Remy Chait, Johan Paulsson, and Roy Kishony. 2013. "Building a Morbidostat: An Automated Continuous-Culture Device for Studying Bacterial Drug Resistance under Dynamically Sustained Drug Inhibition." *Nature Protocols* 8 (3): 555–67. https://doi.org/10.1038/nprot.2013.021.

Wong, Brandon G., Christopher P. Mancuso, Szilvia Kiriakov, Caleb J. Bashor, and Ahmad S. Khalil. 2018. "Precise, Automated Control of Conditions for High-Throughput Growth of Yeast and Bacteria with EVOLVER." *Nature Biotechnology* 36 (7): 614–23. https://doi.org/10.1038/nbt.4151.

BUILDING ETHICAL ENGINEERS: INSIGHTS FROM A GUIDE TO INTEGRATING ETHICS IN CIVIL ENGINEERING EDUCATION

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ABSTRACT

Ethics education is crucial for civil engineers due to the far-reaching impact of their work. This article presents the Chapter on Civil Engineering that is part of the forthcoming "Routledge International Handbook of Engineering Ethics Education". In

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particular, it explores how ethical considerations should be integrated throughout civil engineering in a project's lifecycle, from design to decommissioning. Ethical considerations like professionalism, social responsibility, sustainability, and safety are addressed throughout. Each of these considerations is analysed across project phases, including planning, construction, operation, and decommissioning. Contents related to different civil engineering disciplines are examined (i.e., construction, energy, environment, water, transportation, urbanism). The chapter presented herein aims at fostering discussions around ethics in civil engineering classrooms, with a view of educating new generations of civil engineers that are strong not only technically, but holistically, thus ensuring that their projects prioritise safety, sustainability, and societal well-being.

1 INTRODUCTION

Unlike other engineering disciplines with a more recent origin, civil engineering has a long history dating back to ancient civilisations. From the Roman Empire's roads and viaducts to the achievements in Egypt, Greece, and China, civil engineering has demonstrably shaped societies and improved quality of life by providing essential infrastructure. This rich history is accompanied by the establishment of professional bodies like the American Society of Civil Engineers (ASCE) and the Institution of Civil Engineers (ICE) to ensure ethical practices that benefit society.

Ethics education is crucial for engineers, and it is increasingly being incorporated into engineering programs around the world. However, the importance that civil engineering has for society has not traditionally been reflected in the education of civil engineers. While civil engineers have the potential to solve pressing global challenges and enhance quality of life, undesired outcomes can arise if safety, sustainability, and public well-being are not prioritised. News headlines about infrastructure collapses and corruption cases highlight the importance of ethical considerations.

To avoid these adverse effects, future civil engineers must be equipped to understand and solve ethical dilemmas. Engineering ethics education is vital for this purpose. In addition to technical expertise, a well-rounded civil engineering education should include a comprehensive exploration of ethical questions, real-world case studies that showcase the ethical challenges faced by professionals, and opportunities for ethical decision-making and reflection.

Considering the above, this article presents the Chapter on Civil Engineering (Josa et al.) that is part of the forthcoming "Routledge International Handbook of Engineering Ethics Education" (Chance et al.). It aims to provide an overview of the ethical issues, dilemmas, and challenges that are included in the chapter, which addresses how these issues can be tackled by both students and practicing civil engineers.

2 CONTEXT: THE HANDBOOK

The Routledge International Handbook of Engineering Ethics Education (Chance et al.) is an open-source handbook on Engineering Ethics Education (EEE), which has been compiled by a diverse team of scholars. This handbook aims to be a comprehensive resource for both new and experienced researchers in the field.

The content of the book is organised into six main sections, each focusing on a different aspect of EEE. These sections cover the foundations of the field, explore contributions from other disciplines, delve into various teaching methods, and address the role of accreditation. Additionally, the handbook explores ethical issues specific to different engineering disciplines and provide guidance on assessing various aspects of EEE programs. Each section contains multiple chapters that review existing research and present the different perspectives and dilemmas surrounding each topic.

3 DETAILS OF THE CIVIL ENGINEERING CHAPTER

3.1 Development of the chapter

This chapter's development involved an iterative process through a series of meetings. The first meeting served as an initial discussion, laying the groundwork for the chapter's content and direction. Following this, a matrix was developed to structure the chapter (as will be further detailed later). The matrix then underwent refinement to ensure it effectively captured the intended content. Once finalised, the next phase involved filling the matrix with specific concepts and relevant case studies to illustrate the ethical considerations within the chosen framework.

The review process of the chapter involved discussions with the teams writing the chapters on other engineering disciplines, as well as three rounds of reviews by authors of other chapters and the handbook editors.

3.2 Contents of the chapter

Figure 1 shows how the chapter is organised. The structure of the chapter emphasises that ethical thinking should be integrated from the very beginning of a project and continue through to its completion.

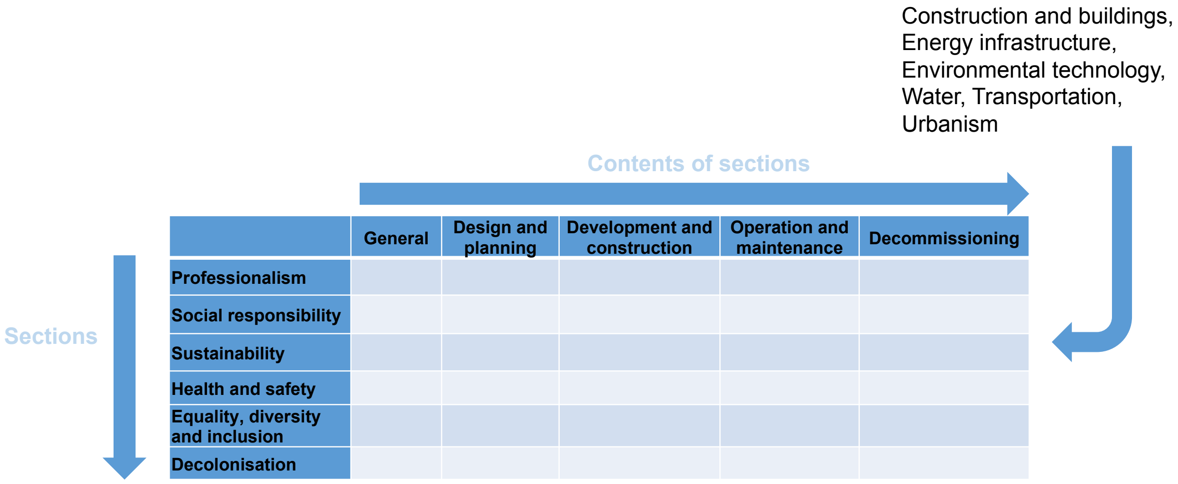

Fig. 1. Structure of the chapter

The chapter focuses on six main areas: construction and buildings, energy infrastructure, environmental technology, water, transportation, and urbanism. Each section is further divided into subsections that explore different stages of a project's life cycle, from general planning and design to construction, operation, and eventual decommissioning.

Then, running alongside the project phases are additional considerations that highlight the importance of ethics throughout the entire process. These ethical considerations include professionalism, social responsibility, sustainability, health and safety, as well as equality, diversity, inclusion, and decolonisation.

There is a part of the Handbook dedicated to methods through which these contents can be integrated into the curricula (e.g., case studies, problem-based learning). In the chapter presented herein, examples of potential case studies are included, together with questions that can be used in class to guide discussions. The titles of the case studies included are: the National Society of Professional Engineers Board of Ethical Review Case 97-13, Saadiyat Island Abu Dhabi and Worker Rights, Powerhouse Kjørbo, La Scala Opera House Asbestos Deaths, Trans-inclusive sanitation, and The Central Corridor, Tanzania.

In what follows, the main contents included for each of the ethical considerations (organised in sections) are presented.

3.2.1 Professionalism

This section discusses the ethical expectations of engineers throughout a project's journey. It starts with foundational concepts, exploring professionalism and its significance in construction. Also, the section delves into established codes of conduct, outlining the principles that guide ethical practice.

As a civil engineering project progresses, the focus shifts to ethical considerations within specific phases. During design and planning, the section discusses maintaining design integrity, avoiding conflicts of interest, and considering the long-term social and environmental impact of projects. A particularly challenging scenario, clashes of obligations, is also addressed here. This involves situations where client confidentiality clashes with public safety, and the section provides questions to critically think about navigating these conflicts while prioritising ethical duties.

The section then continues to the construction phase, emphasising ethical considerations like quality control, adherence to safety regulations, and responsible material sourcing. It also tackles the sensitive issue of corruption and bribery within the industry, offering strategies for identifying and avoiding such practices.

Finally, the section explores the ethical responsibility of whistleblowing. This involves those cases where engineers witness unethical or potentially harmful practices.

3.2.2 Social responsibility

This section dives into the ethical obligations engineers have towards society and the far-reaching consequences of their work. In particular, it opens with a discussion on the concept of social responsibility in engineering drawing on Chance et al. (2021), moving beyond technical considerations to explore the impact projects have on communities and the environment.

The section discusses the ethical principles guiding this responsibility, such as fairness, justice, and the well-being of future generations. It then tackles the distribution of responsibility, identifying who bears the ethical burden for different project aspects. This could involve engineers, contractors, clients, and governments.

The concept of Corporate Social Responsibility (CSR) is explored, examining how engineering firms can integrate social responsibility into their practices. Strategies for minimising negative project impacts and maximising positive contributions are discussed.

Moving into specific project phases, the section focuses on ethical considerations during design and planning. This involves considering the needs of vulnerable communities, minimising environmental disruption, and ensuring equitable access to the project's benefits. Recognising the potential downsides of new technologies, the chapter explores how to identify and mitigate unintended consequences during design. It emphasises the importance of considering the long-term social and ethical implications of innovation.

Regarding ethical considerations during construction, fair labour practices, responsible sourcing of materials, and minimising the project's impact on local communities are addressed. Highlighting the ethical complexities of global supply chains, the section dives into responsible sourcing practices and avoids human rights abuses or environmental exploitation within these chains. A real-world case study, the Saadiyat Island Abu Dhabi and Worker Rights (Human Rights Watch, 2009), is used to illustrate the challenges of social responsibility in construction projects.

Regarding operation and maintenance, this involves ensuring proper infrastructure upkeep to prevent disasters, such as bridge inspections or ensuring proper dam maintenance. The section also delves into the ethical complexities of who bears responsibility when a project fails. Additionally, effective communication with stakeholders throughout the project's life cycle is crucial for social responsibility.

Finally, ethical considerations for decommissioning involve responsible dismantling of structures, recycling or repurposing materials, and minimising the environmental impact of the decommissioning process.

3.2.3 Sustainability

This section dives deep into the environmental impact of engineering projects and how to minimise it throughout the entire process. This section explores the challenges of climate change and the ethical obligation to future generations (intergenerational justice). The section introduces frameworks like the Sustainable Development Goals (SDGs) and the capabilities approach to guide sustainable practices. It also touches on the concept of "Net Zero" emissions.

For design and planning, the focus is on incorporating sustainability principles from the very beginning (Engineering Council, 2021). This involves using design criteria that prioritise energy-efficient buildings, sustainable materials selection, and minimising resource consumption. The section also explores the concept of a circular economy, where materials are reused or recycled, and discuss potential criticisms of this approach.

Ethical sourcing of materials takes centre stage during the development and construction. The section discusses strategies for identifying and using materials with minimal environmental impact, including recycled content or those produced through responsible practices (Cole & Fedoruk, 2015).

As for operation and maintenance, the focus shifts to sustainable operation of the completed project. This involves strategies for maximising energy efficiency throughout the life of the building or infrastructure. A real-world example, the

Powerhouse Kjørbo, a highly energy-efficient office building in Denmark, is used to illustrate these concepts (UNFCCC, n.d.).

The end of a project's life also has sustainability implications. The last part of this section explores the challenges of obsolescence and waste generation during decommissioning. Strategies for minimising waste and promoting repurposing or recycling materials during demolition are discussed (Lawlor, 2015).

3.2.4 Health and safety

The "Health and Safety" section prioritises the well-being of everyone involved in a project, from conception to completion. The section emphasises the importance of identifying and mitigating potential hazards throughout a project's lifecycle.

For design and planning, the focus is on integrating safety considerations from the earliest stages. This involves discussions around incorporating safety features during design, evaluating cheaper versus safer alternatives, and prioritising long-term safety over short-term cost savings (Toole, 2007).

The development and construction section prioritises the safety of workers on the construction site. The section delves into mitigating accidents and risks through proper safety protocols, adequate worker training, and providing the necessary personal protective equipment.

Once the project is operational, the safety of users becomes paramount (Lukhele et al., 2022). This section explores strategies for ensuring safe building or infrastructure use, including emergency protocols and ongoing maintenance to avoid potential hazards.

In the dismantling of a project, safety requires careful consideration. This section discusses the challenges of dealing with harmful materials like asbestos during decommissioning. Strategies for safe removal and disposal of these materials are explored. A real-world example, the La Scala Opera House Asbestos Deaths case, is used to illustrate the potential consequences of neglecting safety during decommissioning (ACTS FACTS, 2016).

3.2.5 Equality, diversity and inclusion

The "Equality, Diversity and Inclusion" section emphasises the importance of creating a level playing field for everyone affected by a project. The section introduces the concepts of inclusive design and how it can address the needs of diverse populations. It discusses the medical vs social model of disability, highlighting the importance of designing for user capability rather than focusing on limitations (Field et al., 2022; Hao et al., 2023).

In design and planning phases, the focus is on designing with accessibility in mind from the start. This involves considering the needs of people with disabilities during building, transportation, and urban planning projects. The section uses a real-world case study, "Trans-inclusive sanitation", to illustrate the importance of inclusive design for all genders and identities.

As for development and construction, the section discusses potential gender inequalities within the construction sector. Then, for operation and maintenance, the focus shifts to ensuring equitable access to the benefits of a project throughout its operation. This involves discussions around energy poverty and strategies for ensuring affordable access to energy for all communities. Additionally, the section explores the ethical obligation to provide universal access to clean water, a basic human right.

The decommissioning stage part addresses the potential negative impacts of demolition on socio-economically disadvantaged communities. Strategies for mitigating these impacts and ensuring a just decommissioning process are discussed.

3.2.6 Decolonisation

This section delves into the historical and ongoing power imbalances within the engineering profession. It examines how engineers can approach their work ethically in a globalised world. It raises questions about the ethical implications of engineering projects in former colonies and explores how to avoid perpetuating power imbalances.

For design and planning, the focus is on ethical considerations when working in foreign settings. This involves discussions about understanding the local context, respecting cultural norms, and acknowledging existing power imbalances between the Global North and South.

For development and construction, the chapter tackles the ethical challenges of modern slavery and global exploitation within the construction industry. Strategies for ensuring fair labour practices and preventing human rights abuses during project development and construction are explored.

Additionally, the ethical dilemmas surrounding the maintenance of colonial-era urban and infrastructure projects are addressed. The section discusses the challenges of balancing historical preservation with the need for modernisation, and how to ensure these projects benefit the local population. A real-world example, the Central Corridor project in Tanzania, is used to illustrate these complexities.

Finally, this section concludes by discussing issues related to minimising environmental impact and ensuring responsible disposal of materials during decommissioning in formerly colonised countries.

4 SUMMARY AND ACKNOWLEDGEMENTS

This article explored ethical issues in civil engineering across project stages, as included in the Chapter on Civil Engineering of the Routledge International Handbook on EEE. While vast and complex, it serves as a starting point for considering ethical responsibilities in education and practice. The chapter emphasises the full project life cycle and key factors for ethical decision-making. Civil engineers need to navigate individual and collective ethics in a changing world.

This chapter is just a glimpse into a complex topic. For responsible practice, a deeper understanding of these ongoing challenges is crucial. We hope that the chapter inspires further exploration and a commitment to ethical and sustainable engineering.

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REFERENCES

Chance, S.; Børsen, T.; Martin, D.; Tormey, R.; Lennerfors, T.; and Bombaerts, G. (eds.) (forthcoming): "Routledge International Handbook on Engineering Ethics Education". London: Routledge.

Chance, S., Lawlor, R., Direito, I., & Mitchell, J. (2021). Above and beyond: ethics and responsibility in civil engineering. Australasian Journal of Engineering Education, 26(1), 93–116.

Cole, J. R., & Fedoruk, L. (2015). Shifting from net-zero to net-positive energy buildings. Building Research & Information, 43(1), 111-120.

Engineering Council. (2021). Guidance on Sustainability for the Engineering Profession. Retrieved from https://www.engc.org.uk/media/3555/sustainability-a5-leaflet-2021-web_pages.pdf

Field, C., Sutley, E., Naderpajouh, N., van de Lindt, J. W., Butry, D., Keenan, J. M., Smith-Colin, J., & Koliou, M. (2022). Incorporating Socioeconomic Metrics in Civil Engineering Projects: The Resilience Perspective. Natural Hazards Review, 23(1).

Hao, H., Bi, K., Chen, W., Pham, T. M., & Li, J. (2023). Towards next generation design of sustainable, durable, multi-hazard resistant, resilient, and smart civil engineering structures. In Engineering Structures (Vol. 277). Elsevier Ltd.

Human Rights Watch (2009) "The Island of Happiness" - Exploitation of Migrant Workers on Saadiyat Island, Abu Dhabi. New York: Human Rights Watch

Josa, I.; Giménez, E., and Nick, C. (forthcoming): "Chapter 14: Ethical considerations in civil engineering". In S. Chance, T. Børsen, D. Martin, R. Tormey, T. Lennerfors, and G. Bombaerts (eds.), Routledge International Handbook on Engineering Ethics Education, London: Routledge.

Lawlor, R. (2015). Delaying Obsolescence. Science and Engineering Ethics, 21(2), 401-427

Lukhele, T. M., Botha, B., & Mbanga, S. (2022). Exploring the nexus between professional ethics and occupational health and safety in construction projects: a case study approach. International Journal of Construction Management.

Toole, M. T. (2007). Design Engineers' Responses to Safety Situations. Journal of Professional Issues in Engineering Education and Practice, 133(2), 121-131.

United Nations Framework Convention on Climate Change (UNFCCC) (n.d.) Powerhouse Kjørbo - Norway. Available at: https://unfccc.int/climate-action/momentum-for-change/activity-database/powerhouse-kj%25C3%25B8rbo

TEACHING WITH A GENDER LENS: INSIGHTS FROM A GUIDE TO INCLUSIVE PRACTICES IN CIVIL ENGINEERING

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Conference Key Areas: *Diversity, equity and inclusion in our universities and in our teaching, Engineering skills, professional skills, and transversal skills*
Keywords: *Gender, Women, Inclusive*

ABSTRACT

Within higher education, integrating gender perspectives into teaching is crucial for inclusivity and addressing gender disparities. This article presents a guideline from

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the "Xarxa Vives Guides," a resource offering educators strategies for incorporating gender considerations across disciplines. In particular, the civil engineering guideline contains general and specific actions aimed at creating a more inclusive learning environment. General recommendations focus on teaching methods, classroom dynamics, assessment, and content. The emphasis is on using diverse methods, promoting respectful dialogue, and employing fair assessments. Additionally, course content should integrate the contributions of underrepresented groups and address gender-related issues within civil engineering. The guideline delves into specific recommendations for various subject areas within civil engineering education. Examples illustrate how to integrate gender perspectives, from considering gendered needs in water access projects to incorporating them into transportation planning. Finally, the chapter presented in this article explores fostering research with a gender lens. This includes supporting students in conducting gender-sensitive research projects and integrating gender considerations throughout the research cycle. By following these recommendations, civil engineering educators can empower students to challenge gender inequalities and contribute to a more equitable and inclusive profession.

1 INTRODUCTION

Teaching with a gender lens in higher education institutions is imperative to promote inclusivity, address gender disparities, and prepare students to navigate diverse professional environments.

Recognising the importance of integrating gender perspectives into teaching methodologies, Xarxa Vives has developed comprehensive guidelines aimed at educators across multiple disciplines. These guidelines serve as a framework for incorporating gender-sensitive approaches into course content, pedagogy, and assessment, fostering critical thinking about gender biases and their implications in various fields of study.

For engineers, competencies acquired by students upon completing their studies should extend beyond technical skills. In the realm of civil engineering, the chapter developed by Xarxa Vives offers practical strategies for educators to integrate gender considerations into the curriculum and final degree dissertations.

By incorporating these guidelines, educators can empower students to recognise and challenge gender inequalities, ultimately contributing to more equitable and inclusive practices within the field of civil engineering and beyond.

2 CONTEXT: THE “XARXA VIVES” GUIDES

2.1 The “Xarxa Vives” guides

The "Guidelines for University Teaching with a Gender Lens" is a collection of guidelines from diverse disciplines and knowledge fields that provide guidance on reviewing courses from a gender perspective. The guidelines present recommendations and indications related to objectives, content, examples, language used, and selected sources, as well as teaching, evaluation, and learning environment management methods and their results.

The resource has become a pioneer in the European Higher Education Area and has received recognition from the European Institute for Gender Equality, which has included it as an example of good practice in its Guide to Tools for Gender Equality in Academy and Research.

The following are the fields of knowledge and disciplines of the collection:

- Arts and Humanities: Anthropology, Philology and Linguistics, Philosophy, History, Art History, Museology and Museography, Translation and Interpretation.
- Sciences: Physics, Mathematics.
- Social and Legal Sciences: Communication, Law and Criminology, Education and Pedagogy, Sociology, Economics, and Political Science, Geography, Tourism, Business Administration and Management, Social Work.
- Life Sciences: Biology, Nursing, Medicine, Human Nutrition and Dietetics, Psychology, Sports Science and Physical Activity, Podiatry.
- Engineering and Architecture: Architecture, Computer Science, Telecommunications Electronic Engineering, Industrial Engineering, Multimedia Engineering, Agricultural Engineering, Naval, Marine, and Nautical Engineering, Civil Engineering.

Each year, this list grows bigger as guidelines are added to the collection. During year 2023, one of the guidelines developed was the civil engineering one, which is presented here (Josa & Real, 2024). Note that, at the moment of preparing this article, the guideline is only available in Catalan. However, the versions translated to Spanish and English are currently being prepared.

2.2 Gender and Civil Engineering

Over the years, the number of female students and professionals in civil engineering has been increasing. However, differences between men and women are still present. According to the 4th UPC Equality Plan 2022-2026 (Universitat Politècnica de Catalunya, 2022), the percentage of new female students in UPC degrees (mainly engineering and architecture degrees) in the 2021/22 academic year was 31%. This represents an increase from the 2016/17 academic year, when it was 24.4%. The Civil Engineering degree is around the average of all STEAM degrees at the UPC, below degrees related to health and environmental sciences and technology, but above degrees related to Information and Communication Technologies (ICT), where percentages are much lower.

The same pattern is reproduced globally. For example, Imperial College London currently has 29% female students studying Civil Engineering (Imperial College London, 2023), around 31% at École des Ponts (ParisTech) (École des Ponts ParisTech, 2023), between 30% and 40% at the National University of Singapore (National University of Singapore, n.d.) and 30% at the University of Sydney (The University of Sydney, n.d.).

Regarding the differences that exist between men and women who enrol in engineering studies, several studies have found that women are often more attracted to studies that are related to "people", while men tend to choose careers more related to "things" (Su et al., 2009). In addition, other studies have highlighted that women's greater interest in more socially oriented careers is motivated by altruism and a desire to help others and benefit society (Freund et al., 2013).

In addition to the differentiated interests between men and women, it is important to consider aspects related to the work environment. Some work environments and cultures can be unwelcoming for women. The lack of diversity and gender equality in organizations and cases of discrimination, harassment, or unequal treatment can create an unfavourable environment for female civil engineers, which can negatively affect their motivation and job satisfaction, and even lead to them leaving the profession. In this context, it is important to note that there are significant salary gaps between men and women in the civil engineering sector (Manesh et al., 2020; Shrestha et al., 2020).

3 CONTENTS OF THE GUIDE

The guide delves into this mainstreaming, proposing the inclusion of gender perspective through the implementation of actions in all stages of teaching: teaching methods, teaching dynamics, evaluation, and content. One of the main innovations it brings is the addition of four levels of complexity of the actions to be implemented: fundamental, easily applicable, advanced, and expert.

3.1 General recommendations for teaching with a gender lens

The gender lens may be introduced through actions in four basic pillars: teaching methods, teaching dynamics, assessment, and content. Furthermore, the actions that can be taken may cover four different levels (see Figure 1).

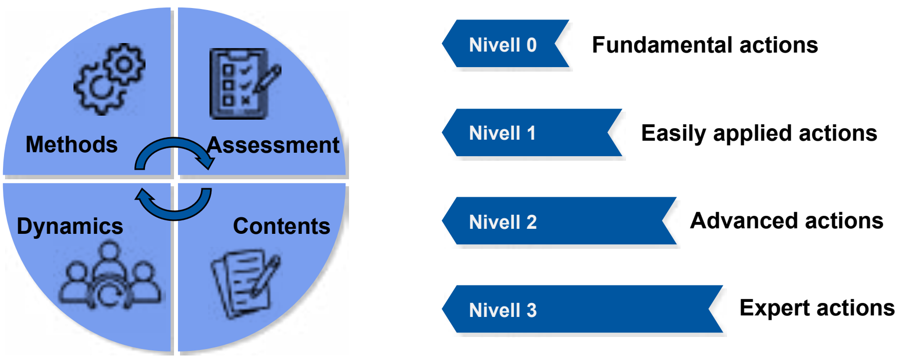

Fig. 1. Structure of the contents of the guideline

Below are general teaching recommendations for each of the pillars:

- Teaching methods: that different backgrounds will result in diverse prior experiences and knowledge. Therefore, based on this, the more diverse the classrooms are (including women, for example), the more varied teaching and learning methods must become – otherwise, the majority group will become dominant and privileged. This emphasis on using varied teaching and learning methods is not just a matter of inclusion. Although active and cooperative learning experiences are inclusive, they are also recommended as strategies to improve learning and motivation for all students, regardless of their characteristics (e.g., gender, socio-economic status, cultural background, prior knowledge, etc.).

- Teaching dynamics: when a gender perspective is applied to teaching dynamics, it implies a reflection on the dynamics that occur in the classroom and in the learning environment. It is important to consider these dynamics to ensure that they are equitable and respectful of diversity. This involves being aware of power relations, promoting inclusive participation, encouraging dialogue and collaboration, and fostering a supportive and inclusive atmosphere where all students feel valued and respected. Some strategies to achieve this include: encouraging students to reflect on their own assumptions and biases, promoting inclusive language and communication, providing opportunities for students to share their experiences and perspectives, and creating a safe and supportive learning environment where all students feel comfortable expressing themselves and participating actively in discussions and activities.
- Assessment: assessment is a crucial aspect of teaching and learning, as it provides feedback on students' progress and achievements and informs future teaching and learning activities. When applying a gender perspective to assessment, it is important to ensure that assessment tasks are fair, equitable, and inclusive of all students. This involves using a variety of assessment methods that allow students to demonstrate their learning in different ways, considering students' diverse backgrounds and experiences, and avoiding bias and stereotypes in assessment tasks and criteria. Some strategies to achieve this include: using a mix of assessment methods (e.g., essays, presentations, projects, exams, etc.), providing clear and transparent assessment criteria and expectations, offering opportunities for students to receive feedback and improve their work, and being mindful of the language and examples used in assessment tasks to ensure they are inclusive and respectful of diversity.
- Content: content refers to the subject matter or material covered in a course or curriculum. When applying a gender perspective to content, it is important to ensure that the content is inclusive, representative, and relevant to all students. This involves integrating gender perspectives into the curriculum and course materials, highlighting the contributions and experiences of women and other underrepresented groups in the field, and addressing gender-related issues and topics in the subject matter. Some strategies to achieve this include: including diverse perspectives and voices in readings and case studies, using examples and illustrations that reflect the diversity of the student body, and exploring gender-related topics and themes in the curriculum. Additionally, it is important to provide opportunities for students to critically reflect on gender-related issues and to engage in discussions and activities that promote awareness and understanding of these issues.

3.2 Specific recommendations for teaching with a gender lens

The specific recommendations related to content are given grouped as shown in Figure 2.

Fig. 2. Organisation of recommendations given for content

3.2.1 Basic subjects

This group of subjects encompasses competencies and content of basic training subjects, namely mathematics, physics, chemistry, and business and legislation. Mathematics is fundamental for structural analysis, force and motion calculations in structures, and the study of hydraulics. Physics is used to understand the fundamental principles of material and fluid behaviour, while chemistry is important for understanding material reactions, properties of construction materials, or water treatment processes.

Despite these subjects appearing gender-neutral at first glance, it is crucial to recognise that gender inequalities can manifest within these areas, influencing participation, academic performance, and student perceptions. Hence, it is important to introduce such issues from the beginning, gradually raising students' awareness throughout their studies. While topics like differential equations or the first law of thermodynamics are gender-neutral, technical content can be taught in different ways, considering gender, learning environment, types of assessment, teaching methods, etc. Additionally, although the theoretical basis remains unchanged, the examples used to illustrate it and the projects proposed in class can be more inclusive than those traditionally used in engineering classrooms.

3.2.2 Scientific and technologic subjects

The scientific and technological group of subjects focuses on applying scientific principles to engineering problems. Subjects like hydraulics emphasise real-world challenges, such as providing clean water access, particularly in rural areas where women often bear the burden of water retrieval. Implementing water distribution networks could greatly improve quality of life and gender equality by relieving women of this responsibility and allowing them to engage in other activities. In addition to technical considerations, it is crucial to consult affected communities to ensure interventions align with their needs and perspectives.

Furthermore, disciplines like materials resistance and geotechnics address gender-related factors in engineering design and analysis. For instance, considering how gender inequalities may affect terrain or landslide risk perception and responses can lead to more inclusive and effective solutions. The integration of gender perspectives extends to statistical analysis and spatial techniques, aiming to uncover hidden disparities and improve decision-making processes.

3.2.3 Applied technologies

This group of subjects encompasses subjects directly applicable to the profession, focusing on specialised content in various areas such as civil engineering and construction, including structures, water, and transportation/urban planning. For instance, within the realm of structural engineering and foundations, the emphasis lies on designing and calculating structures supporting different types of buildings and infrastructure, with a unique opportunity to delve into techniques ensuring safety, reliability, and sustainability. Incorporating a gender perspective in the conception and construction of structures and foundations is highlighted to ensure projects address diverse population needs, promoting equitable and safe access to buildings and infrastructure. Activities like debates and practical cases, such as the Citicorp Center's structural issues and seismic vulnerability, underscore the importance of understanding gender implications in engineering and fostering discussions on integrating gender perspectives in design, calculation, and construction processes.

Furthermore, in water technology and transportation, mobility, and urban planning, the significance of considering gender perspectives in addressing water management, transportation infrastructure, and urban planning challenges is emphasized. By analyzing gender dynamics, especially concerning travel patterns and access to resources like water and transportation, engineering education aims to design inclusive solutions responsive to diverse population needs. Practical cases, like designing water supply systems for rural communities with a gender focus, highlight the importance of equitable access to resources and involving communities in the design process. Debates on gender perspectives in public and private transportation usage aim to explore challenges women face in daily mobility and discuss strategies to enhance gender inclusivity in transport planning and policy-making, fostering collaboration among various stakeholders to integrate gender perspectives effectively.

3.3 Recommendations for doing research with a gender lens

To encourage students to conduct gender-sensitive research, it is essential to integrate aspects of research into teaching. Various methods can be employed to introduce research and its connection with gender in the classroom, such as showcasing research projects and practical cases that have considered gender implications in the field of civil engineering. Additionally, fostering critical reflection on gender biases in civil engineering and how they can affect professional and research decisions is crucial. Supporting research with a gender perspective, whether in academic assignments or final projects, is also vital. It is important to identify the level at which gender aspects are being introduced into research projects, with considerations ranging from blindness to transformation. However, while not all research can be transformative, this shouldn't serve as an excuse to limit gender-sensitive analysis.

Incorporating gender perspective throughout all stages of the research cycle, from conceptualization to analysis, report writing, and conclusions, is crucial and should not be left until the end of the research process, as is often the case. Various conceptual frameworks have been developed to integrate gender considerations into projects, including the Harvard Analytical Framework, Moser's Framework, Gender Analysis Matrix, and others. Integrating gender perspective into research design from the outset is emphasized to fully realize its potential, considering gender as an analytical category or variable rather than the sole focus of research.

Considerations at different stages of a research project include identifying research areas and generating ideas, defining research objectives, conducting research, drawing conclusions, and dissemination. Strategies such as using gender-sensitive methodologies, participatory approaches, and considering gender-specific risks are recommended. Additionally, it is crucial to report data sensitively, analyze gender implications, propose recommendations to address gender biases, and use inclusive language in reporting and dissemination.

Moreover, in various types of final degree projects, such as construction projects, laboratory experiments, simulations, and literature reviews, specific recommendations are provided to integrate gender perspectives effectively. For example, in construction projects, factors like accessibility, lighting, comfort, and signage should be designed considering the needs of all users, while in laboratory experiments, attention should be paid to ensuring equal participation of all students to enrich their learning experiences. Overall, integrating gender into research projects not only benefits the research outcomes but also inspires students and contributes to a more inclusive academic environment.

4 SUMMARY AND ACKNOWLEDGEMENTS

This article presented a guideline from the Xarxa Vives guides that promotes integrating gender perspectives into civil engineering education. This approach aims to create a more inclusive learning environment and address gender disparities in the field.

The guideline suggests incorporating gender considerations throughout the curriculum, from teaching methods and classroom dynamics to assessment and course content. It emphasizes using diverse teaching methods, fostering respectful dialogue, and employing fair assessments.

The content itself should integrate the contributions of underrepresented groups and address gender-related issues within civil engineering. Specific examples are provided on how to consider gender in various subjects, like water access projects and transportation planning.

Finally, the guideline encourages research with a gender lens. This includes supporting students in conducting gender-sensitive research projects and integrating gender considerations throughout the research cycle.

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REFERENCES

École des Ponts ParisTech (2023). The school in figures – Building tomorrow's world.

Freund, Alexandra M.; Weiss, David & Wiese, Bettina S. (2013). Graduating from high school: The role of gender-related attitudes, self-concept and goal clarity in a major transition in late adolescence., European Journal of Developmental Psychology, 10:5, 580-596, https://doi.org/10.1080/17405629.2013.772508

Imperial College London (2023). Our community in numbers. https://www.imperial.ac.uk/civil-engineering/people/ (Accessed 7 July 2023).

Josa, I. & Real, E. (2024). Guidelines for Teaching Civil Engineering with a Gender Lens. Available at https://www.vives.org/book/enginyeria-civil-guies-per-a-una-docencia-universitaria-amb-perspectiva-de-genere/ (Accessed 8-Apr-2024). ISBN: 978-84-09-44333-8.

Manesh, Saba Nikkhah; Choi, Jin Ouk; Shrestha, Binit Kumar; Lim, Jaewon & Shrestha, Pramen P. (2020). Spatial Analysis of the Gender Wage Gap in Architecture, Civil Engineering, and Construction Occupations in the United States. Journal of Management in Engineering, 36(4), 4020023. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000780.

National University of Singapore (n.d.). Civil and Environmental Engineering – Frequently Asked Questions. https://cde.nus.edu.sg/cee/cve-faq/ (Accessed 7 July 2023).

Shrestha, Binit K.; Choi, Jin Ouk; Shrestha, Pramen P.; Lim, Jaewon & Manesh, Saba Nikkhah (2020). .Employment and Wage Distribution Investigation in the Construction Industry by Gender. Journal of Management in Engineering, 36(4), 6020001. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000778

Su, R.; Rounds, J., & Armstrong, P. I. (2009). Men and things, women and people: A meta-analysis of sex differences in interests. Psychological Bulletin, 135(6), 859–884. https://doi.org/10.1037/a0017364

Universitat Politècnica de Catalunya (2022). Pla d'Igualtat de la UPC 2022-2026. Acord CG/2022/03/30, de 05 d'abril de 2022, del Consell de Govern, pelqual s'aprova el 4t Pla d'Igualtat de la UPC 2022-2026.

The University of Sydney (n.d.). Women in engineering – creating the perfect environment for STEM's future female leaders. https://www.sydney.edu.au/engineering/industry-and-community/women-in-engineering.html (Accessed 7 July 2023).

Xarxa Vives (n.d.). Guidelines for University Teaching with a Gender Lens. Available at https://www.vives.org/programes/igualtat-genere/guies-docencia-universitaria-perspectiva-genere/ (Accessed 8-Apr-2024).

ENHANCING ENGINEERING STUDENT ENGAGEMENT WITH INNOVATIVE FINANCIAL INVESTMENT METHOD FOR PEER ASSESSMENT: A PILOT STUDY

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Keywords: *Student engagement, Peer assessment, Entrepreneurial thinking, Financial investment, Research projects.*

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ABSTRACT

Higher Education Institutions (HEIs) face the ongoing challenge of effectively engaging students in the learning process. Traditional methods often fail to fully capture students' attention and foster the necessary entrepreneurial skills for their professional development. This paper presents a new method of engaging students in a university study module and discusses the results of a student survey. A novel Financial Investment Method (FIM) is introduced to enhance student engagement in a graduate course and to develop their entrepreneurial mindset, critical thinking, and overall attentiveness. The survey was conducted to evaluate the impact of FIM on student learning, competency development, and skill acquisition. Of the students who participated in the course, 91% responded to the survey, totalling 53 respondents from three study programs. The survey included both open-ended and closed questions. The results revealed that students were familiar with engagement methods such as group work, team-building sessions, active discussions, and checkpoint presentations. Most importantly, the survey indicated that the new Financial Investment Method increased students' attention and concentration during the course. Although some students did not perceive significant added value, a majority (73%) recommended its continuation in future courses.

1 INTRODUCTION

1.1. Student engagement methods

In recent decades, Higher Education Institutions (HEIs) have experienced a paradigm shift in which students became partners in the learning community rather than 'consumers' (Robinson 2012). This shift has encouraged HEIs to develop new student engagement practices and support students' involvement in educational processes. Since then, many scientific works have been published exploring the phenomenon and proposing various methods to increase student engagement (Tight 2020). In this study, the definition of student engagement is adapted from Bond et al. 2020: *"Student engagement is the energy and effort that students employ within their learning community, observable via any number of behavioural, cognitive or affective indicators across a continuum. It is shaped by a range of structural and internal influences, including the complex interplay of relationships, learning activities and the learning environment. The more students are engaged and empowered within their learning community, the more likely they are to channel that energy back into their learning, leading to a range of short- and long-term outcomes."*

There are three commonly recognized dimensions of student engagement: behavioural, emotional, and cognitive(Bond et al. 2020). Behavioural engagement involves observing students' actions and behaviours in the learning environment. Emotional engagement pertains to students' reactions and attitudes towards learning. Cognitive engagement examines the mental effort students invest in learning activities. Ideally, strategies to enhance student engagement should encompass all three aspects.

One of the most effective methods for student engagement, which significantly increases students' focus during group work, is peer assessment. (Weaver and Esposto 2012). To date, several studies have analyzed the impact of peer assessment on the learning process (Li et al. 2020). Specific peer assessment methods have been introduced to higher education (HE) engineering students by Conde et al. 2017, O'moore and Baldock 2007, and Dominguez et al. 2012.

Conde et al. 2017 proposed a method based on *Moodle Workshop,* which includes a workshop tracking panel with setup, submission, assessment and grading phases. The method improved student's participation in assignments, their motivation and even increased their grades. O'moore and Baldock 2007 introduced a method called "Peer Assessment Learning Sessions (PALS)" that using peer assessment enable frequent, efficient and timely evaluation of large student groups. The method was tested in several courses for Civil Engineering students and received 75-90% of the students recommendations to be extend further. Dominguez et al. 2012 also worked with Civil Engineering students and proposed an online peer assessment algorithm using commonly known tools such as *Google Docs*. Their study highlights the importance of good preparation and supporting guidelines for similar methods.

However, there is still a lack of quantitative and experimental studies examining the assumptions and practical implications of such approaches (Double, McGrane, and Hopfenbeck 2020). Moreover, student engagement can manifest in various shapes and forms, so there is no doubt that introducing unconventional, novel pedagogical approaches or techniques that spark surprise and interest, and thus engagement, is beneficial.

1.2. Entrepreneurial education of engineers

In the fast-developing world, engineering students are generally expected to develop their entrepreneurial skills and innovative thinking. Entrepreneurial education (EE) is a type of education that aims to develop students' entrepreneurial intention (EI). Numerous researches have been carried out on the contribution of education in fostering an entrepreneurial mindset in society, i.e. how EE impacts EI. This raises an important question: can entrepreneurship be taught? Some authors, such as Mueller (2011) and Packham et al (2010) argue that the impact of EE on IE is strongly positive. However, for others, such as Colette et al (2005) and Matlay (2005) this effect remains unclear. In any case, as noted by Sun et al (2016), Lortie and Castogiovanni (2015), and Nabi et al (2016), there is a lack of research on the exact mechanism on how specific educational components enhance EI in students.

Academic EE research is usually aimed at secondary school or business school students, and rarely at students from HEIs. As noted by Mäkimurto-Koivumaa and Belt (2016), this type of education is difficult to implement in engineering study programs, due to the fact that it is easier for lecturers to impart only engineering-specific technical knowledge, leaving less space for entrepreneurial education.

For this reason, Sun et al (2016) conducted an extensive investigation with engineering students on the influence of various education components (know-what, why, who and how) on the three EI areas (or determinants), namely entrepreneurial attitudes, social norms and self-efficacy. The influences were studied on the basis of the Theory of Planned Behaviour (TPB).

Similarly, Barba-Sánchez and Atienza-Sahuquillo (2016) investigated the EE and EI in the case of engineering students, and the results revealed that, among the possible motivations for acquiring EI (need for independence, need for achievement and financial motivation), the need for independence was the most important. Furthermore, the study confirmed the positive effect of EE on students' EI, presumably due to increased self-efficacy. Finally, the authors provided some guidelines on how to improve the EE effect on engineering students including engineering start-up exhibitions, idea generation workshops, business plan creation workshops and organization of inter-university business plan competitions.

Mäkimurto-Koivumaa and Belt (2016) also discussed effective ways of implementing EE in university engineering programs, suggesting a framework in which various aspects of EE are emphasised in the later years of the study program. Action-based learning activities are recommended in the first year to foster personal growth and boost the entrepreneurial mindset. Gradually, in the later years, once students have a basic knowledge of engineering, specific business and entrepreneurship content can be included in related courses.

From the reviewed literature, it becomes clear that encouraging EI through EE in HEI's engineering study programs is still a challenge. Therefore, this paper presents an investigation on the effectiveness of action-based learning activities on the learning outcomes and entrepreneurial mindset of Civil Engineering students.

This study introduces a novel Financial Investment Method, which allows students to invest virtual funds, under a specifically described set of rules, into other students' work based on their initial plan and pitch presentations. In turn, they can earn benefits at the end of the course if their investments prove to be sound. This method was created to engage students and maintain their interest in the work of their peers, as well as foster creative solutions to engineering problems and students' EI.

This paper describes the Financial Investment Method and provides results of a questionnaire survey from graduate students.

2 METHODOLOGY

2.1 The Financial Investment methodology pilot

This study introduced and evaluated a novel method designed to enhance student engagement by incorporating a financial investment element into an educational setting. The method was applied in a course titled "Research Project 1", designed to provide graduate students with the knowledge and research skills to analyse a problematic Civil Engineering task (Fig. 1). During the course, student teams tackled problem-based research challenges on topics such as energy efficiency, novel building materials, structures, construction management and indoor climate. The process involved several stages: defining the research problem, formulating hypotheses and questions, reviewing relevant literature, developing methodology and research design, and preparing and presenting a research article. In addition, the learning outcomes of the course included critical interpretation of research results (from literature analysis to result processing); application of the interactive process to research problem solving; learning to present research work in various formats: oral, research paper, poster presentation. Oral presentations were given in two formats: brief pitches and a poster session at the end of the course.

Fig. 1. Student participants of "Research Project 1" course who took part in Financial Investment Method testing.

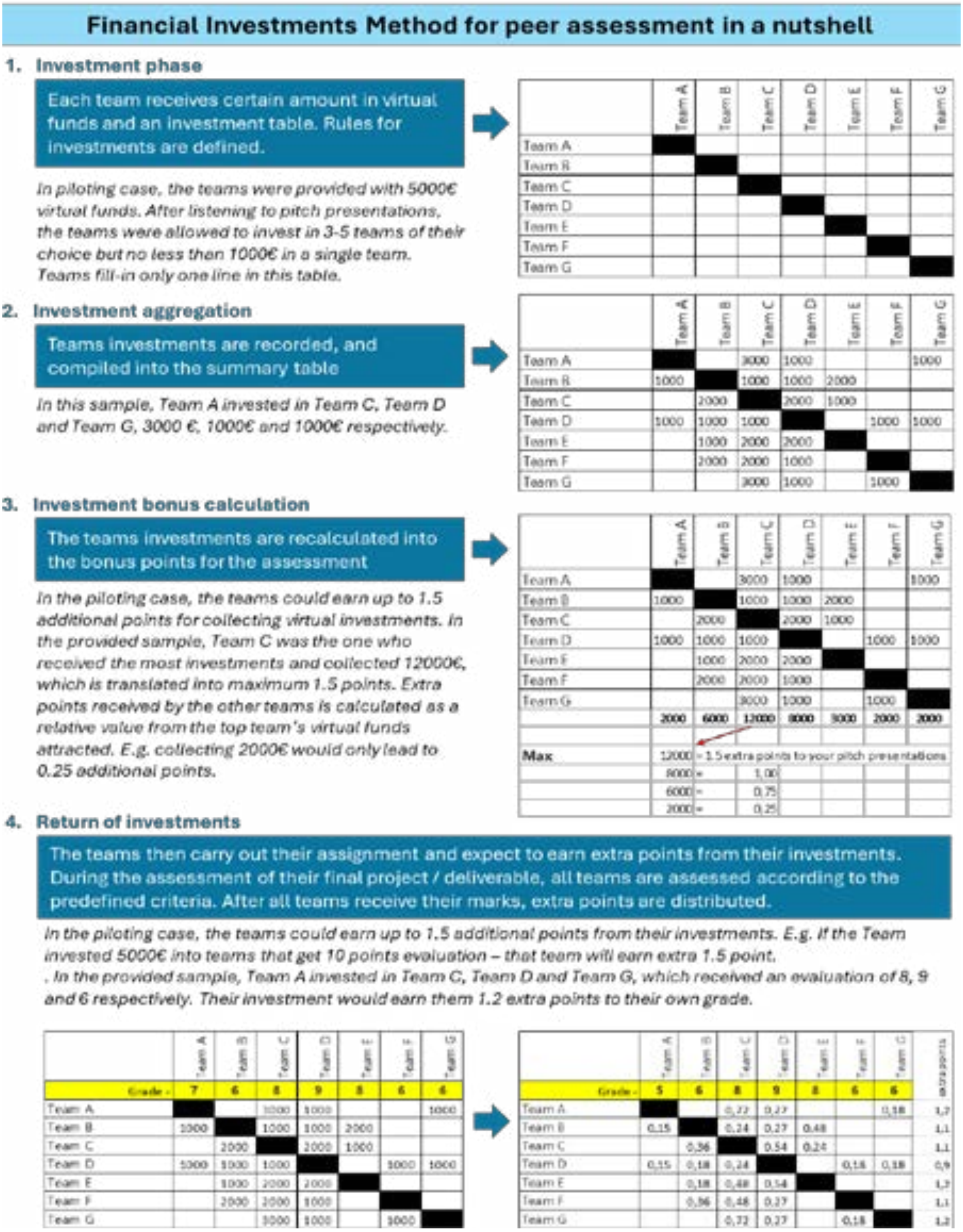

Fig. 2. Financial Investment Method for peer assessment: Implementation workflow with sample calculations

The course included 15 teams (3-5 students per team) from three Civil Engineering master's programmes. After a literature review and definition of their research problem, the teams developed their methodology and research design, leading to a checkpoint where each team presented a 7-minute pitch. These pitches outlined the research problem to be addressed, literature review findings, chosen research methodology, and expected results.

To encourage greater engagement, a Financial Investment Method was introduced, where student teams were given "virtual funds" to invest in other teams based on pitch presentations. This approach aimed to develop students' entrepreneurship, communication skills and critical thinking. It encouraged them to ask insightful questions, particularly about other teams' research plans, and to assess their validity and expected results. The Financial Investment Method had a twofold benefit for the teams. Attracting investments translated into additional points for the pitch presentation evaluation. Therefore, the more investments a team managed to attract, the more bonus points it received for the pitch presentation assessment. On the other hand, successful investments could earn points in the long run - for the subsequent evaluation of their research paper. This innovative methodology, which to the authors' knowledge has not been used before in engineering education, is depicted in Figure 2.

It is worthwhile to note that the main strength of this method lays on the fact that it engages the students through all three dimensions described in Section 1.1: cognitive engagement is achieved when evaluating the research of other teams; emotional engagement takes place when students have to "sell" their own research in an attractive way to their peers; behavioural engagement is addressed in the process of deciding the investments towards the other teams. In this way, Financial Investment Method is suggested as a powerful tool to deeply engage the students in the learning process.

2.2 Questionnaire survey methodology

A total of 58 students took part in Research Project 1 course. The course was completed in January 2024 and the survey was carried out immediately after the completion of the course. A total of 53 participants took part in the survey, with 91% participation rate. The questionnaire included both open and closed-ended questions, ensuring that both quantitative and qualitative analysis can be performed.

3 RESULTS

3.1 Familiarity and effectiveness of student engagement methods

A questionnaire was provided to students who participated in Research Project 1. The first part of the questionnaire aimed to evaluate their previous experience with student engagement methods and didactics aimed to strengthen their entrepreneurial mindset, and the results are provided in Figure 3. Students indicated that, so far, they had been mostly exposed to engagement methods such as group work, team-building sessions, active discussions, and checkpoint presentations where they had to present their progress to their peers and lecturers. The three dimensions of student engagement mentioned earlier (behavioural, emotional, and cognitive) were also reflected in the results. For example, over 40 % of students selected that they had experience in group work and team building – this can be attributed to the behavioural dimension. Group work and team building encourages students to actively participate and collaborate with others, fostering face-to-face communication and collaboration with colleagues. "Active discussions" were also highly ranked in the questionnaire and it can be assigned to all three dimensions. It not only encourages student participation, but also motivates to engage in the discussions, exchange ideas and analyse, which are clearly related to the cognitive dimension.

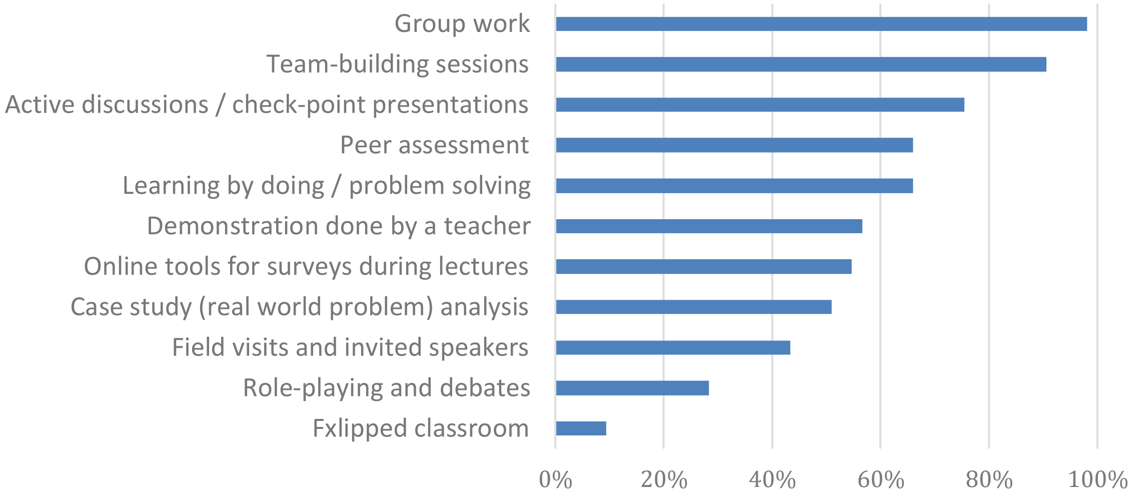

Fig. 3. Results of the questionnaire survey indicating students' familiarity with engagement methods and didactics.

The survey also asked students to indicate which factors contributed most to their engagement during the lectures (see Figure 4). The results revealed that ~80% of the students agreed or strongly agreed that all of the listed engagement methods were effective. The most effective methods were the clarity of content and the use of visual aids. Moreover, students indicated that they were least affected by interactive elements in the classroom, such as online surveys during lectures. They also noted that the variety of engagement methods was not that important.

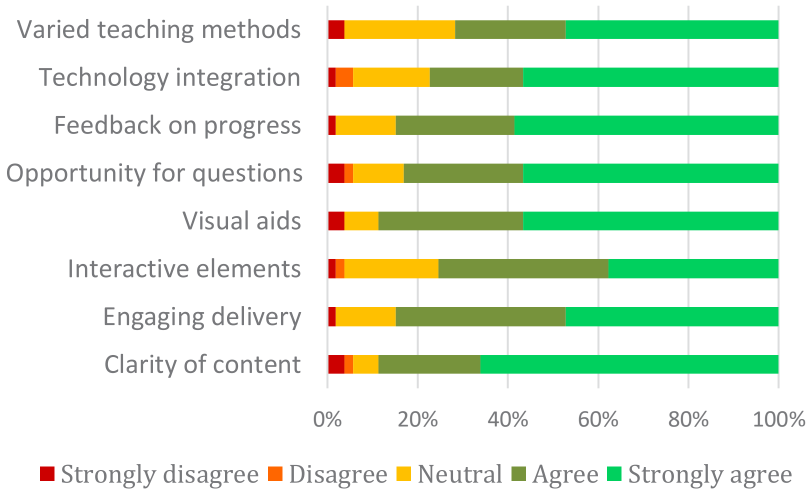

Fig. 4. The importance of factors for engagement in lectures

From a wider perspective, Figure 5 shows the effectivity of the various applied engagement methods in enabling students to acquire the learning outcomes of "Research Project 1". According to the surveyed students, the most effective ones were active discussions and checkpoint presentations in class. They further noted that the initial team-building session and the Financial Investment Method were the least important contributors. However, it is worth noting that the learning outcomes of this course were primarily focused on the development of research competencies, which include conducting systematic literature review, research design preparation, research implementation and presentation in various formats. The benefits of Financial Investment Method are discussed in the next subsection.

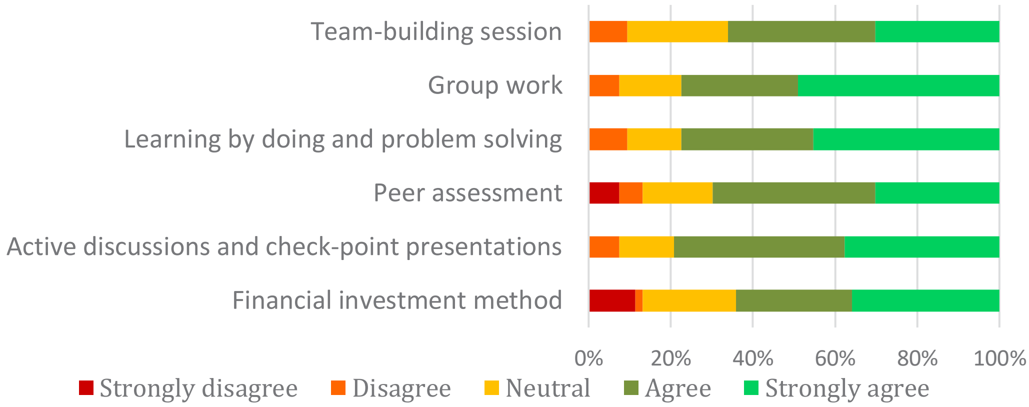

Fig. 5. Engagement method contributed to the achievement of learning outcomes

3.2 The impact of Financial Investment Method on students' learning

In the questionnaire students were asked to evaluate the Financial Investment Method and to indicate which skills it helped to strengthen the most (Fig. 6). More than 50% of the students indicated that the method has made a significant contribution to their skills, with the biggest impact being the increased attention during peer presentations. Only a few students indicated that method did not contribute to their respective skills.

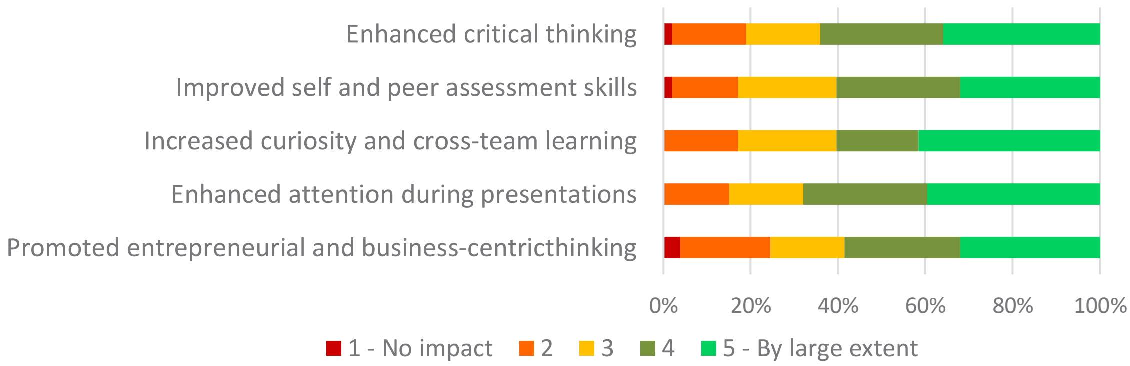

Fig. 6. Contribution of the Financial Investment Method towards skills and competencies

Table 1. Overall experience with the student engagement through financial investments methodology and its impact on learning

Category of responses	**Percentage of responses**	**Summarized comments**
Positive	62%	*Helped to be more active; Encouraged to perform better and pay more attention to presentations; A good method to better prepare for pitch; A new method encouraged to put more effort into preparation for the lecture and to be more active.*
Neutral	21%	*No comments were provided*
Negative	17%	*New method was a little bit confusing, could have been explained better; The methodology of financial investments did not engage*

		me in the course; Really good and interesting method, but it did not increase my engagement.

The survey also included open-ended questions where students could comment on their choices. Table 1 presents a summary of the students' comments, classifying their responses into positive, negative, and neutral categories. As can be seen from the table, 62% of the students responded that this method positively affected their learning, and only 17% of the respondents felt that the method was not well communicated or did not contribute significantly to the learning outcomes of the course.

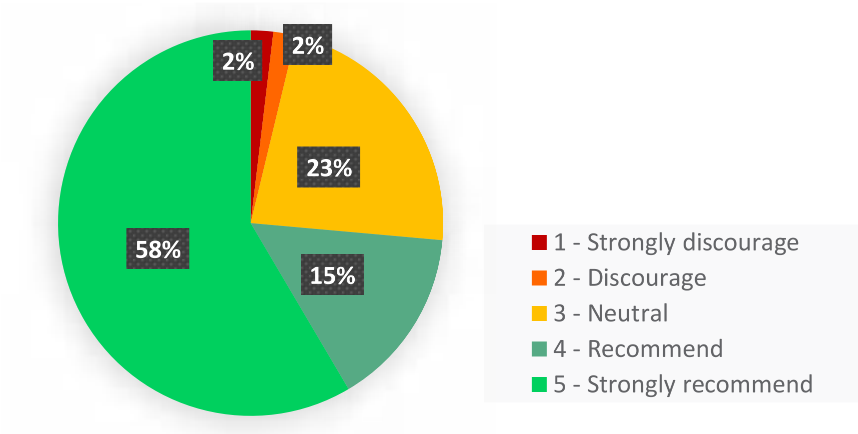

Fig. 7. Student feedback on the recommendation of the Financial Investment Method for the upcoming semester of the "Research Project 1" course.

Although some students did not support the Financial Investment Method, the vast majority would endorse its inclusion in the next semester's course of the "Research Project 1" (Fig. 7). 73% of students would recommend or strongly recommend incorporating this methodology, demonstrating overall satisfaction with this innovative approach for peer assessment that fosters entrepreneurial mindset, and enhances engagement.

This study provides empirical support for the findings presented by Motta and Galina (2022), which underscore the importance of diverse pedagogical methods to enhance student engagement and foster an entrepreneurial mindset. According to Motta and Galina, there has been a significant increase in scholarly attention towards experiential learning methods, as evidenced by the rise in publications on the topic between 2015 and 2019. This trend suggests a growing recognition of the need for innovative engagement strategies in educational settings.

4 SUMMARY AND CONCLUSIONS

- The literature review demonstrated that student engagement methods increase students' focus on courses. A novel Financial Investment Method was introduced in the course to engage students and foster entrepreneurial thinking.
- Over 50% of the students indicated that this method contributed significantly to their skills, with the biggest impact being an increase in their attention during peer presentations.

- The majority's endorsement for integrating the Financial Investment Methodology in future courses (73%) underscores its perceived value in enhancing peer assessment and fostering an entrepreneurial mindset, although refining communication and addressing concerns are necessary to optimize effectiveness and ensure maximum benefit for all students.

REFERENCES

Barba-Sánchez, V., and Atienza-Sahuquillo, C. 2018. Entrepreneurial intention among engineering students: The role of entrepreneurship education. *European research on management and business economics*, 24(1): 53-61. https://doi.org/10.1016/j.iedeen.2017.04.001.

Bond, Melissa, Katja Buntins, Svenja Bedenlier, Olaf Zawacki-Richter, and Michael Kerres. 2020. 'Mapping Research in Student Engagement and Educational Technology in Higher Education: A Systematic Evidence Map'. *International Journal of Educational Technology in Higher Education* 17 (1): 2. https://doi.org/10.1186/s41239-019-0176-8.

Colette, H., Hill, F., & Leitch, C. 2005. Entrepreneurship education and training: Can entrepreneurship be taught? *Education + Training*, 47(3), 158–169, https://doi.org/10.1108/00400910510586524.

Conde, Miguel A, Lidia Sa Nchez-Gonza Lez, Vicente Matella N-Olivera, and Francisco J Rodriguez-Lera. 2017. 'Application of Peer Review Techniques in Engineering Education'.

Dominguez, Caroline, Goncalo Cruz, Ana Maia, Daniela Pedrosa, and Gordon Grams. 2012. 'Online Peer Assessment: An Exploratory Case Study in a Higher Education Civil Engineering Course'. In *2012 15th International Conference on Interactive Collaborative Learning (ICL)*, 1–8. Villach, Austria: IEEE. https://doi.org/10.1109/ICL.2012.6402220.

Double, Kit S., Joshua A. McGrane, and Therese N. Hopfenbeck. 2020. 'The Impact of Peer Assessment on Academic Performance: A Meta-Analysis of Control Group Studies'. *Educational Psychology Review* 32 (2): 481–509. https://doi.org/10.1007/s10648-019-09510-3.

Li, Hongli, Yao Xiong, Charles Vincent Hunter, Xiuyan Guo, and Rurik Tywoniw. 2020. 'Does Peer Assessment Promote Student Learning? A Meta-Analysis'. *Assessment & Evaluation in Higher Education* 45 (2): 193–211. https://doi.org/10.1080/02602938.2019.1620679.

Lortie, J. and Castogiovanni, G. 2015. "The theory of planned behavior in entrepreneurship research: what we know and future directions", *International Entrepreneurship and Management Journal*, 11 (4): 935-957, https://doi.org/10.1007/s11365-015-0358-3.

Matlay, M. 2005. Researching entrepreneurship and education: What isentrepreneurship and does it matter. *Education + Training*, 47(8–9), 665–667, https://doi.org/10.1108/00400910510633198.

Mäkimurto-Koivumaa, Soili and Pekka Belt. 2016. About, for, in or through entrepreneurship in engineering education, *European Journal of Engineering Education*, 41(5): 512-529, http://dx.doi.org/10.1080/03043797.2015.1095163.

Mueller, S. 2011. Increasing entrepreneurial intention: Effective entrepreneur-ship course characteristics. *International Journal of Entrepreneurship and SmallBusiness*, 13(1), 55–74, https://doi.org/10.1504/IJESB.2011.040416.

Motta V.F. and Galina S.V.R. 2023. Experiential learning in entrepreneurship education: A systematic literature review. *Teaching and Teacher Education*, vol. 121, 103919, https://doi.org/10.1016/j.tate.2022.103919.

Nabi, G., Liñán, F., Fayolle, A., Krueger, N., & Walmsley, A. 2017. The impact of entrepreneurship education in higher education: A systematic review and research agenda. *Academy of management learning & education*, 16(2): 277-299, https://doi.org/10.5465/amle.2015.0026.

O'moore, L. M., and T. E. Baldock. 2007. 'Peer Assessment Learning Sessions (PALS): An Innovative Feedback Technique for Large Engineering Classes'. *European Journal of Engineering Education* 32 (1): 43–55. https://doi.org/10.1080/03043790601055576.

Packham, G., Jones, P., Miller, C., Pickernell, D., & Thomas, B. 2010. Attitudes towards entrepreneurship education: A comparative analysis. *Education + Training*, 52(8–9), 568–586, https://doi.org/10.1108/00400911011088926.

Prince, Michael, and Richard Felder. 2020. 'Active Student Engagement in Online STEM -Classes: -Approaches and Recommendations' 8 (4).

Robinson, Carol. 2012. 'Student Engagement: What Does This Mean in Practice in the Context of Higher Education Institutions?' Edited by Carol Taylor. *Journal of Applied Research in Higher Education* 4 (2): 94–108. https://doi.org/10.1108/17581181211273039.

Sun, H., Lo, C.T., Liang, B. and Wong, Y.L.B. 2017. "The impact of entrepreneurial education on entrepreneurial intention of engineering students in Hong Kong", *Management Decision*, 55 (7): 1371-1393, https://doi.org/10.1108/MD-06-2016-0392.

Tight, Malcolm. 2020. 'Student Retention and Engagement in Higher Education'. *Journal of Further and Higher Education* 44 (5): 689–704. https://doi.org/10.1080/0309877X.2019.1576860.

Weaver, Debbi, and Alexis Esposto. 2012. 'Peer Assessment as a Method of Improving Student Engagement'. *Assessment & Evaluation in Higher Education* 37 (7): 805–16. https://doi.org/10.1080/02602938.2011.576309.

A REVIEW OF STUDENT THOUGHTS ON REFLECTIVE PRACTICE

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***Keywords**: Reflective practice, Reflective learning, Learning Approaches, Student perspectives*

ABSTRACT

Reflection is generally considered a key part of learning, enabling the student to clarify their understanding, embed knowledge and identify gaps in proficiency. In this regard it is also a potentially important tool to support lifelong learning. Reflective practice is however often an assumed competence, not always explicitly taught or encouraged. In this work we investigate student attitudes and experiences of reflective practice.

Two groups of students were asked to identify why they feel reflective practice should (or should not) be part of the curriculum while also identifying hurdles to implementation, together with tools and tips to support students in adopting reflection. This was achieved via debate and guided small group work.

Results showed students generally appreciated the benefits of reflective practice.

There was however concern that it might add to the student workload and that less motivated students would not engage. Debates on whether the technique should be compulsory and assessed produced mixed results.

Interestingly, the students interpreted reflection in a very wide sense and wider than might be expected in conventional academic discourse, going beyond reflecting on immediate academic content to reflecting on mindsets, well-being and learning environments. Students expressed concerns however over reflection being another topic to learn, adding load into the curriculum and one difficult to adopt among students otherwise preoccupied with technical methodologies.

1 INTRODUCTION

With an increasingly rapid evolution of the engineering profession, future engineering graduates need to be committed to continuous or lifelong learning and need to able to take responsibility for their own professional development. It is undeniable that continuous development of skills and competences is essential for fostering their employability and career perspectives (Kövesi and Csizmadia 2016). Consequently, to have a successful professional life, they are required to improve their learning effectiveness through their future career (Martinez-Mediano and Lord 2012). Despite its importance, reflective practice is often considered as an inherent or implicit competence so generally not explicitly taught and implemented in the engineering curricula. In the present work, we aim to investigate students' perception about

(1) the implementation of reflective practices into their curriculum and

(2) the possible supports for teaching and learning reflective practice in the most efficient and adapted way.

2 THEORETICAL BACKGROUND

We consider reflective practice as a central element of continuous learning allowing engineering students and graduates to transfer their current practice into different situations or to develop it into future practices. Accordingly, we define reflective practice as "practice which involves the development of learning and understanding through self-review to help determine progress against goals and future learning needs" (Thomson and Kövesi 2023.1). To ensure future engineering graduates have the ability to meet future learning needs, it is particularly important to put emphasis on the development of reflective practice.

We distinguish, based on the work of Bailie et al. (2021), four different interpretations of reflective learning by educators concerning the development of students' (1) professional practice, (2) professional identity, (3) critical consciousness and (4) critical view on the course content. These qualitatively different conceptions indicate the relevance of reflective practice both in educational and professional context in the view of a long-term perspective. According to the empirical study of Baruah et al. (2017), reflective practice is essential for engineering students' personal and professional development. On the one hand, this gives a better understanding of their career aspirations (by the development of professional practice and identity). On the other side, it is useful for identifying eventual competence gaps resulting a better engagement in their courses (by the development of critical consciousness and critical view on the course content).

As mentioned earlier, despite its widely recognised benefits (Menekse et al. 2022, Howell 2021), in most engineering schools reflective practice is not traditionally implemented in engineering curriculum (Sepp et al. 2015). We notice that even if reflective practice is usually integrated into human and social sciences disciplines' curriculum, it is increasingly being implemented in STEM curriculum (Boswell 2023) during the last decades. For Badenhorst et al. (2020, p. 12), integrating reflective learning into engineering curricula allows engineering students to enlarge their vison "to bridge the more technical aspects of their work with a more socially aware professional identity as it expanded their notions of what it is to be an engineer".

The main obstacles for the implementation of reflective practice are at the institutional level, related to the lack of space in the current curriculum or/and the lack of time for the development of new innovative programmes. In addition, it often requires reformulating the traditional curriculum and finding a new balance between the practical and theoretical training (Miranda et al. 2022). We notice also that the implementation of reflexive practice could be challenging for educators (Bailie et al. 2021), especially in STEM disciplines where educators have mainly technical and scientific background and teaching reflective thinking could cause difficulties (Nilsson 2013). For educators, it is not evident to engage and preserve (i.e. avoid their disengagement) students in the reflective activities, to help them to make a link between theoretical and practical knowledge or to find the right balance between students' guidance and autonomous work (Miranda et al. 2022).

Even with a strong technical interest and focus on their engineering studies, students have widely recognised the usefulness and various benefits of implementing reflective practice into engineering curriculum (Howell 2021) as well as they were aware of the importance of being able to reflect in their future professional life. However, the empirical results of Eshuis et al. (2022) indicate an interesting contradiction with students' perception concerning the more frequently used reflections activities (e.g.: journals, reports, essays, portfolios, logs,…) which are considered less worthwhile or meaningful in the educational context. This contradiction raises the question about the more adapted and meaningful tools or dispositives to support reflective learning. This is an interesting question in the context of an increasing digitalisation as the development of new and innovative tools (like e-learning or AI tools) and supports could be a good solution to this contradiction (Baruah et al. 2017).

3 METHODOLOGY

To elicit student views on the theme of reflection as part of the learning process a mixed approach involving small group work on key questions was supplemented by a more open debate type approach.

3.1 Participants

We recruited two sets of students for this work on based on their interest in the topic and motivation to learn more about it.

The first group was recruited in parallel with the European Students of Industrial Engineering and Management (ESTIEM) meetings held in Budapest in November 2023. This group consisted of 15 participants from ESTIEM with a background in Industrial Engineering, 6 male and 9 female. These were drawn from various European countries including Austria, Spain, Italy and Portugal.

The second set were drawn from students of the Budapest University of Technology and Economics (BME) within the framework of the Environmental Economics course. These students were drawn from a mix of engineering, business and management disciplines and consisted of 21 students, 10 male and 11 female. This group composed a mix of Hungarian, American, French, German, Turkish and Italian students.

For both workshops, participant recruitment and selection were on voluntarily basis. For the ESTIEM group, students could choose from various parallel programs including the reflective practice workshop. For the second group, the participation was encouraged by exempting them from submitting one of course requirements. All participants verbally consented for the workshop results to be used in our research.

3.2 Approach

The workshops followed a procedure initially developed to solicit views and opinions among teaching staff on reflective learning with their students (Thomson and Kövesi 2023.1). The workshop began with a 15-minute introduction to the topic of reflective practice (e.g.: definition, applied methods, evaluation, etc.) building on Bloom's cognitive taxonomy. For the guided discussion, student sets were broken down into groups of 3 to 5 students who were then asked to discuss and suggest answers to:

- Why they feel reflective practice should (or should not) be part of the curriculum
- What hurdles are there to implementation
- What tools could support the adoption of reflective practice
- What tips could they suggest to support students in reflection.

To support this, guidance sheets and post-it type notes were provided to the groups to enable free flowing collation of thoughts and ideas (Figure 1).

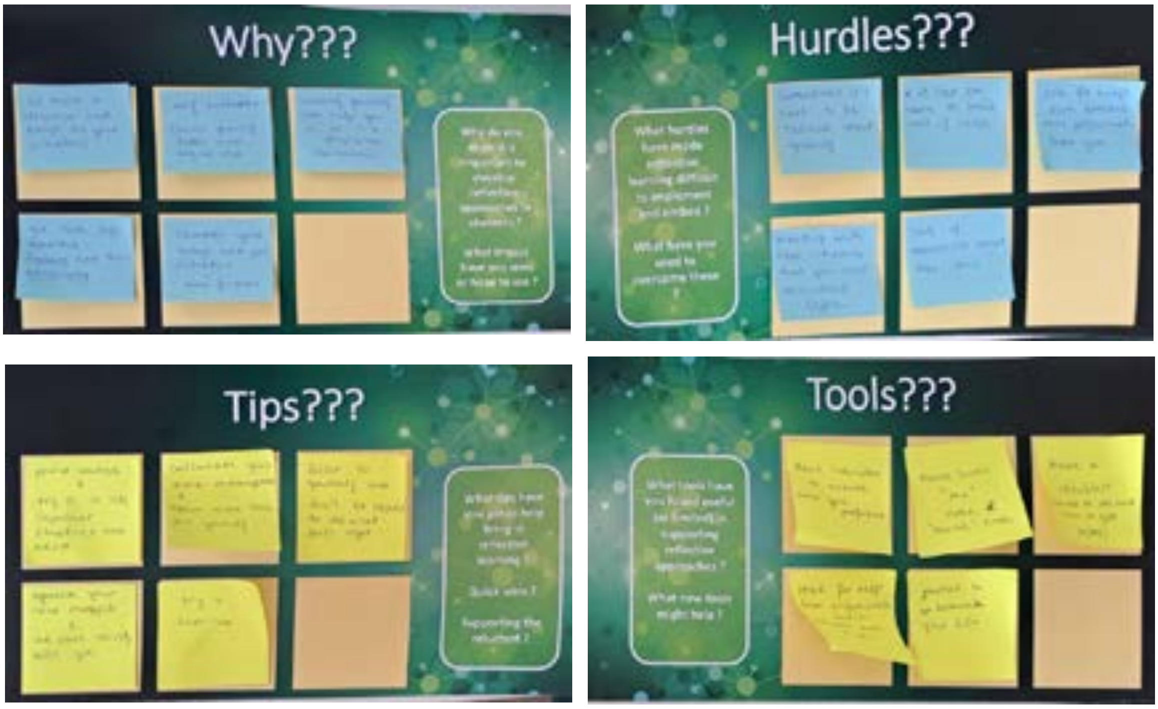

Fig. 1. Exemplar guidance sheets completed by a student group as part of this work to highlight their thoughts on reflective practice.

The student were also encouraged to debate the topic within their larger sets. These debates were set-up with the more general titles of “Should we formally evaluate (mark) reflective practice?” and the closely related “Should we make reflective practice obligatory?”. Out of the four teams, two were assigned the same question - one team to argue in favour, one to argue against it. Each team had the time to present their arguments then they could engage in a discussion with the other team. The debate was followed by a voting process using Kahoot platform where the observing teams voted who won the debate and why. The workshop concluded with feedback round for closure.

3.3 Data analysis

Data was collected through notes, photos and sound recordings taken during the workshops. The recorded discussions were transcribed, and the coding of tables was independently carried out by the authors. The results were discussed, and the differences resolved collectively at the end.

4 RESULTS

4.1 Worksheet result

Results of the work on the worksheet questions can be seen summarised in Figs. 2-4.

Within the tools section (Fig. 2) students single biggest resource in relation to self-reflection tools was to talk to others with notes recorded such as *“Ask for feedback from people close to you”, “Talk to someone (who knows you or the topic)”*. It was notable from some of the responses that the interpretation of self-reflection by the students went beyond that related to understanding of the topic at hand and into a wider and more holistic approach to the learning process. This can also be seen by the relatively high numbers of self-care notes recorded and comments such as "*be good to yourself*", "*self-compassion*". This wider interpretation was not something noted to the same extent in work on reflection with academic staff considering their engagement with students on this topic Thomson and Kövesi (2023,1 & 2).

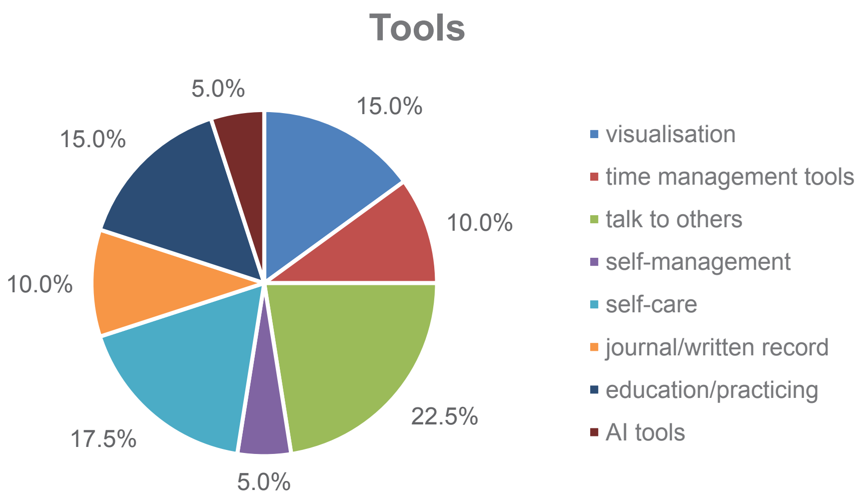

Fig. 2. Tools which students feel would aid reflective practice.

A number of issues were identified by students as hurdles inhibiting the take up of reflective practice (Fig. 3). The most common comments related to finding the time and motivation in an already dense curriculum – *"students unwilling to learn , focused in other areas, tiring routines, no interest in subject"*. The other key issue was reflection being seen as opening up personal weaknesses and worries to themselves or others – *"Afraid to face the truth", "Don't want to hear judgements of other people", "Emotions"*.

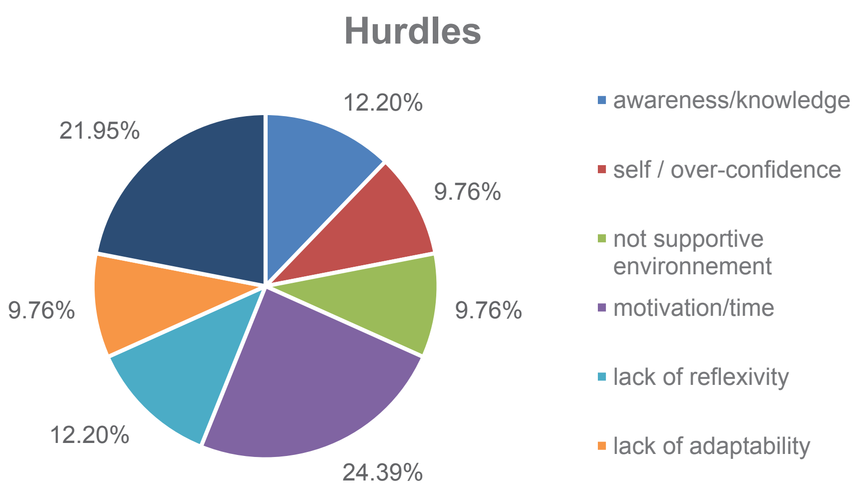

Fig. 3. Hurdles which students feel inhibit reflective practice.

Students had a number of tips to support peers in their uptake of reflective practice (Fig. 4). Again, the students raised the importance of the wider learning environment.

Comments included those related to both how physical environments support a positive approach - *"Clean the environment around you to clean your mind too"* while others addressed anxiety about reflection being associated with self-criticism *"Don't be too hard on yourself"*.

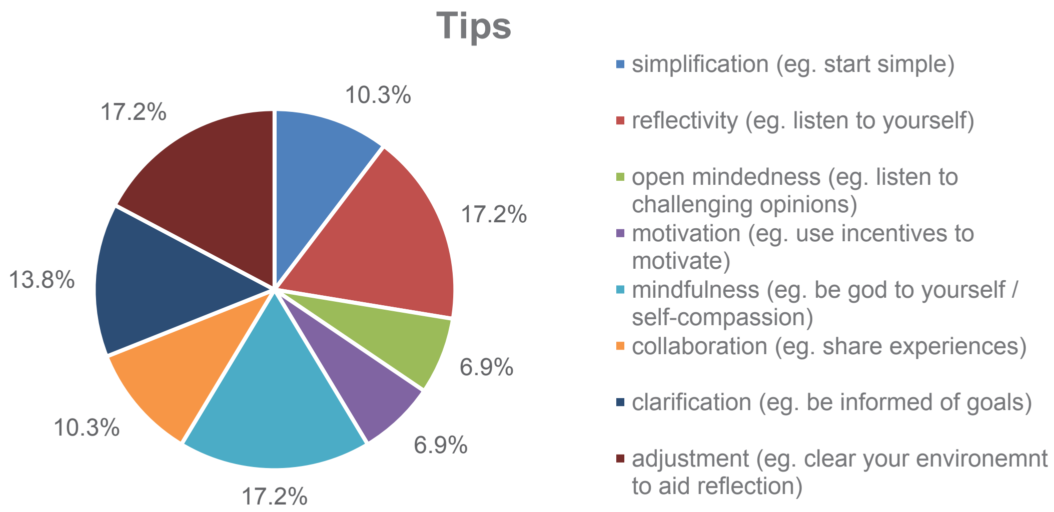

Fig. 4. Tips which students feel support reflective practice.

Students were also asked about whether they felt the need for reflective practice and there was generally a positive response to this from those taking part in the work. Comments included, *"Positive change in professional environment"*, *"Self-evaluation (know yourself better than anyone else)"* and touched on lifelong learning - *"questioning our future works for better outcomes"* and *"deep learning, lifelong knowledge"*. As noted elsewhere long term well-being was among the points raised to develop reflective competence - *"Avoid burning out and overwhelming"* and *"finding your path"*.

4.2 Student debates

Within the debates students reflected similar thoughts to those in the small group activity.

The most common arguments for making reflective practice obligatory in both workshops revolved around its impact on personal growth and professional enhancement. Students emphasized that reflective practice could enhance self-awareness and promote a deeper understanding of goals and personal identity. Those who opposed making reflective practice obligatory argued that reflective practice requires inner motivation and a positive learning environment. They discussed that voluntary engagement fosters involvement and results in better outcomes. Furthermore, the negative impact of pressure on creativity was emphasized.

Students in both workshops who supported the introduction of formal evaluation of reflective practice argued that evaluation could enhance motivation and responsibility resulting in better outcomes from reflective practice. According to them, assessment could improve giving and accepting constructive feedback, promote honest reflection, and facilitate personal growth. The most common arguments against the idea of assessing reflective practice pointed out that it cannot be easily measured, by nature it is subjective, and the evaluation may put an increased pressure on students. They argued that a teacher driven evaluation could affect the personal aspect of the reflection.

The audience assessed the debates using Kahoot platform. Most voting rounds had balanced results except for one where one team's argument was much more structured and logical as per the votes.

The students tended to agree on the importance of reflective practice being introduced in the curricula as a useful method for their self-development, but not as something the teachers should evaluate the students on due to its subjective and generally non-comparative nature.

5 SUMMARY

In summary students appeared to value and to recognise the benefits of reflective practice, in line with the work of Menekse et al. (2022) and Howell (2021), in their programmes in STEM disciplines. Despite their general recognition, they were concerned that it might be seen to carry additional workload and this may be off-putting because the lack of time as it was pointed out by Miranda et al. (2022). A continual theme among the students and one not generally present in staff views of reflective practice previously reported was that the reflection should extend beyond self-appraisal of the extent to which the specific academic material was becoming embedded but to look at reflection as a tool in a much more holistic manner. Students' extended vison of reflective practice indicates that they consider the benefice and usefulness of it in the view of a long-term perspective not only in educational and professional context but also in personnel context as outlined by Baruah et al. (2017). Consequently, this would extend to bringing in mindfulness, self-care and uncluttered physical learning environments in order to create a more caring and productive overall experience and generating an enlarged vison for students (Badenhorst et al. 2020). It therefore should be the case that when developing approaches to reflective learning that we should work together with students and develop reflective practices courses in co-construction to address their concerns and ensure a much broader approaches to reflection. This course design development in co-construction, viewed as a possible improvement of future practical implication, would be also useful for making adjustments as the student thoughts are likely to evolve with the generations and approaches to reflective learning should be continually evolved to match the needs and expectations of current students. Finally, we would like to confirm the possible adaptation of our work in other contexts with some adjustments (for example for the debating session) by taking into consideration the discipline and institutional aspects. As a future perspective, it would be interesting to compare students', educators' and other stakeholders' (ex.: industry representants, policymakers, etc.) perception about the implementation of reflective practice in engineering education at different level.

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REFERENCES

Bailie, A.L., E.H. Gebre, and K. O'Neill. “Instructors' Conceptions of Reflective Learning: A Phenomenographic Study.” *Higher Education Studies* 11, 4 (2021): 102-115.

Badenhorst, C.M., C. Moloney, and J. Rosales. “New Literacies for Engineering Students: Critical Reflective-Writing Practice.” *Canadian Journal for the Scholarship of Teaching and Learning* 11, 1 (2020). https://doi.org/10.5206/cjsotl-rcacea.2020.1.10805.

Baruah, B., T. Ward, and J. Brereton. "An e-learning tool for reflective practice and enhancing employability among engineering students." Presented in the 27th EAEEIE Annual Conference (EAEEIE), pp. 1-6. IEEE, 2017.

Boswell, M. "Investigating STEM pathway students’ perceptions of reflective practice: A case study." The Language Scholar: 12, p. 7.University of Leeds, 2023.

Eshuis, E., K. Mittendorff, and H. Baarslag. "Reflection in technical higher education: student perceptions." In Towards a new future in engineering education, new scenarios that European alliances of tech universities open up, Universitat Politècnica de Catalunya, (2022):1933-1939.

Howell, R. A. "Engaging students in education for sustainable development: The benefits of active learning, reflective practices and flipped classroom pedagogies." *Journal of Cleaner Production* 325 (2021): 129318.

Kövesi, K. and P. Csizmadia. "Industry perception of new engineering graduates: the gap between requirements and reality." In Proceedings of the 44th SEFI Conference, vol. 11. 2016.

Martinez-Mediano, C., and S. M. Lord. "Lifelong learning competencies program for engineers." *International Journal of Engineering Education* 28, 1 (2012): 130.

Menekse, M., S. Anwar & Z. G. Akdemir. “How do different reflection prompts affect engineering students’ academic performance and engagement?” *The Journal of Experimental Education* 90, 2 (2022): 261-279.

Miranda, M., Á. Saiz-Linares, A. da Costa, and J. Castro. "Active, experiential and reflective training in civil engineering: evaluation of a project-based learning proposal." *European Journal of Engineering Education* 45, 6 (2020): 937-956.

Nilsson, P. "Developing a scholarship of teaching in engineering: Supporting reflective practice through the use of a critical friend." *Reflective Practice* 14, 2 (2013): 196-208.

Sepp, L. A., M. Orand, J. A. Turns, L.D. Thomas, B. Sattler, and C.J. Atman. “On an upward trend: Reflection in engineering education”. Presented in the 2015 ASEE Annual Conference & Exposition: 26-1196.

Thomson, G. & K. Kövesi. “Student Reflective Practice As Part of Engineering Programmes”. 19th CDIO International Conference, CDIO 2023, Jun 2023, Trondheim, Norway: 770-779.

Thomson, G. & K. Kövesi. “Reflective Practice In STEM Degrees To Support Adaptability And Lifelong Learning.” European Society for Engineering Education (SEFI). DOI: 10.21427/N0PF-J843.

HOW TO TEACH CONSCIOUS LEADERSHIP TO FUTUR ENGINEERS? THE DEVELOPMENT OF AN INNOVATIVE ACTIVE TEACHING AND LEARNING PROGRAMME

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ABSTRACT

In this paper, we aim to present the development of an innovative teaching and learning programme. The programme was designed to enhance transversal competences more particularly in conscious leadership for final year IEM (Industrial Engineering Management) engineering students – competences which are essential for effective and ethical workforce management.

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To develop this new programme, we applied an innovative course design embracing various pedagogical practices with an active learning approach including virtual reality experiences related to sensitive topics (such as everyday sexism in male-dominated environments, discrimination at work, mental health prevention) expected to generate strong emotions. We will present the development of this new programme, his implementation and evaluation based on student feedback.

Our results indicate that the use of various pedagogical methods and virtual reality by diverting the attention of sensitive students makes this innovative module attractive and well suited to their requirements. Students reported a stimulating virtual reality experience enabling a deeper understanding of complex and sensitive topics in uncertain, conflictual, and challenging situations where conscious leadership needed.

This work provides support for educators and teachers for developing engineering students' transversal competences in conscious leadership in an innovative way via active learning applying various pedagogical approaches. In future, this programme could be adapted and used in other engineering trainings for enhancing students' emotional and social competences.

1 INTRODUCTION

In a constantly changing world, we believe that it is important to prepare engineering students by developing their transversal competences in conscious leadership for enable them to face future sustainability challenges. Future engineering graduates will work in an increasingly VUCA (volatile, uncertain, complex and ambiguous) world (Bennett and Lemoine 2014) where human capital will play a central role, more specifically in technical domains requiring effective leadership based on strong ethical and value-based attitudes and behaviour (Beagon et al. 2019). The engineering profession is widely recognised as a leader for solving the challenges of SDGs (Sustainable Development Goal). However, engineering leadership depend on engineers' self-recognition and acceptation as a leader (Rottmann et al. 2015) that requires a well-established leadership identity. For this reason, including leadership education in the engineering curriculum is an important issue in engineering education also for developing engineering students' identity as leaders (Wolfinbarger et al. 2021).

The implementation of an innovative teaching and learning programme was essential, as indicated by the results of students' satisfaction survey, because traditional practices have limited efficiency with the new generation of students who have a very different learning approach. On the one hand, they have limited interest in engaging in traditional programmes applying passive learning approaches. On the other, their engagement in active learning is promising, resulting in increasing students' involvement, motivation, engagement, and learning performance.

In the case of developing transversal competences, and especially conscious leadership, active learning is particularly relevant as it fosters students' interactions and collaborative learning (Ang et al. 2021). It is in line with the recent results of Routhe et al. (2024, p. 558) that for engineering leadership education "it is not enough to merely participate in leadership activities: more supporting actions and understandings are necessary". Consequently, to enhance the conscious leadership competence of our engineering students, we chose an active learning approach including various pedagogical methods and a 360° immersive experience (Slater and Sanchez-Vives 2016) by the creating a virtual and experiential learning space (Kolb 1984, Kolb and Kolb 2005, Bédard et al. 2020).

2 Engineering leadership development

The implementation of engineering leadership education in the engineering programmes is related to widespread acceptance and recognition of engineering as a leadership profession in society. Based on the results of Rottmann et al. (2015), there is a mismatch between the traditional notions of leadership (leaders viewed as charismatic visionaries, influence at the top of a hierarchy, agentic individuals, executive problem-solvers, delegators, or agents of change) and engineers' professional identities (engineers viewed as applied scientists, service professionals, team players, technical problem-solvers, task-oriented doers, or process-optimizers). Despite these discrepancies, professional practice for engineers involves traditionally and professionally legitimate forms of engineering leadership (technical mastery, collaborative optimization or organisational innovation). For this reason, in an engineering context, engineers' leadership identity is an important component of engineering leadership development. As highlighted by Wolfinbarger et al. (2021), leadership identity development enables engineering students to understand leadership not as a position, but as a process requiring more inclusive and collaborative behaviour. From this point of view, the ethical dimension of leadership is particularly important for practicing a 'consideration-oriented leadership' style focusing on treating employees with fairness, honesty and respect.

In the present work, we clearly distinguish between conscious and responsible leadership. We define conscious leadership as "the demonstration of normatively appropriate conduct through personal actions and interpersonal relationships and the promotion of such conduct to followers through two-way communication, reinforcement and decision-making" (Brown et al. 2005, p. 120). In line with the recent work of Kubátová and Kročil (2022), we consider conscious leadership as a larger concept embracing not only responsible leadership but also other leadership forms (like moral, ethical, or sustainable leadership). However, we underline the central role of the leader who practices fully human and social leadership, putting humanity at the center of interests.

3 Pedagogical design: five learning units with mixed pedagogy

We applied a constructivist approach when designing the new leadership teaching and learning programme, and took into consideration Richardson's (2003) critical view on student learning and effective constructivist teaching. We established a student-centred view based on discussions, interactions and collaborations between peers as well as between students and teachers or facilitators.

Our innovative course design was composed of five units with various learning and teaching content:

(1) First, students worked in groups to choose a case study on a specific topic (such as conflict management, performance interviews, or abuse of

authority in team management), developed a scenario and prepared an artefact (e.g.: improvisation, role-play, or short film). During this collaborative work, student learning is constructed by discussion of ethical, managerial and social issues. As recommended by Carl Rogers and Jerome Freiberg in "Freedom to Learn” (1994), this discussion between students and the teacher/facilitator by raising various questions is a first step for generating ideas. A second discussion was then held between peers, allowing them raise their own questions and reflect on it.

(2) Next, students had the opportunity to meet a professional Human Resources Manager with a large international company who provided constructive feedback on their case study. This professional leader presented and explained the application of the Social Responsibility Policy in his company in detail (using numerous examples) that was an important step for showing students the reality of a real work environment. This unit provided an opportunity to students to make iterative improvements on their case study resolution with the support of a professional leader in human capital management.

(3) After that, students attended tailored courses in situational leadership (Hersey-Blanchard model) and socio-dynamics providing theoretical concepts related to their case studies. We presumed that students would then be more receptive to theoretical concepts, enabling them to acquire academic knowledge that could be transferred to their cases. By directly applying the theoretical concepts presented to their case studies, a process called "concept testing" according to Jean Piaget, students can more easily assimilate and retain the knowledge gained. This application helped them to confirm their understanding.

(4) Students also participated in 360° immersive experiences using virtual reality headsets (Oculus Quest 2) and watching short films recorded using a 360° camera. The actors spoke to them, but not interactively (no response expected). The sound quality was very high and in stereo, further enhancing the sense of immersion. Students were thus immersed in virtual situations related to sensitive topics (such as everyday sexism at work, bullying, discrimination, and mental health prevention) generating intense and complex emotions. We decided to use this innovative method, with all the associated ethical considerations and students’ prior informed consent, to encourage empathy and decentring (in Piagetian theory, this is the ability to view a feeling from a third person perspective and consider multiple aspects of a situation or problem). For students, the use of virtual reality through 360° immersive technology provides an opportunity to consider diversity and integrate assertiveness by “living an experience” that is very different from their usual frame of reference. This experiential learning unit ended with a team debriefing guided by the teacher.

(5) Finally, in the last unit, after presenting their final version of their learning artefact (role-play or improvisation), students participated in debates on sensitive topics (e.g.: controversy over positive discrimination for women, controversy over the obligation of quotas to include minorities) related to their initial case study in order to help them in their decentring process and leadership development.

As this is a 16-hour compulsory module (divided into four three-hour lessons and one four-hour lesson), students assessment is required for grading. We opted for an assessment based on the presentation of a learning artefact using a criterion-based assessment with peer feedback allowing students to learn from the work of others.

4 APPLIED METHODOLOGY: MIXED QUANTITATIVE AND QUALITATIVE ANALYSIS

The programme was evaluated using mixed-methods, combining qualitative and quantitative approaches so as to make connections between our two data sets and better grasp students' perception from different perspectives. To gather quantitative data; we conducted a survey before and after the programme mainly focusing on the use 360° immersive technology for educational purposes. More specifically, we investigated students' expectations and learning experiences related to using such technology. The qualitative approach was achieved by organising a focus group discussion at the very end of the programme, prior to students learning their grades (to avoid being influenced by their feelings related to their grades). We developed a focus group guide focusing on student expectations, motivations, challenges, and perception of the applied mixed pedagogical approaches and learning outcomes. With the prior consent from participating students, the focus group was recorded and transcribed.

29 engineering students from two cohorts at Master 2 level participated in the study, and all of them were specialized in IEM (Industrial Engineering Management). This student population was composed of 8 (28%) female and 21 (72%) male students. This proportion is representative of gender distribution in our engineering school. Concerning their experiences with virtual reality headsets, 19 students (66%) reported having used it at least once before and 10 students (34%) had never used it.

We must highlight the heterogeneity of our students' population concerning their workplace and leadership experiences. On the one hand, we had 13 regular engineering students with only limited work and professional experience (in form of short internships) and no leadership experience. On the other, we had 4 military students who, prior to starting their engineering studies, completed one year of work experience in the army, including leadership training. They were required to manage senior and more experienced people in military missions allowing them to develop solid leadership competences. We also had 12 apprentice engineering students with at least two years of professional experience but generally without leadership roles.

Primary descriptive statistical data analyses were conducted on our quantitative data using SPSS. Subsequently, for the analysis of our qualitative or textual data, we conducted a thematic content analysis with the participation of three researchers. As this analysis is still in progress so we can only present our preliminary results in the following section.

5 RESULTS: STUDENTS BECOME ACTORS OF THEIR TRAINING

One of our most interesting results is that 71% of participating students believe that the new conscious leadership programme helped to prevent or decrease the risks posed by non-conscious leadership practice by making participants more aware of the dangers of discrimination, harassment, or mobbing in the workplace. In addition, half of the students confirmed changes in their perception concerning stereotypes and prejudices after their participation in the conscious leadership programme. They considered this programme an important and necessary part of their future professional development: “we're young, but we will have to manage people...and will encounter these situations which we've talked about so much”. It is interesting to note that several students underlined the importance of this programme in preparing them for sensitive and conflictual situations in a safe and secure learning environment. As they said “I think it's important to be confronted with it before being confronted with it for real” and “what was very, very good was that for once it wasn't based on consensual standards with an obvious solution, it was a real situation of conflict. I think it's very good and very important to show that sometimes there aren't obvious solutions”.

There were significant differences between students with and without leadership experience concerning their understanding and argumentation related to complex ethical, managerial and social issues. Students with leadership experience showed a deeper understanding of complex concepts and were able to deal with complexity more effectively, with a higher level of reflexivity and a more holistic view. Students without leadership experience recognized that “it's difficult to manage people when you've just come out of school. It seems completely relevant to have courses on how to manage people” in conflictual, complex, uncertain and sensitive situations.

The application of an active learning approach, which includes various pedagogical methods and virtual reality experiences, stimulated students’ expectations. As one of them said, “we came out of curiosity” and wanted to find out more of the new subject that we “really want to understand”. This mixed pedagogy was positively perceived by students for several reasons. It helped students: (1) better maintain their attention (memorial anchoring learning), (2) experience stimulating and creative interactions (e.g.: group discussions, exchange with a professional leader, improvisations) and (3) for facilitate their understanding of complex concepts through application.

In Table 1, we summarize students’ perceptions of their attention, understanding, stimulation, impact and surprise related to their participation in the new programme. We include some recommendations for improvements based on students’ feedback.

Table 1: Summary of students’ perception about the applied pedagogy and recommendations for improvements

Questions	Verbatim	Recommendations
Attention: *Was attention sustained throughout the course?*	"Better attention because you're in the action", "More captivating than a traditional course", "it doesn’t feel like taking a course"	Course planned over a period of three months. It should be over a shorter period to better maintain momentum.
Understanding: *Are the concepts more firmly anchored in your memory*?	"The range of points of view", "We get away from our usual references”, "The choice of case study is important"	Students' initiatives are constantly valued (positive education – Joseph et al. 2020) and students have the opportunity to choose a case study facilitating their learning process.
Stimulation:	“An individual experience that lets you feel strong emotions", "A course that allows you to express	Need for regular stimulation to ensure students’ involvement. It is important to keep on the autonomy of students’ teams.

Were you stimulated during the training?	yourself", "Freedom of action", "Twists and turns in the course"	
Impact: *What did you find most impactful?*	"The most impactful part of the programme was the discussion with a professional leader" (unanimous among students)	Discussion with a professional leader highlighted the usefulness of the programme for professional competences development.
Surprise: *What surprised you most?*	"Other people's views on a sensitive subject", "Debates on subjects we don't usually discuss "	Integration of socio-technical controversies makes it possible to address sensitive ethical and societal issues.

We investigated students' virtual reality experience in their programme by examining their motivation, interests and related stress (Table 2). Generally, students reported positive feedback on their immersive experience perceived as a stimulating and secure learning environment, which is important especially in the case of sensitive issues generating strong emotions. This point is in line with the findings of Bertagni et al. (2023).

Table 2: Summary of students' perception about the use of virtual reality and recommendations for improvements

Questions	Verbatim	Recommendations
Motivation	"Involvement in the story and feeling the emotions", "it's fun", "A digital tool for our generation", "Mobility and proximity of the actors who immerse us in the scene", "Hyper-realistic immersion"	Students immediately got to grips with virtual reality in a fun way with a realistic feeling but we should make sure to use virtual reality in a responsible and ethical way.
Interest	"I've already used virtual reality for instructions on board the ship and for seasickness, where the emotions were stronger", "Awareness of perceptions other than my own"	Interesting in the field of management and interpersonal relations because of the subjectivity involved. Post-stimulation debriefing is essential and reassuring.
Stress	"More curiosity than stress", "Small teams so more confidence", "Possibility of stopping if you want", "in virtual reality we experience much more shock and emotion"	There was no perceived stress. It is important to provide a safe virtual learning environment with strong ethical considerations and students' preliminary approval.

With the words of one participating student: "when we did the role-play, it was still quite light-hearted. If we start talking about sexual harassment, we can benefit from it [the use of virtual reality]". We have to highlight that the use of virtual reality was efficient for diverting the attention of sensitive students but requires strong ethical considerations for ensuring a safe and secure learning environment.

6 CONCLUSIONS

From our point of view, the main challenge of this new teaching and learning programme is shifting students' focus away from their initial values, beliefs, convictions and behaviours into a more people-centred and ethical perception of leadership. The main added value is that students have the opportunity to develop conscious leadership competences that will be essential for their future careers, through various learning experiences in a safe and secure learning environment. We underline the relevance of active and experiential learning in engaging students and encouraging them to question, reflect, share and adjust their perception of conscious leadership.

We consider that the use of virtual reality is a real asset for learning about the humanities as it supplies a safe experiential space where students can explore and manage their strong and sometimes destabilising emotions. Moreover, experiencing complex and challenging situations improves the understanding and acceptance of diversity and difference. This experience offers an interesting opportunity for participants to develop their emotional intelligence as a useful relational competence for human capital management in their future professional careers.

This new programme could be applied to contexts beyond engineering education but would require some alterations concerning the leadership identity development process (Wolfinbarger et al. 2021). Expanding the programme to other engineering schools at master level would be relatively easy with a more structured framework. However, engineering students' professional experience could be taken into consideration when designing the learning situation. As we mentioned earlier, we noticed important differences between students with or without professional leadership experience that would require some variations. The introduction of this programme at undergraduate level remains an open question as it would require significant modifications for students who have no previous experience of management or leadership education (Routhe et al. 2024).

We are currently considering developing this new programme in a more structured competency framework based on the revised Bloom's taxonomy (Bloom et al. 1956) in the affective domain. The main objective is to put more emphasis on the development of students' self-awareness, discernment capacity and emotional intelligence.

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REFERENCES

Ang, K. C., F. Afzal, and L. H. Crawford. "Transitioning from passive to active learning: Preparing future project leaders." *Project Leadership and Society* 2 (2021): 100016.

Beagon, U., B. Tabas, and K. Kövesi. "Report on the future role of engineers in society and the skills and competences engineering will require." Reports (2019).

Bennett, N. and J. Lemoine. "What VUCA really means for you." *Harvard Business Review* 92, 1/2 (2014).

Bertagni, B., Gardner, R., Minehart, R., and Salvetti, F. "An Immersive and Interactive Setting to Practice Emotional Intelligence." *International Journal of*

Advanced Corporate Learning (iJAC), *16*, 3 (2023): 21–26. https://doi.org/10.3991/ijac.v16i3.35735

Bédard, D., J. Bibeau, C. Pilon, and A. Turgeon. "L'Espace Expérientiel (E²) : Une pédagogie Interactive. ", *Les Annales De QPES* 1 (1), (2020). https://doi.org/10.14428/qpes.v1i1.55803.

Bloom, B. S., M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl. "Taxonomy of educational objectives: The classification of educational goals. Handbook 1: Cognitive domain." New York: Longman, 1956.

Brown, M. E., L. K. Treviño, and D. A. Harrison. "Ethical leadership: A social learning perspective for construct development and testing." *Organizational Behavior and Human Decision Processes* 97, 2 (2005): 117-134.

Joseph, S., D. Murphy, and J. Holford. "Positive education: A new look at Freedom to Learn." *Oxford Review of Education*, 46, 5 (2020): 549-562. https://doi.org/10.1080/03054985.2020.1726310.

Kolb, D. A. "Experiential Learning. Experience as the Source of Learning and Development." *Englewood Cliffs (N.J.)* : Prentice-Hall. 1984.

Kolb, A. Y., and Kolb, D. A. "Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education". *Academy of Management Learning & Education, 4*, 2 (2005): 193–212. https://doi.org/10.5465/AMLE.2005.17268566

Kubátová, J., and O. Kročil. "A conscious leadership competency framework for leadership training." *Industrial and Commercial Training* 54, 2 (2022): 279-292.

Richardson, V. "Constructivist pedagogy." *Teachers College Record*" 105, 9 (2003): 1623-1640.

Rogers, C. R., and H. J. Freiberg. Freedom to learn. Merrill/Macmillan College Publishing Co, 1994.

Rottmann, Cindy, Robin Sacks, and Douglas Reeve. "Engineering leadership: Grounding leadership theory in engineers' professional identities." *Leadership* 11, 3 (2015): 351-373.

Routhe, H. W., Egelund Holgaard, J., and Kolmos, A. "Students' learning of management and leadership in engineering education–a literature review." *European Journal of Engineering Education* 49, 3 (2024): 540-576.

Slater, M. and Sanchez-Vives, M.V. "Enhancing our lives with immersive virtual reality." *Frontiers in Robotics and AI*, 3, Article 74. (2016). https://doi.org/10.3389/frobt.2016.000 74

Wolfinbarger, K. G., R. L. Shehab, D. A. Trytten, and S. E. Walden. "The Influence of Engineering Competition Team Participation on Students' Leadership Identity Development." *Journal of Engineering Education* 110, 4 (2021): 925–948.

COLLABORATIVE COURSE (RE)DESIGN: ADAPTING ABC LEARNING DESIGN TO SUPPORT CURRICULUM TRANSFORMATION

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***Keywords**: learning design, academic development, course design, ABC Learning Desing*

ABSTRACT

The COVID-19 outbreak set in motion a ripple of changes that continue three years after the pandemic has subsided. Under pressure to provide flexible education, higher education institutions called for an increase in online and blended learning offerings. This placed a burden on educators to rapidly develop new pedagogical knowledge and skills and master online course design principles. The objective of this paper is to share the results of a pilot curriculum design process, based on the ABC Learning Design method, which has been effective in helping teachers to (re)design courses quickly and collaboratively. The process consists of a series of workshops, that encourage intense collaboration with the course team to create a visual map or storyboard of the course from the learners' perspective. To support this process in our faculty, our eLearning team modified the storyboard template and developed a course profile tool designed to enhance alignment between the course team members before they start (re)designing their course. This externalizes the vision that each team member has for the course, making it easy to have an in-depth group reflection about course goals, aiming for consensus, and helping to produce a more cohesive product.

1 INTRODUCTION

1.1 Background

In response to the post-pandemic trend towards online and blended education, our faculty determined to transition our programme to multi-modal delivery. Rather than designing one course for blended delivery and another for online delivery, a multi-modal design would mean that the same course could be delivered either fully online or face-to-face in a blended mode with only minor adjustments required. In addition to accommodating changing student expectations, the strategy is intended to offer more flexible education. A 5-phase curriculum design process was set up to enable the transformation of our programme. The process consists of Inventory, Analyse, Evaluate, Design, and Implement (Blanford and Verplanke 2023). This paper focuses on the process in Phase 4, the redesign of the courses and enabling faculty to deliver flexible education. The outputs from the first three phases were used to develop a series of workshops and resources to support educators in designing and redesigning their courses for multi-modal delivery.

The most logical first step to implement the multi-modal approach is to design fully online versions of our courses. It’s easier to adapt an online course to blended or face-to-face delivery, than working the other way around. However, we are cognizant of the challenges of transitioning to a fully online mode of delivery (Kebritchi, Lipschuetz and Santiague 2017). Rather than recommending this, we focussed on equipping teachers with practical tools and skills to support the course design process. We also wanted to provide exposure to alternative teaching approaches and best practices for online learning.

Three learning design methodologies caught our attention in terms of their practical, hands-on approach and effectiveness in supporting the design of online and blended courses: Carpe Diem Learning Design (Salmon and Wright 2014), the Creating Aligned Interactive educational Resource Opportunities workshops (Usher 2014), and ABC Learning Design (Young and Perovic 2016). All three methods are discipline-agnostic and require teachers to design courses collaboratively. However, Carpe Diem and the 7C's have a two-day workshop format. Considering the size of our programme, the workload of our academic staff, and the limited capacity of our support staff to run the workshops, these approaches were not viable for our faculty. In the case of Carpe Diem, by the end of the workshop, participants will have partly built their module in their learning management system (Salmon and Wright 2014). We didn't want any learning materials to be built until after we had aligned all courses within the programme. Courses might require a couple of iterations before the course design is finalised.

With this in mind, we developed a workshop based on the ABC Learning Design (ABC) method which was developed by Nataša Perović and Clive Young at University College London (Young and Perović 2016) and incorporates Laurillard's six learning types (Laurillard 2012). These workshops run over ninety minutes and are designed to help course teams quickly redesign their curriculum using a storyboard or visual representation of the student's journey through the course.

At the beginning of 2023, we ran several workshops and used this experience to gauge interest, determine challenges, and test and refine workshop materials so that we could start a full rollout in 2024 to support the revision of our programme. In this paper, we discuss how we adapted the ABC learning design method to meet the requirements of our programme revision process. We consider the results of the 2023 workshops and how we have further modified the course (re)design process for the upcoming workshop sessions in 2024.

1.2 The ABC Learning Design method & Laurillard's learning types

ABC Learning Design Workshops were first offered at UCL from 2015 to 2016 as a streamlined approach to curriculum (re)design (Young and Perović 2016). Since then, it has been adopted and modified by tertiary institutions in the United Kingdom and beyond. The method is built on the conversational framework developed by Prof Diana Laurillard (Laurillard 2002). Laurillard's six learning types (Laurillard 2012) are used to create a storyboard or visual overview of the course that outlines the sequence of learning activities that the student will follow. The learning types include Acquisition, Collaboration, Discussion, Investigation/Inquiry, Practice, and Production (Laurillard 2012). Five of these are active learning types, helping to prioritise active learning in the design of the course.

Overview of the original ABC workshops

The workshops were designed to encourage collaborative course creation. To do so, a series of activities are used to encourage interactive team discussions. Course teams are seated around large-format storyboards to provide opportunities to focus attention on educational strategies, gain an overview of course activities, and discuss issues raised by teachers or students.

The workshops are comprised of a series of activities that (i) start with icebreakers to encourage open discussions among course teams followed by (ii) creating a high-level map or storyboard using sequences of learning types (iii) selecting learning activities for each of the learning types in the sequence (Fig 1) (iv) and evaluate the storyboard based on several criteria e.g. learning types, online/offline mix, active learning etc. The method can be adapted to a variety of contexts by customizing the workshop introduction and the discussion and evaluation at the end.

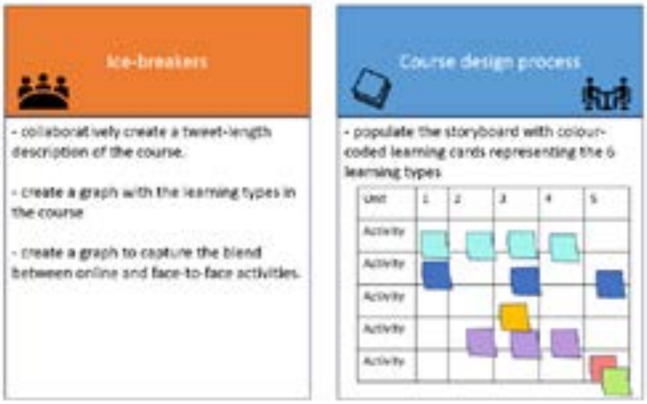

Fig 1. Overview of icebreakers and colour-coded storyboard capturing the 6 learning types used in a course.

There are many reasons that this method is a logical choice for our purposes. ABC Learning design has been particularly effective for (re)designing programmes and in transitioning courses to blended delivery. The process is activity-based, flexible, student-centered, prioritises active learning, is scalable, encourages discussion and collaboration, and is time-efficient. A map of the entire course can be created in ninety minutes to two hours (Young and Perovic 2016).

2. The Collaborative Course (Re)Design Process: Adapting the ABC method for our faculty

Localisation of the ABC method is easy to implement and was incorporated into the Collaborative Course (Re)Design (CCRD) workshop process. At UCL, most courses were verified courses, with approved learning outcomes and assessments. This was not the case for the CCRD workshops. Our programme learning outcomes have recently been revised and the course approval process in our faculty is being reconceived. As a result, we will need to support the constructive alignment of courses within the workshop.

The classic or 'Base' ABC Learning Design workshop process focuses on active learning, and diversifying learning activities. These strategies are beneficial in most educational contexts. However, in our faculty, due to the practical nature of our spatial engineering and geographic information science courses, most of our teachers already take an active approach, which means that the primary benefit for our faculty would be that it gets participants to think about diversifying their learning activities. To increase the value and impact of our Workshops, we wanted to include additional strategies and best practices for online and blended learning in the workshop process. The ABC method provides an opportunity to mention these strategies during the workshop introduction, but they are not integrated into the workshop activities. The Course Profile met this requirement in that it stimulates discussion about several course characteristics that impact online/blended learning before participants start with the design process.

Besides these adjustments, the CCRD workshop tasks and structure remain close to the original ABC method.

In 2023 we ran a pilot to test and evaluate the effectiveness of these workshops. The goal of the workshop was to enable teachers to (re)design their course within a two-hour workshop session.

2.1 Modifications to the storyboard

To make the ABC Learning Design fit for our purpose, we modified the design of the storyboard (Fig 2). One of the most important requirements was to align with a project being developed in our faculty to create a searchable catalogue of the education that we offer. The platform being developed will allow teachers and students in our Spatial Engineering and Geographic Information Science programmes to search for content by properties such as topic, software, delivery mode etc, and view elements linked to courses such as learning outcomes, European Credit and Accumulation Transfer System credits (ECTS), delivery mode, didactical approach etc. The output of our programme revision process needed to be in a format that is easy to transfer to the platform. We also needed to be able to customise the structure of the tool to our requirements.

We considered several open-source versions of the ABC Learning Design storyboard. Among these were templates created on Trello, Mural and Google Sheets and two web applications: the Learning Designer (Laurillard et al. 2018), developed at UCL and the Balanced Design Planning (BDP) tool which was developed at the University of Zagreb (Divjak et al. 2022). However, each of these presented challenges, either in terms of the General Data Protection Regulation (GDPR) requirements or adaptability. As a result, we created our own template in Microsoft Excel which is a modified version of the original ABC storyboard with some elements of the BDP tool and the Learning Design Planner (Gallenne and Jourde, 2023).

Although we modified the storyboard tool significantly, we adhered closely to ABC's storyboarding process, except for the addition of a step to write learning outcomes. Once learning outcomes and assessments have been aligned, the storyboarding process is the same as the original ABC method. First, the sequence of learning types is determined with the use of colour-coding. (See # 2 in Fig 2). Thereafter learning activities are selected for each of the cards (original ABC method) or coloured cells (CC(R)D process (see #3 in Fig2)

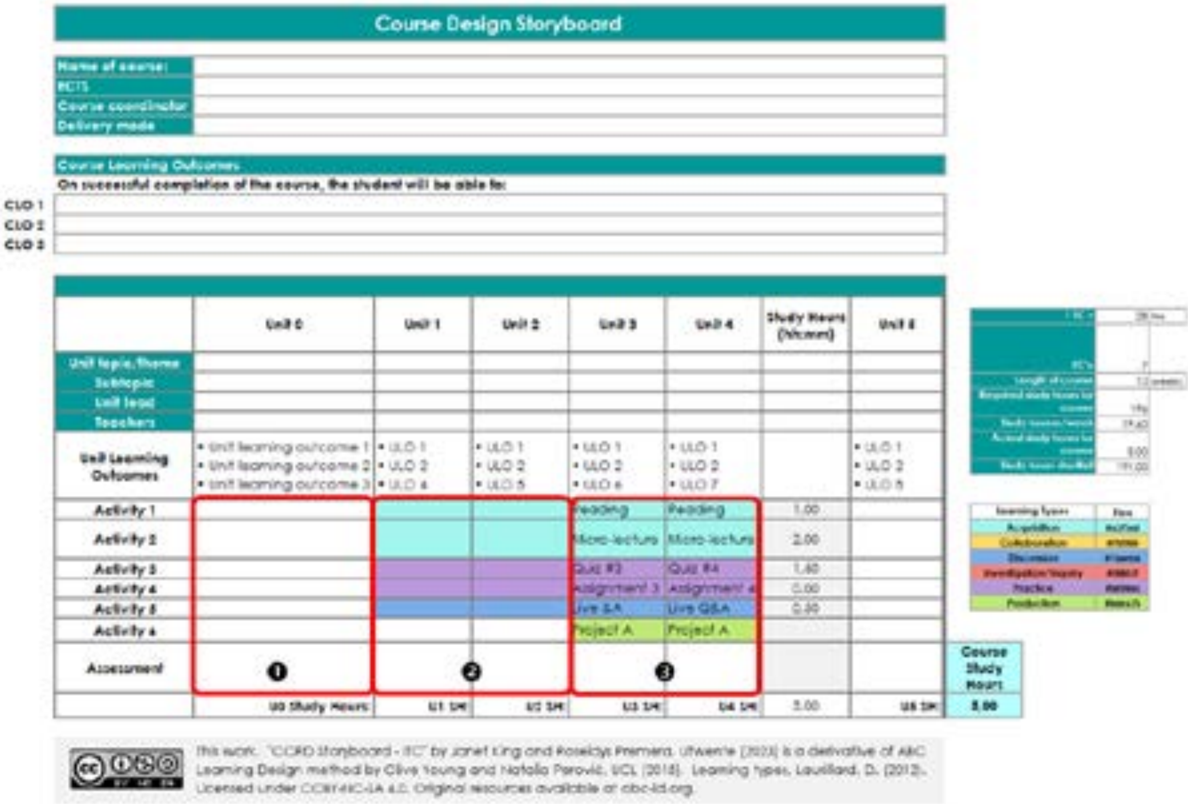

Fig. 2. Collaborative Course (Re)Design Storyboard 2023 and 2024

Adjustments included:

- **Course Learning Outcomes (CLOs).** CLOs are entered at the top of the storyboard and assessments at the bottom to support constructive alignment. There are also unit learning outcomes (ULOs) which are particularly helpful for fully online courses, if there is less interaction and feedback from teachers, because they help students monitor their own progress.
- **Storyboard layout.** The units/weeks run vertically from top to bottom rather than horizontally from left to right across the page, to make it easier to check alignment.
- **Assess workload for students.** Formulas calculate workload based on the ECTS (e.g. 1 ECTS=28 hours) and length of the course (e.g. 10 weeks). The formula captures the number of hours required to complete an activity based on the estimated times entered for each of the learning activities. The time fields are hidden by default but in Fig. 2, one of the fields has been unhidden.
- **Digital tools.** We selected MS Excel because it's easier and less time-consuming to store, share, compare and modify data. For each course team, we created an Excel workbook to capture all their workshop activities for example the course overview, the course profile, the storyboard the action plan.

2.2 Modifications to the workshop process

Our pilot workshops in 2023 followed a similar structure to the original ABC method with the addition of a couple of activities. Besides the tweet, course shape, and blend activity, we asked teams to define several other course characteristics e.g. synchronous vs asynchronous learning and group work vs individual activities, which together became the course profile.

Table 1: Overview of workshops, structure, and the activities used during the workshops.

Workshop	**ABC Learning Design**	**Workshop 2023 (Pilot)**	**Workshop 2024**
Workshop tools Format	• Physical	• Physical & Digital	• Digital only
Preworkshop tasks	N/A	• N/A Read definitions of learning types • Colour code inventory storyboard	• video on learning types
Workshop(s)	• Storyboarding workshop	• Storyboarding workshop	• Preworkshop • Prerequisite: Quality aligned CLOs • Workshop 1: Course profile, LO's & introduction • Workshop 2: Storyboarding • Workshop 3: Optimising course design
Workshop activities	• Tweet • Course shape (learning types) • Blend (online vs. face-to-face)	• Tweet • Course shape • Online vs. face-to-face blend • Synchronous vs. instructor paced • Individual vs. group work • Instructor/content centred vs. student-centred/active	• Tweet • Faculty vision on education • Course shape (learning types) • Online vs. Face-to-face • Self-study vs teacher-led activities • Synchronous vs asynchronous • Types of assessment e.g. summative, peer, self-assessment, auto-graded etc • Group vs individual • Kinds of feedback e.g. instructor to group or individual,

Based on feedback from the pilot workshops we made several adjustments and have established a set of three workshops to support the course design process (Table 1), each running between 1 hour and 2.5 hours. Workshop 1 is the introduction and includes the creation of a course profile and learning outcomes, Workshop 2 is the storyboarding workshop where teams create a first draft of their course design, and Workshop 3 introduces alternative teaching strategies and best practices and allows participants to optimise their course design by implementing some of these strategies.

The course profile activity was further extended to include among other characteristics, contact hours vs self-study, assessment types, and alignment with our faculty's vision on education (Fig.2). The discussion stimulated by this activity can help course teams to reach consensus about their goals for the course (in terms of these characteristics) before the course design process starts. This can potentially make course design quicker and easier and produce a more cohesive course.

Besides the pedagogical discussions within teams, we scheduled moments of sharing between teams to facilitate alignment and eliminate redundancies in the programme. Sharing the course profile is one of the tools that course teams can use to communicate their vision of the course with other teams.

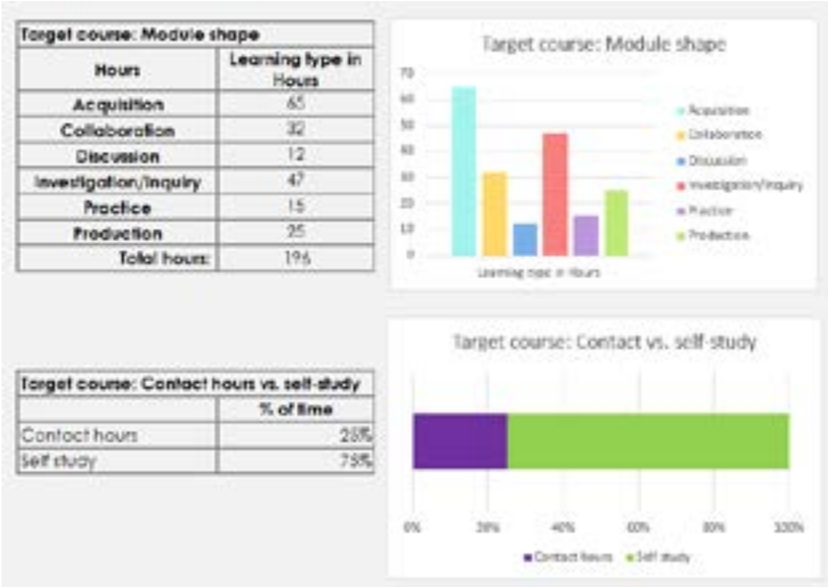

Fig. 2. Examples of some of the charts that make up the CC(R)D Course profile: Module shape chart and Contact hours vs. Self-study chart.

The course profile is easily transferable to other settings, however, the characteristics included in the tool should be selected based on the priorities of the context it's used in. For example, in our faculty we want to increase online and blended learning and reduce contact hours, therefore, it's useful to discuss the balance of self-study and teacher-led activities as well as synchronous vs. asynchronous learning. The amount of group work is significant because this can impact the sense of community online as will the quality and distribution of feedback.

3 RESULTS

In March and April 2023, seven course teams attended a CCRD workshop. Four workshops took place and 25 participants attended in total. Participants completed a Wooclap survey at the end of the workshop and we received responses from 17 of the 25 participants.

We are currently running the CCRD with the 3 workshops for the complete development of a new course for one-course team (N=7 participants).

Table 2: Workshops conducted, duration of workshops and number of participants.

Year	Workshop	N	Duration
2023	CCRD Pilot workshop	25	2 hours
2024	CCRD Workshop 1: Introduction to CC(R)D process & creating a course profile	+/-7	1 hour
	CCRD Workshop 2: Storyboarding	+/-7	2.5 hours
	CCRD Workshop 3: Optimise your course for online/blended delivery	+/-7	2.5 hours

3.1 2023 Workshops Results

Participants found the workshop process and tools valuable and most said that they would continue to use the tools after the workshop. Although the course storyboards differed in the level of detail, all but one team achieved the workshop objective which was to complete a first draft of their storyboard. Five of the course teams revised an existing course and one designed a new course. The team that didn’t complete their storyboard spent time discussing learning outcomes and ran out of time as a result.

Once the storyboards had been completed, teams were asked to evaluate them. Evaluating the extent of active learning in the storyboard was easy because of the colour-coded learning types. Evaluating other elements of the storyboard was not as successful. We had not provided an effective way to connect the best practices and strategies that we discussed to the evaluation step. Nor was there a way to reflect and record the additional detail. Further extending the course profile is one of the ways that we will tackle this challenge. Course teams define their target course characteristics (e.g. a ratio of 25% contact hours to 75% self-study) using the course profile tool, before designing the course. Ater their storyboard is completed they create a second course profile that reflects the actual course design. A comparison can be made between the two versions and discussed within the team.

Table 3: Survey results for 2023 pilot

question	response
Most useful aspects of the workshop	• having the opportunity to think about, discuss, and brainstorm their course design • usefulness of applying Dianna Laurillard’s learning types to their course design (N=6) • storyboard was useful (N=4) • A hands-on approach, • allocated time with the course team to talk about the course, • checking the boxes regarding the synchronous/asynchronous and online/face-to-face blend, • having to argue about the validity of activity types for the various LOs, • discussing the organization in the storyboard, • brainstorming in a structured manner, • colourful storytelling, • ideas and models for practical redesign online
What will staff continue to use	• use the process/tools that were shared with them in the workshop (N=13), one said that they already use it, and another gave an unclear answer
Improvements	• more time to complete the activities (N=4) • more examples would be helpful (N=2) • clearer instructions on how to use the workshop tools and complete the tasks (N=2)

3.2 2024 Trial Observations/Results

The team completed their storyboard design for a fully online course. The course profile activity proved to be a highly effective method to stimulate discussion within the group, particularly if the team is not yet fully aligned. As a result of our experiences with this trial, we will eliminate all pre-workshop tasks, except for an optional video about the learning types. Teachers are already overburdened so we have designed future workshops to ensure all tasks can be completed within the time they have set aside to attend a workshop.

Future goals

We will continue to develop and evolve the CCRD process, by adding and upgrading resources and providing examples of storyboard designs that have proved to be effective for online environments. What we ultimately hope for is to develop the process and tools to a point where teachers want to use these independently, outside of the workshop process. We are looking for suitable alternatives to the MS Excel storyboard. If we want it to include all of the features that we need, we will have to build this ourselves. The ABC learning design method was the right choice for our faculty because it didn't put an unnecessary time burden on our teachers or support staff and we were able to adapt it to our goals, priorities, and vision without affecting the consistency and effectiveness of the outcomes.

REFERENCES

Blanford, J. I., and J. Verplanke. 2023. "Transforming Curriculums For An Age Of Multi-Modal Education: A 5-Phase Approach." Paper presented at *51st Annual Conference of the European Society for Engineering Education (SEFI)*. Dublin, Ireland: Technological University Dublin, 2023.

Divjak, B., D. Grabar, B. Svetec, and P. Vondra. 2022. "Balanced Learning Design Planning: Concept and Tool." *Journal of Information and Organizational Sciences* 46, no. 2 (December): 361-375. https://doi.org/10.31341/jios.46.2.6

Gallenne, E., and F. Jourde. 2023. "Learning Designer Suite" accessed June 10, 2024, Last modified Mar 18, 2023. https://sites.google.com/view/learning-designer-suite/

Kebritchi, M., A. Lipschuetz, and L. Santiague. 2017. "Issues and Challenges for Teaching Successful Online Courses in Higher Education: A Literature Review." *Journal of Educational Technology Systems* 46, no. 1 (September): 4-29. https://doi.org/10.1177/0047239516661713

Laurillard, D. 2002. *Rethinking University Teaching: A conversational framework for the effective use of learning technologies*. 2nd Edition. London: Routledge.

Laurillard, D. 2012. *Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology*. 1st Edition. New York, Routledge.

Laurillard, D., E. Kennedy, P. Charlton, J. Wild, and D. Dimakopoulos. 2018. "Using technology to develop teachers as designers of TEL: Evaluating the learning designer." *British Journal of Educational Technology* 49, no. 6 (September): 1044-1058. https://doi.org/10.1111/bjet.12697

Salmon, G., and P. Wright. 2014. "Transforming Future Teaching Through 'Carpe Diem' Learning Design" *Education Sciences* 4, no. 1 (January): 52-63. https://doi.org/10.3390/educsci4010052

Usher, J.M. 2014. “Demystifying the CAIeRO” Learning Technology (blog). University of Northampton. December 24, 2014. https://blogs.northampton.ac.uk/learntech/2014/12/24/demystifying-the-caiero/

Young, C., & N. Perović 2016. "Rapid and creative course design: as easy as ABC?" *Procedia-Social and Behavioral Sciences* 228 (July): 390-395. https://doi.org/10.1016/j.sbspro.2016.07.058

MIRTE: an affordable, open, mobile robot education platform

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Keywords: *Robotics, STEM education, open educational resource, engineering education*

ABSTRACT

With robots becoming an increasingly constant feature in daily life, we must prepare and educate current and future generations. Although robotics outreach and robotics education are not new in engineering education, many educators and outreach providers face the same hurdles when using educational robots: Educational robots are expensive to buy, can become obsolete quickly and are time-consuming to maintain. In addition, many people feel unequipped to select the right robot for their purpose. This paper describes the development and implementation of a family of modular, affordable, open educational resource, mobile robots called MIRTE, that can be implemented across the entire educational spectrum and how continuity of the robots is ensured by following the principles of Open Education and Open Science. In the paper, current educational implementations are highlighted and plans for future developments and future research are discussed.

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1 Introduction

Robots are becoming a common occurrence in our society, with the use of robots no longer limited to industrial and medical applications but also as everyday appliances ranging from self-driving cars to robot vacuum cleaners. This will affect how we live and work in the not-so-distant future. Therefore, we must prepare and educate current and future generations for a life in which interacting with robots is commonplace. Using robots in education is not new. These days, courses in robotics at various levels of complexity, are common practice in most bachelor programmes in engineering. There is also an increasing trend towards dedicated bachelor, master and PhD programmes in robotics worldwide (Tilbury and Xiao 2023). In addition, many secondary schools have been using educational robots as a focal point for years as part of their science and technology curriculum (Evripidrou et al. 2020) as do many STEM outreach programmes aimed at the K-12 audience, such as First Lego League and RoboCup Junior (Eguchi 2016). All these programmes and initiatives face the same hurdles when using robots in their education and outreach: buying and maintaining robots in education is expensive and time-consuming and teachers often feel unequipped to select the right robot for their purpose.

In this paper, we will present an innovative, open-source, open-hardware, open-education mobile robot platform family for implementation in all levels of education which also can serve as an innovation and research platform for industry and research institutes.

1.1 Challenges of current robots used in education

Typically, three types of robots can be identified: fixed-base manipulators, as often seen in medical and industrial applications and two types of mobile robots: the legged robots, such as Boston Dynamics Spot and the rolling mobile robots, such as a robot vacuum cleaner, using tracks or wheels to move around with various levels of autonomy and self-learning capabilities. For education purposes, rolling mobile robots are used most frequently. Generally, educators across the entire education spectrum face several challenges when using robots in education:

1. Educational robots are not cheap, ranging from €100 - €600 per unit, with typically one robot needed per 2 – 8 students for meaningful engagement.
2. Robots become obsolete quickly, either because the manufacturer ceases to exist or because they cease support for the robot or its operating system. The latter is the case with the LEGO Mindstorms robots.
3. Robots are often only used a few hours per week during a few weeks per year, making robots an expensive investment for education (Arvin et al. 2019).
4. Many robot platforms are only aimed at one education level, for instance, only primary education. Few platforms offer flexibility across the educational spectrum and making the step to a more complex robot is an (unsurmountable) big step.
5. The educational focus of many robots is only on programming the robot. The robot itself comes as a finished product with LEGO Mindstorms and mBot being the most well-known exceptions.
6. Many robots are incompatible with standard components or other platforms, limiting possibilities and leading to educators being locked into one supplier (See Table 1).

It is therefore not surprising that many schools have outdated robots or are less keen to invest in yet another new robot, aside from the sustainability issues of schools having to keep purchasing new equipment.

Table 1. Comparison of a selection of low-cost mobile robot platforms for education (HW =Hardware, SW = Software, ★ = Supports ROS 1 and 2)

Robot	Cost (€)	Open Source (HW/SW)	Last OEM update	Easily available	Intended for use in			3rd party compatible (HW/ SW)	Visual Program.	ROS compatible
					Primary Education	Second.& Higher Educ.	Research			
Edison	660	✗	2023	✗	✓	✗	✗	✗	✓	✗
Europa II	120	HW/SW	2020	✓	✗	✓	✓	✓	✗	✓
mBot	79	SW	2023	✓	✓	✗	✗	✓	✓	✗
Thymio	195	SW	2023	✗	✓	✗	✗	✗	✓	✓
MARRtino	220	HW/SW	2022	✓	✗	✓	✓	✓	✗	✓
JetBot	250	HW/SW	2023	✓	✗	✓	✓	✓	✗	★
JetRacer AI Kit	234	SW	2023	✓	✗	✓	✓	✓	✗	★
PHeeno	27	HW/SW	2020	✗	✗	✓	✓	✓	✗	★
Duckiebot	370	HW/SW	2022	✓	✗	✓	✓	✓	✗	✓
Robobo	400	SW	2022	✓	✓	✓	✗	✗	✓	✓
LEGO EV3	500	SW	2023	✗	✓	✓	✗	✗	✓	✗
Koala 2.5	526	✗	2016	✗	✗	✓	✗	✗	✗	✗
Turtlebot 3 (burger)	650	HW/SW	2021	✗	✗	✓	✓	✓	✗	✓
Linorobot (2WD)	100	HW/SW	2018	✓	✗	✓	✓	✓	✗	✓
Mona	120	HW/SW	2019	✗	✗	✓	✗	✗	✗	✗
MIRTE Pioneer	**100**	**HW/SW**	**2024**	✓	✓	✓	✓	✓	✓	★

1.2 Introducing MIRTE

Frustrated with these challenges, in 2019, the first author, a lecturer in Mechanical Engineering at TU Delft set out to develop an affordable mobile robot platform, inspired by the One-Laptop-Per-Child initiative (Ames 2019) so that all children should have access to a robot, that like them, evolves in its capabilities as children become older. The aim of creating such a robot was to enable all levels of students to practice robotics making optimal use of the principles of Open Science to reduce cost and avoid the threat of obsoletion. This resulted in the development of MIRTE, which stands for: "*MIRTE, an Inspiring Robot for Technology Education".* In the remainder of this paper, we will present MIRTE, its features and capabilities and share our experiences in using MIRTE in education and its non-anticipated use for research and development purposes.

2 DESIGN PRINCIPLES BEHIND MIRTE

The first author's primary goal was to create an affordable robot that would last during the entire time any child anywhere spends in their formal education and that the robot itself would always be able to work, developing on par with the developments in the field of robotics and not be hindered by proprietary limitations. This gave rise to two main frameworks guiding the design:

Educational Framework: the robot must fit within the existing educational frameworks. Hence, in line with TU Delft's vision of education, the framework of Biesta (2021) was chosen which is based on the principles of *qualification* (foundational STEM knowledge at the appropriate level), *socialisation* (being able to think critically across cultural and societal contexts by working together in diverse classrooms) and *subjectification* (teaching students to take responsibility for their choices). The Biesta framework is designed for primary, secondary, and higher education and allows for continuous challenging of learners at their level.

Open Science Framework: To keep the cost of the robot to a minimum and to ensure the robot and its operating software would never become obsolete or that users run into limitations due to proprietary issues an Open Source approach was chosen. All software used in the robot is open source and will be made available through GitHub allowing others to contribute and continue development even if the initial creators are no longer involved. In line with that, all educational resources developed for the robot should be free and shared as much as possible as Open Educational Resources (OER). An Open Hardware approach must be used for hardware: no proprietary hardware was to be used and as few custom parts as possible. All components should be generic off-the-shelf components and any custom parts should be producible locally by a user. Using these principles, the cost can be kept at an absolute minimum and the robot will be as accessible, modular, and as inclusive as possible.

3 MIRTE ROBOT FAMILY

Following these principles, a family of affordable robots was created using an onion analogy, which allows the consumer of the onion to peel away a layer at a time (Fig.1). With each layer being removed, the next, more complex layer of technology is revealed underneath, allowing the learner to be challenged in deepening levels of education, delving deeper into the robot with increasing levels of hardware, the operating software and its complexity. This has resulted in an initial MIRTE family of three. In increasing order of hardware complexity and educational and software challenges, they are the MIRTE Light (Fig. 2a), the MIRTE Basic (Fig. 2b), and the MIRTE Pioneer (Fig. 2c).

Fig. 1. MIRTE's Onion Approach (blue = software, red = electronics, yellow = mechanical/design)

3.1 Design Features

All MIRTEs (https://www.mirte.org) share a common hardware basis consisting of a (wooden) chassis, wheels, motors, battery pack, and light sensor which allows users to add more hardware depending on their needs (modularity) and are powered by a standard 5V power bank. The base is not an off-the-shelf product, instead, we provide the DXF, STL, and FreeCAD files for people to make their own. Alternatively, they can use an existing or custom base. For the MIRTE Pioneer, we developed a dedicated PCB as an alternative to the Open Hardware solution of a breadboard combined with an MB102 Micro USB Interface Breadboard Power Supply Module and a splitter cable. More details on MIRTE's hardware options can be found in the MIRTE Docs (https://docs.mirte.org). In addition, a variety of sensors can be added to the robot, depending on needs and budget. The MIRTE chassis is partially compatible with LEGO Technics to allow for more modularity. In terms of software, the core of the onion is based on the open-source Robot Operating System (ROS: www.ros.org). All source code can be found in our GitHub repository (https://github.com/mirte-robot).

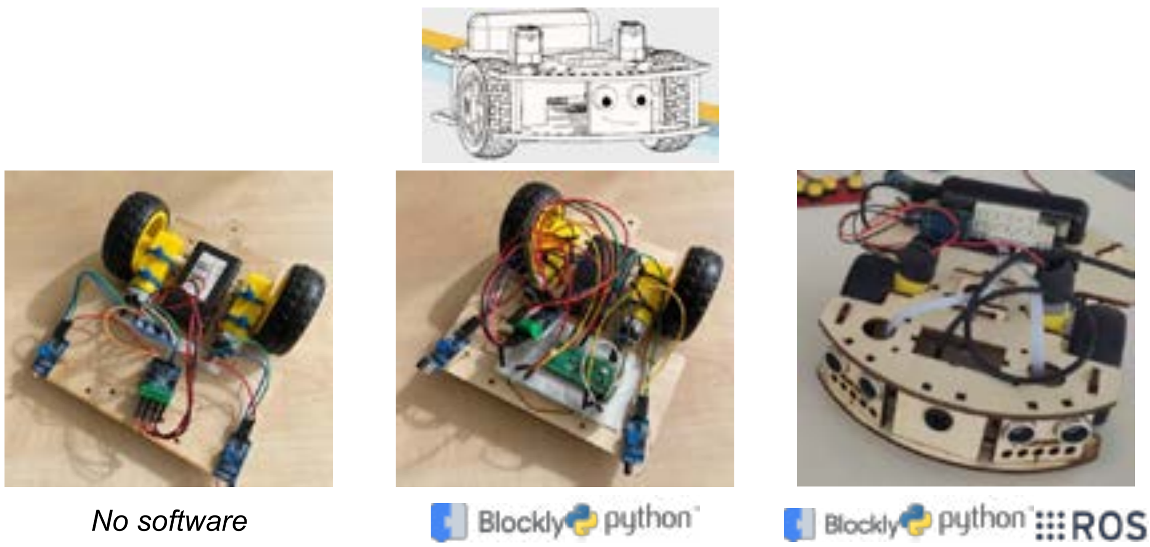

Fig. 2a. MIRTE Light (€15)Primary Education | *Fig. 2b. MIRTE Basic (€25)Primary and lower Secondary Education* | *Fig. 2c. MIRTE Pioneer (€100 – kit: €150) Secondary and Higher Education*

(prizes shown based on sourcing components and self-assembly)

From an educational viewpoint, ROS is suitable for use in Higher Education but likely too complex for primary and secondary education, hence two layers of software to reduce complexity have been added. A Python shell was added, for use in secondary education allowing students to code their robot. As this may still be too complex for most primary school students, an additional layer was created using Blockly. By varying the complexity of the hardware on the MIRTE Basic and MIRTE Pioneer and whether or not students are given a built robot or are assembling the robot themselves, students can also be introduced to different levels of complexity in electronics. You can use an off-the-shelf PCB or allow students to delve deeper into the electronics of the robot by using the breadboard alternative instead. You can also vary the types of sensors and actuators to enable students to learn more about signals and sensors.

Within the development process, the MIRTE Pioneer was developed first and is currently furthest in its development and implementation. At the core of this onion is a small, but complex, versatile, mobile, semi-autonomous robot, the MIRTE Pioneer, (Fig. 2c) primarily intended for use in secondary and higher education. The MIRTE Pioneer is fully programmable using ROS, with the ability to use many different sensors varying in complexity including a LIDAR which allows the robot to have simultaneous location and mapping (SLAM) to aid its navigational capabilities. MIRTE Basic and MIRTE Pioneer are currently being developed further, with emphasis on creating additional educational resources and teacher training modules as teachers in primary and secondary education need more support in teaching robotics and computer science.

3.2 Under Development

The MIRTE family is growing. The current MIRTE family can more than cover the domains of primary, secondary, and bachelor education. Recently, a larger, more powerful MIRTE, the MIRTE Master, was developed, (see Fig. 3) with a mobile robot arm, a LIDAR, a depth camera, omnidirectional wheels and a dedicated PCB. It was developed based on a design by 4 BSc students in Mechanical Engineering, showcasing the software modularity of MIRTE. The MIRTE Master is intended for use in BSc final year projects and MSc education as well as research and development projects that require a heavier base and the use of a robot arm. Whilst working under the same principles using the same software, all hardware components of the MIRTE Master have been upgraded and extended compared to the MIRTE Pioneer. It is currently being tested in a BSc final project and an MSc course at our university. Design iterations are being made to further modularity. As soon as the testing phase is finished we will make its open resources available. As

Fig. 3. MIRTE Master (€560)

ROS2 is rapidly becoming mainstream, we are also in the final testing stages of the ROS2 support for the MIRTEs which will be used in our education from next academic year and will be added to our GitHub later this year.

a) MIRTE Basic *b) Trash Sorting BSc ME* *c) Cow Herding MSc ME*

Fig. 4 MIRTE robots in use in education & outreach

4 MIRTE DEPLOYMENT

Since their creation MIRTEs have been used across the educational spectrum.

4.1 Primary and Secondary Education and Outreach

MIRTE is currently being used regularly at four local primary schools to introduce young students to the foundational concepts of robotics, and computational thinking. In addition, through outreach programmes, many primary schools source workshops on Robotics using MIRTE (Fig. 4a). MIRTE fits seamlessly into our national STEM curricula, providing a hands-on approach to learning that complements theoretical studies in STEM fields. Currently, MIRTEs are used as an integrated part of the STEM curriculum in three local secondary schools. In addition, students and staff regularly give 2-hour workshops at secondary schools.

Due to their affordability and diversity MIRTEs are an excellent tool to promote STEM with young people. Through workshops, facilitated by dedicated educators and robotics enthusiasts, young people are provided with hands-on experiences that not only teach the fundamentals of robotics but also encourage creative problem-solving and collaborative learning. These workshops take place both on campus and on location on an almost weekly basis. Within this initiative, there is also a strong emphasis on instructor training to equip more educators and STEM volunteers with the knowledge and tools needed.

There is a clear need for resources and support for primary and secondary teachers and workshop facilitators. We are therefore developing dedicated (open) education resources. For primary schools, we are in the process of creating open resources based on our workshops. For secondary education, we have developed open educational resources (https://workshops.mirte.org/nl/) in workshop format. We also provide workshops for primary and secondary school teachers to gain first-hand experience with MIRTE. We are currently in the process of developing a full MIRTE-based robotics learning line for the subject Nature, Life, and Technology, which is an elective in Dutch upper secondary schools.

4.2 Higher Education

MIRTEs are already used intensively in the BSc and MSc Mechanical Engineering (ME) and the BSc of Computer Science and Engineering (CSE) at TU Delft:

1. In the second year BSc Robotics project (6 EC) at ME students are taught about robotics, electronics and sensors. 600 Students build their own MIRTE pioneer in pairs and design and manufacture parts of their base and a small robot arm to perform a specific task, such as trash sorting (Fig. 4b).
2. MIRTE pioneers are also used in the 20 EC, interdisciplinary robotics honours programme for excellent BSc students.
3. In the Introduction to ROS course (2 EC) of the interdisciplinary minor Robotics (30 EC) in the 3rd year of the BSc.
4. MIRTE pioneers have also been used in our MSc Robotics - Fig. 4c (Saunders-Smits et al. 2023, van der Niet et al. 2023) having been replaced by MIRTE Masters this year (Fig. 3).
5. Within the 2nd year BSc course Embedded Software some 100 CSE students make different use of the MIRTE Pioneer, programming the microcontroller but do not change the design of the base.

The affordability of MIRTE allows students to not have to settle for programming simulations, they can test their programmes on a real robot. MIRTE allows lecturers flexibility to select which feature of MIRTE can aid them in achieving the desired learning objectives.

4.3 Commercial and Research and Development Use

An unexpected, but much-valued, user area of MIRTEs also emerged from this project. Due to their affordability combined with their versatility and ROS capabilities, startups and the R&D departments of companies such as Lely and Alliander have started to use MIRTE as a research and development platform which led to demand for us to produce MIRTES for others. However, in line with the non-profit status of our university and our Open Hardware philosophy of build-you-own, we decided not to produce and sell MIRTEs commercially ourselves. To meet this demand and to make it easier for 'non-makers' to get started with MIRTE, the "I am MIRTE Foundation" (https://iammirte.org) was created which produces and sells MIRTE kits to aid those unable or unwilling to source MIRTE materials with all proceeds being used to fund MIRTE workshops in underprivileged areas.

5 REFLECTION AND FUTURE DEVELOPMENTS

With MIRTE approaching its 5th birthday, most of the initial objectives of the first author to make an affordable, open mobile platform have been reached. Although the exact number of robots produced is hard to estimate, as MIRTE is open hardware, more than 1600 MIRTEs have been produced for use within TU Delft and our outreach workshops. To our knowledge, MIRTEs are currently owned and used by 8 schools and universities, with many more schools choosing not to own robots but buy in MIRTE workshops. Starting this summer, we are increasing our promotion activities, for instance through workshops at the RoboCup Junior Symposium in Eindhoven, and presenting this paper at this year's SEFI conference. Using this snowballing approach, we hope to add more users and developers to the MIRTE community, which can be found at: https://www.mirte.org/.

MIRTE Pioneer has matured well, but we foresee the following future developments:

1. Make the MIRTE Basic and MIRTE Light more accessible for primary schools and STEM outreach for that age range by developing open educational resources to aid primary school teachers and STEM volunteers.
2. Facilitate and expedite the use of MIRTE Pioneers in secondary education by developing educational frameworks and modules together with the Science Education and Teacher Training Specialists of both TU Delft and TU Eindhoven to fit within government-set STEM learning outcomes.
3. Expand the use of MIRTE to more universities: a project with the Mechatronics programme of The Hague University of Applied Sciences is awaiting a funding decision and further (inter)national collaboration is high on our wish list.
4. Continue development of the MIRTE Master and its outdoor sibling to add them to the Open Family of MIRTEs.
5. Continue to Grow an Open Science Community of MIRTE users and developers beyond the doors of our university and its immediate surroundings.
6. Scientifically evaluate MIRTE's educational and outreach contributions and carry out long-term studies on its impact, allowing evidence-based improvements to the educational qualities and potential of our MIRTEs across all levels of education
7. Arrange more funding to realise our ambitions

We believe these developments are needed to allow MIRTE to become the affordable (and hence more inclusive) open platform of choice in robotics.

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REFERENCES

Ames, Morgan G. 2019. *The Charisma Machine: The Life, Death, and Legacy of One Laptop per Child*. Cambridge: MIT Press.

Arvin, Farshad., Jose Espinosa, Benjamin Bird, Andrew West, Simon Watson, and Barry Lennox. 2019: "Mona: an Affordable Open-Source Mobile Robot for Education and Research." *Journal of Intelligent and Robotic Systems* 94(2019):761–775. https://doi.org/10.1007/s10846-018-0866-9 .

Biesta, Gert. 2021. *World-centred education*. London/New York: Routledge.

Eguchi, Amy. 2016. "RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition." *Robotics and Autonomous Systems*, 75(B):692-699. https://doi.org/10.1016/j.robot.2015.05.013

Evripidou, Salomi, Kyriakoula Georgiou, Lefteris Doitsidis, Angelos A. Amanatiadis, Zinon Zinonos, and Savvas A. Chatzichristofis. 2020. "Educational Robotics:

Platforms, Competitions and Expected Learning Outcomes." *IEEE Access*, 8(2020):219534-219562. https://doi.org/10.1109/ACCESS.2020.3042555

Saunders-Smits, Gillian, R.H. Bossen, and Joost de Winter. 2023. "A first look at robotics alumni – are they ready to handle future challenges?" Paper presented at *SEFI 2023 Annual Conference*, *Dublin, 10-14 Sept. 2023*. https://doi.org/10.21427/3VA6-M479

Tilbury, Dawn, and J. Xiao. 2023. "Formal Robotics Education Programs: Best Practices and Future Opportunities*." IROS 2023 Forum, Michigan, Oct. 2023.* http://robotics.umich.edu/irosforum

Van der Niet, Astrid, Cilia Claij, and Gillian N. Saunders-Smits. 2023. "Educating future Robotics Engineers in multidisciplinary approaches in Robot Design." Paper presented at *SEFI 2023 Annual Conference*, *Dublin, 10-14 Sept. 2023.* https://doi.org/10.21427/W6WB-Z113

ON EMPLOYER VIEWS REGARDING ALUMNI'S CONTRIBUTIONS TO SUSTAINABLE DEVELOPMENT

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***Keywords**: Investigations on Companies, Sustainable Development, Alumni Contributions to Companies*

ABSTRACT

In Sweden various laws and regulations related to Sustainable Development (SD) has been implemented, and Swedish companies must adhere to such laws and regulations and declare how those are met. Moreover, directives from the European Union point out obligations that even further increases the sustainability demands on the companies. Thus, alumni's' competences and skills regarding SD should be valuable to fit well into their employers' SD strategies, and possibly be contributing to such. This contribution aims to study how well alumni from the Computer Science dept. of Kristianstad University, Sweden, contribute to their profession and working place with respect to SD, *seen from an employer perspective*. A survey was sent to representatives of companies collaborating with the university to provide a preliminary view on how well the alumni contribute to the companies' SD context. From the responses, which came only 25% of the survey participants, we observe an awareness of SD knowledge and an approach of integrating SD into their organisations. Furthermore, it could be valuable to equip students with additional knowledge of the companies' situation regarding SD regulations.

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1 INTRODUCTION

1.1 Background

Since early 2017, Swedish companies have been required to report on their sustainability efforts, including environmental, social, and anti-corruption measures, as well as their organizational strategies for improvement (QBase 2024). Additionally, the European Union's (EU) Corporate Sustainability Reporting Directive (CSRD) aims to standardize sustainability reporting for companies within the EU (PERSEFONI 2024).

Given these regulations, educating students in SD is crucial for enhancing their employability and benefiting employers. Swedish universities are also mandated to integrate SD into various organizational levels, incorporating relevant knowledge and experience into programs and courses (UHR, Act 2023).

1.2 Educational Frameworks

From a historical perspective, it may be interesting to see Aristotle's three forms of knowledge, Episteme (scientific knowledge), Techne (skill and crafts) and Phronesis (often translated as practical wisdom) (Järnerot, Veelo and Lund 2019). Here, Phronesis in particular stands for competencies regarding ethics and relation to politics and society (Einarson and Melén Fäldt , HKR 2017), and (Steyn and Sewchurran 2021) argue that this virtue as a form of practical wisdom should be an integral part of management development.

Moreover, the Swedish Higher Education Ordinance (UHR, Ordinance 2023) specifies the general forms for the learning outcomes that must apply to the various education programs. The learning outcomes are mainly divided into three sections, that is, 1) Knowledge and understanding, 2) Competence and skills, and 3) Judgment and approach. For each of these sections, it is then specified what these contain. For example, for a Degree of Bachelor (DA399E 2024), the third section for instance includes:

- demonstrate the ability to make assessments with regard to relevant scientific, societal and ethical aspects in the field of computer science (learning outcome 3.6)
- demonstrate insight into the role of computer science in society and the responsibility of the individual for how it is used (learning outcome 3.7).

It can be interpreted as that this corresponds to a future-oriented approach, where the students will be prepared for insights into how their knowledge and skills should be implemented in a societal perspective, and in responsible and ethical ways.

In the above contexts (Einarson and Fäldt, 2017) discusses the striking similarity between the Higher Education Ordinance's sections on knowledge and Aristotle's forms of knowledge and points out the following relationships:

1) Knowledge and understanding - Episteme.
2) Competence and skills - Techne
3) Judgment and approach – Phronesis

Here, sustainability is not mentioned explicitly, but it is of particular interest in this paper to see the conditions regarding point 3) above. When it comes to social impact and ethical aspects, we here see SD as a way to correspond to such issues. With the knowledge the students have acquired, how are these used in appropriate ways in the working contexts in which they in the future will operate? Einarson discusses how point 3) is implemented in one of the courses in computer science program (Einarson, HKR 2017).

Computer Science at Kristianstad University (CS@HKR) has been a member of an international network and educational framework CDIO (CDIO n.d.), for several years. CDIO proposes a set of learning outcomes (CDIO Syllabus 3.0 n.d.) for engineering courses to prepare students to face the complexities faced by business. It is interesting to see here that this is not only a question of elucidating the mentioned points 1) and 2) above, but also essentially point 3). For instance, examples that illuminate on this and moreover address SD, include:

- Visions for a sustainable future for society and for one's profession,
- The impact of engineering on the environmental, social, knowledge and economic systems in modern culture,
- Considering one's contributions to the local community and (global) society.

1.3 The CS@HKR Case

The Bachelor Program in Software Development at Kristianstad University in Sweden is a three-year program provided to both national (Swedish) and international students. Following multiple revisions, the program now offers a well-defined progression through its courses. It also emphasizes the development of academic skills and integrates sustainable development principles throughout the curriculum. Already at the beginning of the first semester, the students take part in the concepts within SD and especially with a starting point in Agenda 2030 and the 17 Sustainability Goals (SDGs). With this as inspiration, students then write a report focusing on an imagined system with SD contributions, enabling them to make simpler assessments with regard to relevant social and ethical aspects (learning outcome 3.10). In the second year, students take a further step by implementing their systems and reporting on how these contribute to SD. During the third year, the students participate in a larger project, in the direction of smart home technologies for quality-of-life values for disabled young people. This approach is further detailed in reports by (Klonowska, Teljega and Einarson, SEFI 2023). In addition, reflecting on SD-aspects is mandatory in the degree thesis, aligning with the assessments outlined in the "Judgment and approach" learning outcomes described above.

A survey showed that the students predominantly thought it was important that software developers consider ethical and sustainable issues in their work

(Klonowska, Teljega and Einarson, SEFI 2023). Furthermore, it also emerged that the students considered that they had acquired good knowledge within SD and how they can contribute to SD.

Another component in this context concerns how well the students are prepared in the education for professional life through contacts with the surrounding society, such as with companies. (Einarson, Frisk and Klonowska, CDIO 2022) reports on concepts regarding Work-Integrated Learning (WIL) and Work-Based Learning (WBL) and addresses the good values that such educational elements have. Although (Einarson, Frisk and Klonowska, CDIO 2022) also sees challenges in finding good forms for this within the highly specialized IT industry, the meetings between student and company are seen as valuable for several reasons.

One form adopted at HKR is the Imagine project (Imagine 2023), (Klonowska, Teljega and Frisk, SEFI 2023). Imagine is applied with the aim of preparing the students in their professional role, to be able to actively contribute to their workplace and work to identify and find innovative solutions to societal challenges. Imagine is offered several times a year with different main themes, such as, City and Society of the Future, Sustainable Food Production, and Food of the Future / Healthy Life / Purchasing Behaviour. Several external actors participate as clients, such as from business and municipalities. The concept has generally been seen as very successful from the perspective of all involved parties.

From the above presented discussions, it is motivated to believe that students are fairly well prepared to meet the demands on companies regarding SD and the impact they may have on SD. Still, while the universities are in control during the study programs, it is not always clear what the effect is at the students' transform into alumni. This contribution aims to investigate the awareness of SD in society seen from a perspective of their professions, and of their employers.

1.4 Related work

To the best of our knowledge, there is no specific research that examines companies' perspectives on education related to sustainable development (SD) in a broad sense. However, numerous articles document the outcomes of various projects that involve collaborations between universities and companies with a focus on SD, e.g. (Swacha, et al. 2021), or from students' perspective, e.g. (Fourati-Jamoussi, et al. 2021).

2 METHODOLOGY

2.1 Context and Participants

During the spring of 2024, the authors of this contribution designed a survey that was sent to representatives of companies collaborating with CS@HKR. The first question focused on the companies understanding of SD. Further questions were assessed of alumni perceptions and experiences regarding the integration of SD principles within their professional contexts and the effectiveness of their education in preparing them for roles related to SD within their companies. Since we did not find similar study, all questions were prepared from scratch.

The survey of this study has addressed the following questions:

1. What role do you believe knowledge in sustainable development plays in promoting innovation and competitiveness within the company?
2. Is sustainable development a topic discussed within the company with alumni as part of their professional framework?
3. Can you perceive how well-prepared alumni are to take responsibility for sustainable development within their profession?
4. Can you observe how effectively alumni contribute to sustainable development at various levels of the company's operations?
5. Do you feel that there is anything additional that alumni should have learned from their education in sustainable development to carry out their work responsibly?

2.2 Data collection and Analysis

The questionary has been sent to 32 individuals from 22 companies collaborating with the university. There were 8 responses, equivalent to a 25% response rate.

Since the questionary was anonymous, it is not possible to determine whether the responses came from the same company or different companies. This survey was based on qualitative data.

3 RESULTS AND ANALYSIS

Questions (1 to 5) and their corresponding answers were grouped into incremental agreement categories represented by a scale, including "not relevant/not applicable" (denoted as **N**), "potentially meaningful" (denoted as **P**), and "meaningful" (denoted as **M**). The distribution of the answers is presented in Table 1 below.

Table 1. Distribution of answers

	N	P	M
1	0	1	7
2	0	3	5
3	2	4	2
4	2	1	5
5	3	4	1

Below are exemplified some of the responses, where example answers are indexed according to **[Row,Column]**.

1. What role do you believe knowledge in sustainable development plays in promoting innovation and competitiveness within the company?
   - **[1,P]**: Generally speaking, quite a small role. For some narrower areas, it can be of great importance, but the majority of companies are largely governed by the limitations "sustainable development" creates. Knowledge of future policies and directives is of course directly valuable, but is again often a limitation, even if innovation and competitiveness are affected by knowledge of the area.
   - **[1,M]**: In view of the CSRD reporting that will soon become a legal requirement, this is a requirement. The companies that succeed in embracing CSRD as a tool in their efficiency work will do better than their competitors who see CSRD as a burden and cost.
2. Is sustainable development a topic discussed within the company with alumni as part of their professional framework?
   - **[2,P]**: Yes and no. My experience is that it is discussed, but too little.
   - **[2,M]**: Within XXX, we have an organization that works with sustainability issues related to Agenda 2030.
3. Can you perceive how well-prepared alumni are to take responsibility for sustainable development within their profession?
   - **[3,N]**: The employees we have who are trained in computer systems are reasonably well prepared technically but not commercially. Use cases and their possible sustainability aspects often require several years of concrete commercial activity to create relevant creative competence.
   - **[3,P]**: It largely depends on the role and area of responsibility. It will be a huge waste of resources if everyone in a company focuses their energy on that

issue. Of course, it can have an impact on many areas, but it is usually not the primary area.
- **[3,M]**: Sustainable development is a need that we recognize is needed in these new times. This means new solutions that require new knowledge from various educational programmes. However, this also requires constant learning after school. Something that alumni definitely need to bring with them in their jobs.

4. Can you observe how effectively alumni contribute to sustainable development at various levels of the company's operations?
   - **[4,P]**: I am sure they can contribute with academic and research-based knowledge
   - **[4,M]**: Take, for example, AI, which is a new field (well, the mathematics is from the 40s) where development is happening at breakneck speed. It is a good example of how courses that both make students more attractive, but also alumni quickly become senior. There aren't that many people who have worked on this subject.
   - **[4,M]**: Having a broader perspective usually accompanies people with higher education.
5. Do you feel that there is anything additional that alumni should have learned from their education in sustainable development to carry out their work responsibly?
   - **[5,P]**: According to the reply to 3 "genuine" internships if they are possible to get. The company is an odd bird in this context, a small privately owned development company (about 20 developers) but with global customers and technical expertise.
   - **[5,P]**: You have to put everything in perspective so you don't sub-optimize and because this is a "tool" that everyone works with in some respect, you can waste a lot of resource time. Much like with the fact that everyone in the EU approves Cookie settings still to really very little use. An incredible amount of resources are put into it, both to build and to manage.
   - **[5,P]**: My education is too far back in time, so it's hard for me to determine how much is being done today. Nor can I tell from today's alumni how much they know or have learned. The short answer is therefore: I would have liked to have seen more knowledge on the subject.
   - **[5,M]**: ESG/CSRD, how will it affect companies and their role in the future. Many companies today are looking for expertise in ESG/CSRD. Issues of traceability will be of great importance both in terms of the physical flow but also in terms of data.

The respondents´ positive responses on two first questions confirm the awareness of knowledge in SD and indicate an approach of integrating SD into the organisation. In questions 3 – 5, the respondents classified in **N** column usually put the answers of type ‘No’ or ‘Not concrete’. One respondent claims that several years of experience are required to take responsibility for sustainable development. Another respondent considers sustainable development as a broad perspective subject where the responsibility lies with people with higher education (question 4). Question 5 was mostly qualified as a recommendation to the university.

What can possibly be sensed on the part of the entrepreneurs is a certain frustration at having to be pressured by regulations that are difficult to understand and deal with. Their primary priorities are of course mainly on doing business. What can be mentioned in this context is that the UN's Agenda 2030 for SD is based on three dimensions, the environmental, social and economic (Sweden 2024). CSRD does not actually mention the third dimension, i.e. economy, but where this seems to be seen more as a trade-off. The Agenda 2030's 17 SD Goals are interrelated and where both synergies and balances are discussed in, for example, (Wong 2021). Trade-offs and possible negative consequences may itself justify regulations to avoid bad impact from the part of companies. This, in turn, entails a need for greater knowledge of such regulations on the part of the companies.

4 SUMMARY AND ACKNOWLEDGEMENTS

Educational frameworks address student adaption towards their future work through pointing out learning outcomes regarding social and ethical aspects. While SD may not always explicitly be pointed out, it can be understood that such aspects also regard SD. Alumni’s’ competences and skills regarding SD should be valuable to fit well into their employers’ SD strategies, and possibly be contributing to such.

This study, even with the limited number of responses (8) confirms that the companies (included in the study) generally seem to have good knowledge of SD. What emerges, however, is that it is more challenging to work with SD-based assignments than to give such assignments to newly graduated students, especially computer science students. Employees with such responsibilities usually have more experience than recent graduates. Our students obtain fairly good competences in concepts regarding SD. However, it is recommended to contribute to the students with additional knowledge of the companies' situation regarding SD regulations such as CSRD. This could benefit companies as well as students' future career opportunities. What one can ask, however, is how reasonable it is to provide such themes within a Computer Science education. One possibility, which will be investigated further, is to use WIL, as previously described in this contribution, to look further into the IT companies' SD activities and the regulations regarding them.

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REFERENCES

CDIO. *CDIO.* n.d. http://www.cdio.org/about.

CDIO Syllabus 3.0. n.d. http://www.cdio.org/content/cdio-syllabus-30.

DA399E. "Course syllabus - Bachelor Thesis in Computer Science - 15 credits - DA399E , English | HKR.se." 2024. https://www.hkr.se/en/course/DA399E/course-syllabus.

Einarson, Daniel. "Värderingsförmåga och förhållningssätt i Software Engineering (in Swedish)." *Kristianstad University Press*, 1 2017: 72-80.

Einarson, Daniel, and Maria Melén Fäldt . "Introduktion till Temanumret: läraktiviteter för att uppnå värderingsförmåga och förhållningssätt (in Swedish)." *Kristianstad University Press*, 1 2017: 2-15.

Einarson, Daniel, Fredrik Frisk, and Kamilla Klonowska. "Work-Based Learning in Computer Science Education: Opportunities and Limitations." *18th CDIO International Conference.* Reykjavík, Iceland: CDIO, 2022.

Fourati-Jamoussi, Fatma, Michel J. F. Dubois, Marie Chedru, and Geoffroy Belhenniche. "Education for Sustainable Development and Innovation in Engineering School: Students' Perception." *Sustainability* 13, no. 11 (2021): 6003.

HKR, Imagine Project. 2023. https://www.hkr.se/en/collaboration/Collaboration-for-students/hkr-innovation/imagine-innovation-training/.

Järnerot, Anna, Nicole Veelo, and Anne Lund. "How Can Aristotle's Classification Of Knowledge Be Used To Analyze Teacher students' development of professional understanding/identity?" *ECER.* Hamburg: ECER, 2019.

Klonowska, Kamilla, Marijana Teljega, and Daniel Einarson. "A three-year academic track towards literacy in Sustainable Development: - A Computer Science Study Program Case." Edited by SEFI. *European Society for Engineering Education: Engineering Education for Sustainability.* Dublin, Ireland: SEFI, 2023.

Klonowska, Kamilla, Marijana Teljega, and Fredrik Frisk. "Engaging Students Through Innovation in Computer Science Education." Edited by SEFI. *European Society for Engineering Education: Engineering Education for Sustainability.* Dublin, Irland: SEFI, 2023.

PERSEFONI. *CSRD: A Guide to the Corporate Sustainability Reporting Directive, .* March 31, 2024. https://www.persefoni.com/en-gb/blog/what-is-csrd#why-did-the-european-commission-propose-the-csrd (accessed 04 04, 2024).

QBase. *Legal compliance.* 2024. https://qbase.se/en/law-compliance/ (accessed 04 04, 2024).

Steyn, Francois, and Kosheek Sewchurran. "Towards a Grainier Understanding of How to Encourage Morally Responsible Leadership Through the Development of Phronesis: A Typology of Managerial Phronesis." *Journal of Business Ethics* 170, no. 4 (2021): 673 - 695.

Swacha, Jakub, et al. "Introducing Sustainable Development Topics into Computer Science Education: Design and Evaluation of the Eco JSity Game." *Sustainability* 13, no. 8 (2021): 4244.

Sweden, Government Offices of. *The Global Goals and the 2030 Agenda for Sustainable Development.* 2024. https://www.government.se/government-policy/the-global-goals-and-the-2030-Agenda-for-sustainable-development/ (accessed 04 04, 2024).

UHR Act, UHRCouncil for Higher Education. *The Swedish Higher Education Act (1992:1434).* June 30, 2023. https://www.uhr.se/en/start/laws-and-regulations/Laws-and-regulations/The-Swedish-Higher-Education-Act/.

UHR Ordinance, *The Swedish Higher Education Ordinance (1993:100).* November 6, 2023. https://www.uhr.se/en/start/laws-and-regulations/Laws-and-regulations/The-Higher-Education-Ordinance/Annex-2/.

Wong, Anson. *Exploring the Interconnectedness of Sustainable Development Goals.* October 15, 2021. https://earth.org/the-interconnectedness-of-sustainable-development-goals/ (accessed 04 04, 2024).

Responsibly Educating Responsible Engineers

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ABSTRACT

Educating responsible engineers is the challenge engineering schools are tackling today to address the needs of society, today and in the future. Instead of thinking of how to redesign courses and curricula to include relevant topics on ethics, sustainability and more generally social science and humanities subjects, in this paper we propose an institutional strategy that engages diverse stakeholders in creating a holistic engineering education. Focusing on our approach to enrich the learning journey with transversal skills opportunities for all students at our institution, we promote the integrated view of curricular and extracurricular activities to bring a responsible mindset in focus, while acknowledging the importance that self-directed learning has on the motivation to become a responsible professional able to solve complex challenges of the future.

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1 THE BRICK ROAD: STUDENT LEARNING JOURNEY

Fig. 1. Illustration of a student learning journey through higher education

Caption: A vast network of brick roads through diverse landscapes, each brick represents a curricular element on the student's learning journey and the landscape represents everything else the student engages with during this journey, all of it contributing to various extents to the student's learning

1.1 Education ecosystem: responsible consideration of levels, dimensions and stakeholders

Higher education encompasses a multifaceted ecosystem that operates on several levels and dimensions and with a diverse set of stakeholders, each playing a crucial role in the functioning of the institution, and more importantly, each also plays a role in how students are educated. In this ecosystem, holistic student development is increasingly recognised as paramount (Grasso and Burkings 2010), bringing forth learning beyond what we traditionally conceive as knowledge, i.e. learning to do and learning to be. The attention to competences, attitudes and values highlights how teachers teach the content of their courses, but also significantly emphasizes the influence of the hidden curriculum and the extracurricular activities in developing of a responsible professional.

While curricular planning, content, outcomes and impact have been studied extensively, the significance of extracurricular activities and their impact on shaping a more comprehensive image of student learning has been gaining attention from engineering education scholars and educators alike only in the last decade (Figure 2).

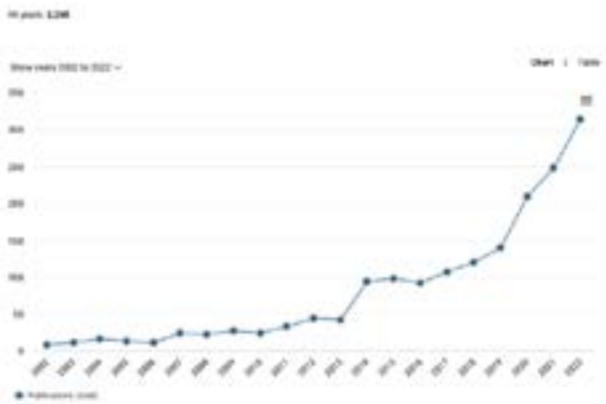

Fig. 2. Number of articles including “engineering education” and “extracurricular activity” in the last 20 years (graph generated in April 2024 using https://dimensions.ai)

Research indicates that student participation in extracurricular activities at universities correlates positively with academic performance and it is beneficial for skills development (Buckley and Lee 2018) as well as contributing positively to the feeling of belonging and well-being (Sisto, Huq, and Dickinson 2021). These studies include a wide range of stakeholders, such as students, alumni, recruiters and industry members, some of them showing that extracurricular activities are especially important for students from underrepresented backgrounds, helping them develop skills and improve their academic life (King, McQuarrie, and Brigham 2021). Furthermore, concluding a narrative synthesis of 39 articles from 2010-2021 about the impact of extracurricular activities on employability, Ribeiro et al. (2023) recommend a stronger promotion of activities outside of the classrooms to foster holistic student development.

In engineering education, Dalrymple and Evangelou (2006) connect the benefits of extracurricular activities to gaining social capital and developing social networks important for graduates' professional lives. Positive outcomes seem to be seen in terms of gender, particularly for strengthening confidence and leadership skills (Dalrymple and Evangelou 2006). Communication, leadership skills, problem-solving and “people skills” are also prominently mentioned in most studies in engineering education (Dalrymple and Evangelou 2006; Fakhretdinova, Osipov, and Dulalaeva 2021; Fisher, Bagiati, and Sarma 2014).

Moreover, the interconnection of curricular and extracurricular content within the academic framework promotes a holistic understanding of disciplinary knowledge and enhances student’s involvement in their own learning (Astin 1999). The benefits for the students go beyond the obvious and they are well known in the current state-of-the-art; coherent education and learning opportunities help students build resilience, learn time management and enhance their abilities to navigate the complexities of professional environments.

Beyond this, hidden curriculum has a multifaceted and significant impact on students’ character and development of identity. Since it refers to the unspoken lessons, norms, values and expectations that are absorbed within the environment and through educational experience, it is exceptionally important to be aware of the existence of hidden curriculum and its impact on students’ personal and professional formation (Villanueva et al. 2018). Rea et al. (2021) note that hidden curriculum has a subtle but powerful contribution to students’ overall learning experience. Examples of hidden curriculum thus include, but are not limited to (Cotton, Winter, and Bailey 2013):

- Course content: what to include and exclude from teaching, what and how to assess learning,
- Pedagogy: ways in which teachers' views form lessons, ways teachers act as models for certain behaviours and which behaviours are deemed unsuitable,
- Institution at large: messages that are passed in the physical environment, values that are communicated, and narratives present or missing from the public discourse.

Uncovering the values passed through the hidden curriculum has its significance in discovering how and why certain competences and identities are strongly present and persistent (Villanueva et al. 2018), but furthermore, it helps us understand how to coherently and comprehensively drive change in higher education institutions (Koutsouris, Mountford-Zimdars, and Dingwall 2021).

1.2 Co-creation, ownership and coherent framework to educate responsible engineers

Moving the academic discussion forward into what it means to have a responsible and responsive education system, especially considering the holistic development of students through their learning journeys, requires us to address the responsible approaches and the role of each stakeholder. Thus, we postulate that responsible education cannot be reduced to classrooms and auditoriums alone, but rather needs to be co-created and owned by everyone at a university.

Co-creation and ownership in a broad sense, but also in the educational sphere, emphasise the importance of collaborative efforts between diverse members of a community with the objective of more sustainable and impactful outcomes. Yet, literature and evidence on creating a coherent, co-constructed engineering education ecosystem that draws on multiple stakeholder engagement and considers diverse curricular aspects of the learning journey is scarce. Responsible engineering education often refers to embedding ethics and/or sustainability in the curricular offer, or at best referring to social responsibility as a learning outcome (Lathem, Neumann, and Hayden 2011). Even though Anderson (2000) rightfully questions who is responsible for student character development, the teacher seems to be the central figure in most of these studies, thus the quest for comprehensive co-construction is again diluted.

In their systematic literature review on strategic policy creation and implementation, Viennet and Pont (2017) note that one of the critical elements of effective policy implementation is stakeholder engagement. Sometimes referred to as "educational change", bottom-up theories of policy implementation suggest that it does not matter whether the change makes sense to those who initiate it, but rather what is the generated reaction of those who carry the work. Yet, as with anything in a complex system, awareness-raising and negotiation between those who need to be engaged is paramount (Viennet and Pont 2017). Nonetheless, there is a lack of literature on strategy development and leadership in higher education through the engagement of a complete ecosystem and here we wish to describe our practice.

1.3 Our role in co-creation of a responsible education ecosystems

We both work at the Transversal Skills and Career Centre at EPFL, and our mission in the last year has been to propose a strategic direction for transversal skills across the entire spectrum of curricular and extra-curricular learning and teaching activities. We have complementary backgrounds in STEM and social sciences, years of teaching and research in various educational contexts, and strong experience in transversal skills and institutional change.

2 BRICKS AND LANDSCAPES: BUILDING A COMPREHENSIVE AND TRANSPARENT METHODOLOGY

Building onwards, we look into what it means to develop an education system that integrates all learning opportunities and promotes the responsibility of all stakeholders, focusing on the transversal skills framework. Based on our understanding of educational change, the interaction and influence of different aspects of the curriculum and the importance of engagement of all stakeholders, we approached our transversal skills strategic direction in a co-constructive way.

To create a comprehensive and coherent approach, we devised a strategic direction based on two main missions, curricular and extracurricular, with proactive transparent information sessions for all the stakeholders in our institution. These two main missions run along our efforts to develop a coherent research and impact assessment initiative and are supported by awareness raising at all levels and with all stakeholders.

2.1 Responsibly involving stakeholders in the curricular strategic direction

Even though we advocate that learning at the university is complex, we nonetheless start with the obvious “brick road” – curricular content embedded in the courses and educational programs as the most visible and prominent activity, receiving high value from both teachers and students.

With a mandate to develop a new transversal skills framework, and with a thorough understanding of skills frameworks evidenced in the literature and by the engineering education community, we engaged in the bottom-up approach to help with the emergence of local context and hidden institutional and disciplinary values and attitudes. In collaboration with the EPFL Teaching support centre, we created 90-minute workshops and invited teachers from each department to discuss the future skills within their respective disciplines. To avoid disengagement of certain teachers, we avoided mentioning “transversal skills” at the beginning but rather embraced the open discussion on the important technical and non-technical skills future-oriented engineers would require to be considered competent in their field.

The teacher workshops serve two distinct aims:

1. Providing space for teachers to express in their own words what they feel are the skills that future graduates should have,
2. Providing an opportunity to discuss the place of teaching and learning skills, and particularly transversal skills, in the core curriculum, and outside of it.

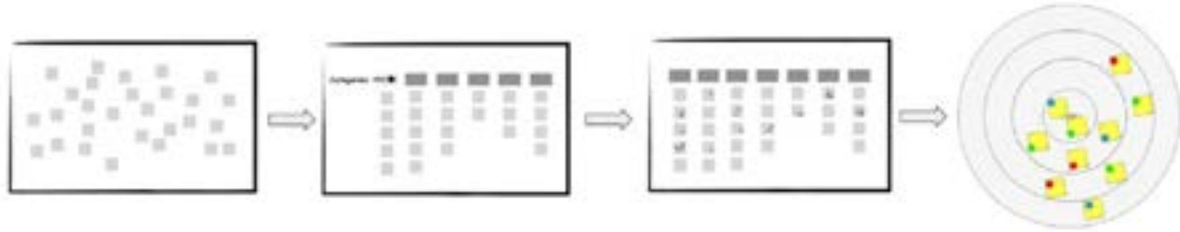

Fig. 3. Workshop with teachers to determine relevant skills for the future-ready engineers

Caption: Phase 1 consists of freely listing all the technical and transversal skills each teacher finds relevant, expressed in their own words. Phase 2 is a collaborative unguided categorisation that supports discussing similarities and subtle differences while the teaching team connects skills into relevant skills groups. In Phase 3 each teacher votes for the most relevant skills across different groups, supporting the final phase where the most voted skills are placed in "circular curriculum map2, to indicate where they should be taught and learnt, with the core disciplinary curriculum at the centre, and the extracurricular learning at the outer edge of the circle.

All steps described in Figure 3 have been carefully chosen to emphasise awareness raising and support co-creation:

1. We ask teachers to specify the skills in their own words, rather than providing a pre-set list; we use this (a) to gain an understanding of the vocabulary in specific disciplines, and (b) as an input for definitions grounded in first-hand evidence,
2. We ask teachers to classify and categorise the skills themselves, rather than suggesting a well-designed framework; in this step, teachers who usually might not ever speak about skills have the opportunity to discuss and exchange their viewpoints,
3. While we stress that all of their input is important, we offer teachers only 10 votes to allocate to a few skills they find most important; in this way, we raise awareness that it is not possible to teach all of the relevant skills and that there is a limited amount of time and resources, thus supporting a more responsible selection of key skills for future graduates,
4. Finally, by seeing the circular model where they can place certain skills in the core curriculum and others elsewhere in the wide scope of educational activities at our institution, we raise the point that while some skills might need to be taught in their own courses, others could be learnt elsewhere, i.e. in educational activities offered by service centres or through the student engagement in student associations. This raises awareness that students' learning happens across the rich institutional offer.

We use the data collected from each department to create a red thread through the core curriculum and extracurricular offer, in an attempt to understand the commonalities, and to identify disciplinary differences in skills relevant for each profession.

The data gathered from teachers is then triangulated with a similar process of collection from student representatives, grouped to create interdisciplinary groups to examine the student perspective on their learning journey independently of their field of study, and a slightly different model of data collection from industrial and civil/governmental institution representatives. Contrary to the data collection for students, we use a simplified Q method when working with external industrial and nonindustrial stakeholders do not work within the context of (extra)curricular activities. The Q method allows us to collect rich qualitative and quantitative data, comparable to the approach we use with teachers and students, thus allowing us to complete the picture of what relevant stakeholders hold important to teach future graduates.

2.2 A coherent extracurricular offer that gives ownership to students and valorises learning outside the classroom

While the core curricular content is complex and slow to change, the extracurricular offer makes part of the learning journey that does not follow strict institutional procedures and accreditation guidelines, and where experimentation can be done more frequently and freely. Student engagement in extracurricular activities is more self-driven and is not tightly dependent on the transactional nature of credits and grades. However, the nature of the extracurricular offer at our, and most other, institutions is that it is dispersed and incoherent and the skills development from extracurricular activities is seldom assessed for quality or depth.

To provide a clearer picture of how students can develop transversal skills through extracurricular activities, we have started by organising information sessions for different services and centres that provide extracurricular skills development on campus. Our focus is on transparent communication of our mission to consolidate the transversal skills offer, and seeking opportunities for engagement and co-construction.

Additionally, we reach out to each service to discuss their educational offer and the ways this offer can be valorised in terms of student skills development, offering coaching and co-creating extracurricular activities when needed. Specifically, our work consists of discussing the educational offer and exploring ways to valorise student development with the aim of increasing the visibility of skills development pathways.

To streamline the existing training offer, we use a single platform (https://epflcareer.ch/en/skills/overview/) as a one-stop shop for all the extracurricular activities related to the development of transversal skills. The benefit of processing the available transversal skills offer through a single platform is access to data on (a) which specific topics students are interested in working on outside regular courses, and (b) what times and periods are most effective for learning besides the regular courses. Beyond this, the extracurricular offer is usually shorter and more modular than regular course content and thus can be quickly developed, tested and evaluated. Being completely voluntary, it offers students a chance to shape their own learning journey, adding crucial experiential learning and mindset development outside of the classroom. Finally, in the long-term, the single platform can serve as a collection of extra-curricular learning, and help students understand better their current skills development level, and how their intended objectives could be satisfied with the existing extra-curricular learning opportunities.

3 WHAT LIES ON THE HORIZON OF THE COMPREHENSIVE STUDENT LEARNING JOURNEY

We presented above a student-centred institutional strategy for developing transversal skills through a diversity of interlinked learning opportunities. Our approach requires that all education providers agree on the same direction, while also allowing student engagement to be at the foundation of their learning journey. Working in such a direction takes time, patience and effort, yet by creating a mutually accepted education strategy, we address not only the alignment of the curricular and extracurricular activities but also nourish the hidden curriculum that supports the transversal skills development.

3.1 Responsibilizing each student to construct their learning journey: e-portfolio

Synchronising curricular and extracurricular offers, aligning stakeholders, and having transparent and active communication around transversal skills, are all relevant elements that support students' holistic development. Nevertheless, we return to the illustration of the bricks and landscapes of the student learning journey (Fig 1). By acknowledging that the most important element there is the student, we move forward with a proposal that mobilises student engagement in the journey and their ownership of their learning.

Part of the purpose of aligning teaching, learning and assessment of transversal skills is to bring all of it together in a student e-portfolio. We know from prior evidence that portfolios support student active learning and engagement (Hernández de Menéndez et al. 2019; Kovacs, Milosevic, and Niculescu 2023). We also acknowledge that engaged students feel more ownership over their learning; Besterfield-Sacre et al. (Besterfield-Sacre, Atman, and Shuman 1998) note that engaged students are more likely to participate in extracurricular activities which provide opportunities for hands-on learning and real-life application of engineering principles. This supports their holistic development and cultivates a growth mindset.

Thus, an e-portfolio comes as a self-directed roadmap of the student learning journey with three objectives:

1. Enables students to reflect on which skills they want to learn at which level (where and how far do I want to go?)
2. Integrates all learning related to transversal skills and maps it across the full ecosystem (what are all the options and different pathways I have available on my journey?)
3. Offers procedures for validation of skills, through self-assessment, peer-assessment and assessment by experts (how do I know where I am now and how far do I still have to go to reach my destination?).

Skills listed in the e-portfolio will be those resulting from a co-constructive work on a framework through curricular and extracurricular data collection, focus groups, and workshops. The proposed skills framework will integrate the linguistic nuances and discipline-specific content, interlinked with more interdisciplinary and transdisciplinary perspectives of students, external stakeholders and educators in services. In addition to this, a gradual progression of each skill which will make the assessment and evaluation more accurate for students and those in charge of assessment. Finally, the e-portfolio system will tie into a map of learning opportunities for transversal skills, and connect the key learning outcomes from both curricular and extracurricular learning opportunities, making it possible to valorise the whole learning journey in the diploma supplement as the ultimate outcome.

4 RESPONSIBLE EDUCATION FOR RESPONSIBLE ENGINEERS OF THE FUTURE

In the landscape of higher (engineering) education, the holistic development of students is increasingly recognised as crucial to providing relevant professional development. While academic curriculum lays the foundation for disciplinary knowledge and skills acquisition, extracurricular activities serve as indispensable complements, enriching the learning journey by fostering personal growth, leadership and decision-making abilities, and a sense of community engagement. The impact of this integrated approach to education is not only to prepare students for the complexities of professional life but also to nurture well-rounded individuals capable of contributing meaningfully to society. Furthermore, appreciating the complexity of the learning journey sends a message that learning is valued in all forms, and different ways of skills assessment are nurtured, which builds into a coherent hidden curriculum.

> “In order to improve the quality of education that university students receive, universities need to take a close look at the way they promote and assess learning and development, bridging the gap between academic and non-academic education experiences. Higher education institutions should create conditions to promote activities with an educational purpose outside the strictly curricular objectives and beyond the classrooms, promoting more holistic development of students” (Ribeiro et al. 2023, 14).

This holistic perspective on engineering education underscores the collective and individual responsibility of all actors within the university ecosystem – faculty, administrators, service staff, leadership, and students themselves. In this paper, we exposed our practice in developing and implementing systemic institutional change towards responsible education, the value of which is to promote co-creation, ownership and coherence, and pave the way towards ever-evolving responsible and responsive education systems of the future.

REFERENCES

Anderson, Donna. 2000. ‘Character Education: Who Is Responsible?’ *Journal of Instructional Psychology*, September. https://www.semanticscholar.org/paper/Character-Education%3A-Who-Is-Responsible-Anderson/b00b93478b3022756fddb537eb7bcce8512fca9b.

Astin, Alexander W. 1999. ‘Student Involvement: A Developmental Theory for Higher Education’. *Journal of College Student Development* 40 (5): 518–29.

Besterfield-Sacre, Mary, Cynthia J. Atman, and Larry J. Shuman. 1998. ‘Engineering Student Attitudes Assessment’. *Journal of Engineering Education* 87 (2): 133–41. https://doi.org/10.1002/j.2168-9830.1998.tb00333.x.

Buckley, Patrick, and Paul Lee. 2018. 'The Impact of Extra-Curricular Activity on the Student Experience - Patrick Buckley, Paul Lee, 2021'. 2018. https://journals.sagepub.com/doi/full/10.1177/1469787418808988.

Cotton, Debby, Jennie Winter, and Ian Bailey. 2013. 'Researching the Hidden Curriculum: Intentional and Unintended Messages'. *Journal of Geography in Higher Education* 37 (2): 192–203. https://doi.org/10.1080/03098265.2012.733684.

Dalrymple, Odesma, and Demetra Evangelou. 2006. 'The Role of Extracurricular Activities in the Education of Engineers'. *Semantic Scholar*. https://www.semanticscholar.org/paper/The-Role-of-Extracurricular-Activities-in-the-of-Dalrymple-Evangelou/34626432c1d832ffd55589941e51940e148d8203.

Fakhretdinova, G. N., Petr Osipov, and L. P. Dulalaeva. 2021. 'Extracurricular Activities as an Important Tool in Developing Soft Skills'. In , edited by Michael E. Auer and Tiia Rüütmann, 1329:480–87. Advances in Intelligent Systems and Computing. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-68201-9_47.

Fisher, Dara R., Aikaterini Bagiati, and Sanjay E. Sarma. 2014. 'Fostering 21st Century Skills in Engineering Undergraduates through Co-Curricular Involvement'. In , 24.623.1-24.623.10. https://peer.asee.org/fostering-21st-century-skills-in-engineering-undergraduates-through-co-curricular-involvement.

Grasso, Domenico, and Melody Burkings. 2010. *Holistic Engineering Education: Beyond Technology*. Edited by Domenico Grasso and Melody Brown Burkins. 1st ed. New York, NY: Springer New York. https://doi.org/10.1007/978-1-4419-1393-7.

Hernández de Menéndez, Marcela, Antonio Jr, Juan Tudón-Martínez, Diana Hernandez-Alcantara, and Ruben Morales-Menendez. 2019. 'Active Learning in Engineering Education. A Review of Fundamentals, Best Practices and Experiences'. *International Journal on Interactive Design and Manufacturing (IJIDeM)* 13 (September). https://doi.org/10.1007/s12008-019-00557-8.

King, Alyson, Fiona McQuarrie, and Susan Brigham. 2021. 'Exploring the Relationship Between Student Success and Participation in Extracurricular Activities'. *SCHOLE: A Journal of Leisure Studies and Recreation Education* 36 (1–2). https://doi.org/10.1080/1937156X.2020.1760751.

Koutsouris, George, Anna Mountford-Zimdars, and Kristi Dingwall. 2021. 'The "Ideal" Higher Education Student: Understanding the Hidden Curriculum to Enable Institutional Change'. *Research in Post-Compulsory Education*. Routledge. Available from: Taylor & Francis, Ltd. 530 Walnut Street Suite 850, Philadelphia, PA 19106. Tel: 800-354-1420; Tel: 215-625-8900; Fax: 215-207-0050; Web site: http://www.tandf.co.uk/journals.

Kovacs, Helena, Tamara Milosevic, and Alexandra Niculescu. 2023. 'Planned, Taught, Learnt: Analysis Of Transversal Skills Through Curriculum Using Portfolio'. *Research Papers*, October. https://doi.org/10.21427/R0JP-8277.

Lathem, Sandra, Maureen Neumann, and Nancy Hayden. 2011. 'The Socially Responsible Engineer: Assessing Student Attitudes of Roles and Responsibilities'. *Journal of Engineering Education* 100 (3): 444–74. https://doi.org/10.1002/j.2168-9830.2011.tb00022.x.

Rea, Stephen Campbell, Kylee Shiekh, Qin Zhu, and Dean Nieusma. 2021. 'The Hidden Curriculum and the Professional Formation of Responsible Engineers: A Review of Relevant Literature in ASEE Conference Proceedings'. In . https://peer.asee.org/the-hidden-curriculum-and-the-professional-formation-of-responsible-engineers-a-review-of-relevant-literature-in-asee-conference-proceedings.

Ribeiro, Norberto, Carla Malafaia, Tiago Neves, and Isabel Menezes. 2023. 'The Impact of Extracurricular Activities on University Students' Academic Success and Employability'. *European Journal of Higher Education* 0 (0): 1–21. https://doi.org/10.1080/21568235.2023.2202874.

Sisto, Marco De, Afreen Huq, and Genevieve Dickinson. 2021. 'Sense of Belonging in Second-Year Undergraduate Students: The Value of Extracurricular Activities'. *Higer Education Research & Development* 41 (5). https://doi.org/10.1080/07294360.2021.1902951.

Viennet, Romane, and Beatriz Pont. 2017. 'Education Policy Implementation: A Literature Review and Proposed Framework'. Paris: OECD. https://doi.org/10.1787/fc467a64-en.

Villanueva, Idalis, Marialuisa Di Stefano, Laura Gelles, and Katherine Youmans. 2018. 'Hidden Curriculum Awareness: A Comparison of Engineering Faculty, Graduate Students, and Undergraduates'. *World Education Engineering Forum Conference*, November, 1–6.

SERVICE-LEARNING: AS A WAY TO ENHANCE STUDENTS' COMPETENCIES

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***Conference Key Areas**: Teaching foundational disciplines of Mathematics and Physics in engineering education, Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing.*

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ABSTRACT

Service-Learning (SL) has emerged as an important high-impact practice in contemporary higher education. Rooted in experiential learning, SL constructs alliances between faculty-led academic courses and community-based organizations and institutions aiming to enhance several students' competencies. In this context, second-year Mechanical Engineering students, enrolled in a Statistical Methods course, were tasked with conceptualizing and executing Service-Learning initiatives in collaboration with an institution. Possible Service-Learning projects were proposed to address the specific needs of the institution while aligning with the diverse students' interests. Moreover, students participated in pre- and post-questionnaires to quantify the development of competencies associated with the service-learning experience they undertook. This paper presents the experience of integrating Service-Learning principles within the curriculum, specifically within the Statistical Methods course for second-year Mechanical Engineering students, to cultivate practical problem-solving skills, foster meaningful community engagement, and evaluate the impact on student competencies through rigorous assessment measures. Service-Learning steps performed, and the fruit of this experience are also discussed.

1 INTRODUCTION

Service-Learning (SL) has emerged as an important high-impact practice in contemporary higher education. Rooted in experiential learning, SL constructs alliances between faculty-led academic courses and community-based organizations aiming to enhance several students' competencies (Hadlock 2005).

Community service, as many of us know, has been a part of educational systems for years. Nevertheless, what takes Service-Learning to the next level is that it combines serving the community with the rich academic frontloading, assessment, and reflection typically seen in project-based learning. In a service-learning unit, goals are clearly defined, and there are many kinds of projects that classrooms can adopt. Classes or students can be involved in direct issues that are more personal and face-to-face, like working with the homeless or performing a data analysis survey for an institution or company. Involvement can be indirect when the students work on broader issues, perhaps a local environmental problem. It can include advocacy to educate others about pertinent issues, it can be research-based where the students act to curate and present information based on public needs. Different types of projects can be developed. A possible classification is as follows:

- Direct or external projects: these are those that are carried out on-site, in the

association itself or in the community, outside of classrooms or university spaces.

- Indirect or internal projects: take place mainly on campuses or university facilities. Research projects or research for information that the community needs can be included here.

A description of SL pedagogical methodology and the effects of SL quality on self-efficacy and engagement may be found in Joseph A. Allen, et al (2021) paper. A widespread of SL applications in engineering courses may be found at (Queiruga-Dios, et al. 2021).

In all SL projects it is necessary to consider and overcome the following phases (Queiruga-Dios, et al. 2024):

Fig. 1. Service-Learning process

1.1 Service-Learning and Mathematics

Engineering students often encounter mathematical difficulties during their academic journey. The need for abstract thinking of some complex nature of mathematical concepts and their applications in engineering fields can pose challenges for students, especially those in the early stages of their education (Lawson et al. 2020). Recognizing this problem, the authors have increasingly turned to innovative approaches, including SL, to engage students in addressing societal problems while gaining competencies, both scientific and personal (Caridade, et al. 2018; Queiruga-Dios, et al. 2020; Rasteiro, D.M.L.D., et al. 2024). Service-Learning, as an active methodology, integrates classroom learning with hands-on experience in community-based projects. By immersing themselves in real-world challenges, such as analysing environmental data for local organizations as was done in the curricular unit of Statistical Methods, students not only apply mathematical principles but also gain a deeper understanding of their relevance and impact. Engaging students with societal problems through SL enhances their educational experience by providing a sense of purpose and relevance. By addressing pressing issues related to local societal problems students see firsthand the potential their skills must make a positive impact on society. This experiential learning approach encourages critical thinking, creativity, and ethical decision-making as students navigate complex engineering challenges. Moreover, SL promotes the development of competencies beyond scientific knowledge. Through collaborative projects and interactions with community members, students refine their communication, teamwork, and leadership skills. They learn to effectively communicate technical concepts to diverse audiences, collaborate with stakeholders, and adapt to changing circumstances - a crucial skill set for success in both academia and the professional world. In addition to gaining scientific competencies, students also experience personal growth through their engagement with societal problems. They develop a deeper sense of empathy, cultural awareness, and social responsibility as they grasp the ethical implications of their work. This holistic approach to education nurtures well-rounded engineers who excel in their technical field and positively contribute to society. As a result, by integrating SL as well as other active methodologies, educators empower engineering students to become innovative problem solvers and responsible global citizens. Thus, students are not only better equipped to overcome mathematical difficulties but also inspired to make meaningful contributions to the world around them. It is worth mentioning that the skills gained by students with SL pedagogical methodology are transversal skills, therefore this pedagogical methodology is applicable within all education fields.

2 METHODOLOGY

2.1 Statistical Methods course

The Statistical Methods curricular unit is one of the mandatory units of the 1st year of Engineering graduation courses at the Coimbra Engineering Institute, Polytechnic University of Coimbra. It is designed to equip students with a comprehensive understanding of fundamental statistical concepts and their applications in engineering and other fields. The course is structured around mandatory content areas, ensuring a systematic and thorough exploration of key topics. The course begins with an introduction to probabilities, laying the groundwork for understanding random experiences, spaces for results, and events. Students delve into probability definitions, conditional probability, independent events, as well as foundational theorems such as the Total Probability Theorem and Bayes' Theorem. Moving forward, the course progresses to the study of random variables and discrete probability distributions. Students learn about discrete random variables, including their probability functions, distribution functions, and key parameters such as location and dispersion. Special discrete distributions such as the Bernoulli, Binomial, Hypergeometric, and Poisson distributions are explored in detail. Additionally, students examine discrete bidimensional random variables, joint and marginal probability functions, conditioned probability functions, and concepts of independence and correlation. Continuing the exploration, students delve into continuous probability distributions, understanding probability density functions, distribution functions, and parameters of location and dispersion. Special attention is given to prominent continuous distributions such as the Normal, Chi-square, and T-Student distributions, with brief references to Uniform and Exponential distributions. The course then transitions to sampling and sampling distributions, where students learn about the principles of random sampling, statistics, and the distribution of sample averages and variances. Building upon this foundation, students explore estimation techniques, including point and interval estimation, with a focus on constructing confidence intervals for both population means and variances. Finally, the course concludes with a study of parametric hypothesis tests, providing students with fundamental notions and methodologies for testing hypotheses about population means and variances. Through rigorous examination and practical applications, students develop a solid understanding of statistical methods and their relevance in scientific research, engineering analysis, and decision-making processes. To enhance student learning and achievement of key competencies (Alpers et al. 2013; Niss 2003; Niss and Højgaard 2019), active methodologies are integrated into the course design. Community study using Padlet allows students to collaborate and engage in problem-solving activities beyond the classroom (Rasteiro, D.M.L.D., et al. 2024). Additionally, office hours are dedicated to real problem-solving activities, providing students with opportunities for one-on-one guidance and application of statistical methods to real-world scenarios. These methodologies foster the development of competencies such as thinking mathematically, reasoning mathematically, posing and solving mathematical problems, modelling mathematically, representing mathematical identities, handling mathematical symbols and formalism, communicating in, with, and about mathematics, and making use of aids and tools (Alpers et al. 2013; Niss and Højgaard 2019). By linking active methodologies with the course content, students not only master statistical methods but also cultivate essential skills for success in their academic and professional endeavours.

To achieve mastery of the course content and competencies, students are encouraged to utilize software tools such as IBM SPSS Statistics (Version 27) and R software (RStudio Team 2020), as well as any model of calculator that supports probability distributions. Attending to this course the authors had 115 students (4 female and 111 male).

2.2 Service-Learning methodology followed

At the beginning of the semester, students were introduced to the concept of Service-Learning, explaining the distinction between volunteer work within organizations. Emphasis was placed on the integration of content learning with service-oriented activities, which would subsequently be evaluated. The procedural framework comprising seven steps- observation, preparation, action, reflection, data registration, evaluation, and recognition (Figure 1. above)- was clarified to the students. Subsequently, students were encouraged to enrol for participation. Upon conclusion of the registration period, a total of 16 students (all male) had submitted applications and from those, 10 students engaged in this learning experience. A meeting with the chosen non-profit organization (NPO) was promoted where besides presenting the organization and its projects, its President also presented the needs where students' knowledge of Statistical Methods could be of service. The NPO chosen was CASPAE. CASPAE, Social Support Center for Parents and Friends of the School, is an IPSS that develops Free Time Activities in several primary schools in the municipality of Coimbra, in partnership with the respective Parents' Associations and School Groups. With the mission of promoting responses of a social nature, personal development and well-being of individuals, with a view to their inclusion in society, there is the CASPAE Sports Academy, which promotes sport for all ages and also provides the Take care of yourself with a Home Support Service specialized in responding to the needs of elderly people.

Currently, CASPAE makes a strong investment in projects that cover several areas, from education to nature, to technological education for all, including projects that aim at social inclusion, as well as valuing the elderly, among others. It is also the entity that coordinates support programs for the most needy people, also developing several initiatives to collect and distribute essential goods. For further details on this NPO the reader is invited to access https://caspae.pt/PT/ . Some students who were not able to be present in person were present online. Students were invited to brainstorm from all they watched and heard and identify what major topics could be addressed (Observation and Preparation phases). At the same time, students were divided into groups of 2. The themes chosen to be worked were:

- Characterize the population that uses the CASPAE. That is, understanding the factors that lead parents to enrol their children in the various services/activities provided and analyse other information collected in the registration forms;
- Study the projects (areas) that beneficiaries seek to complete the CASPAE offer. Understand why there is no interest in other projects already created and with little support;

- Study secondary and higher education students to assist the CASPAE in detecting gaps in the use of technology to support learning, as well as detecting differences in this understanding between genders;
- Analyse the activities carried out by the CASPAE from its beginnings to the present, with emphasis on the evolution of the number of children served, the expansion of training offered over time, and the increase in the number of activities over the years;
- Study current CASPAE projects that cover a large number of beneficiaries and understand their success to help other less successful projects.

Throughout the semester, while in the action phase, regular meetings with students were held, mostly online to clarify questions, reinforce their motivation, and explain mathematical concepts related to Statistical Methods.

While in the action phase some of the groups needed to develop questionnaires and collect data with all the knowledge gathered on how to correctly do it, and all groups had to perform data analysis. The data analysis was performed using Excel and/or SPSS with professor guidance and help.

Reports were performed and presented orally to the CASPAE President. After, and sometimes during, reports presentation discussion periods were held about the results and the reality of CASPAE, which gave students a sense of involvement that would not be possible if this learning activity was not performed.

The evaluation phase consisted of taking stock of the entire project development process, analysing the results obtained, and the fulfilment of the proposed objectives. A self-assessment was also necessary, evaluating possible improvements and future projects. Students answered pre- and post-questionnaires to quantify the development of competencies associated with the service-learning experience they undertook.

A SL rubric adapted from Coverdell's World Wise Schools publication Looking at Ourselves and Others (Washington, DC: Peace Corps, 1998, p. 6) was used to evaluate students. In the next section, the experience we will present the results obtained.

3 RESULTS

3.1 Pre- and post-questionnaire analysis

Pre- and post-questionnaires had 21 questions, see Table 1 below, graded from 1- *Not at all important* to 7- *Very much important* as Likert scale. As said previously, students answered the questionnaires before starting the SL activity and after concluding it.

Table 1. Pre- and post-questionnaire questions

Q1 - Experience personal growth	Q11 - Apply problem-solving techniques
Q2 - Ability to work with others	Q12 - Build my self-confidence
Q3 - Improve my leadership skills	Q13 - Conflict resolution

Q4 - Improve my communication skills	Q14 - Ability to take personal responsibilities
Q5 - Gaining a greater understanding of cultural and racial differences	Q15 - Learn practical skills in the workplace
Q6 - Improve my social responsibility and citizenship skills	Q16 - Ability to learn from experience
Q7 - Community involvement	Q17 - Develop organizational skills
Q8 - Ability to have influence in the community	Q18 - Connect theory with practice
Q9 - Apply information learnt in the classroom to real-life scenarios	Q19 - Establish affectionate relationships
Q10 - Problem analysis and critical thinking	Q20 – Empathy and sensitivity to the situation of others
Q21 - Demonstrate that I am someone who can be trusted	

The results obtained from the pre- and post-questionnaire analysis reveal significant improvements in various competencies among the students. According to their answers, there is a notable enhancement in the following areas: (Q2.) Ability to work well with others, (Q3.) Improving leadership skills, (Q5.) Gaining a greater understanding of cultural and racial differences, (Q6.) Improving social responsibility and citizenship skills, (Q10.) Problem analysis and critical thinking, (Q11.) Applying problem-solving techniques, (Q18.) Connecting theory with practice.

Data collected indicates, see Figure 2, that students perceive a marked improvement in their collaborative skills, leadership abilities, appreciation and understanding of cultural and racial diversity, sense of social responsibility, and citizenship. It is also notable the enhancement in students' ability to analyse problems and think critically, and their proficiency in applying problem-solving techniques. Questionnaires' answers also suggest that students have successfully bridged the gap between theoretical knowledge and practical application. This suggests that the Service-Learning experience has facilitated effective teamwork and cooperation among peers. These results indicate to us, as professors, that SL is a learning and teaching methodology that allows students to accomplish their learning path regarding curricular unit's contents curriculum, but also allows students to improve other social competencies as well. These findings validate the effectiveness of integrating SL initiatives into the curriculum to enhance students' holistic growth and learning outcomes.

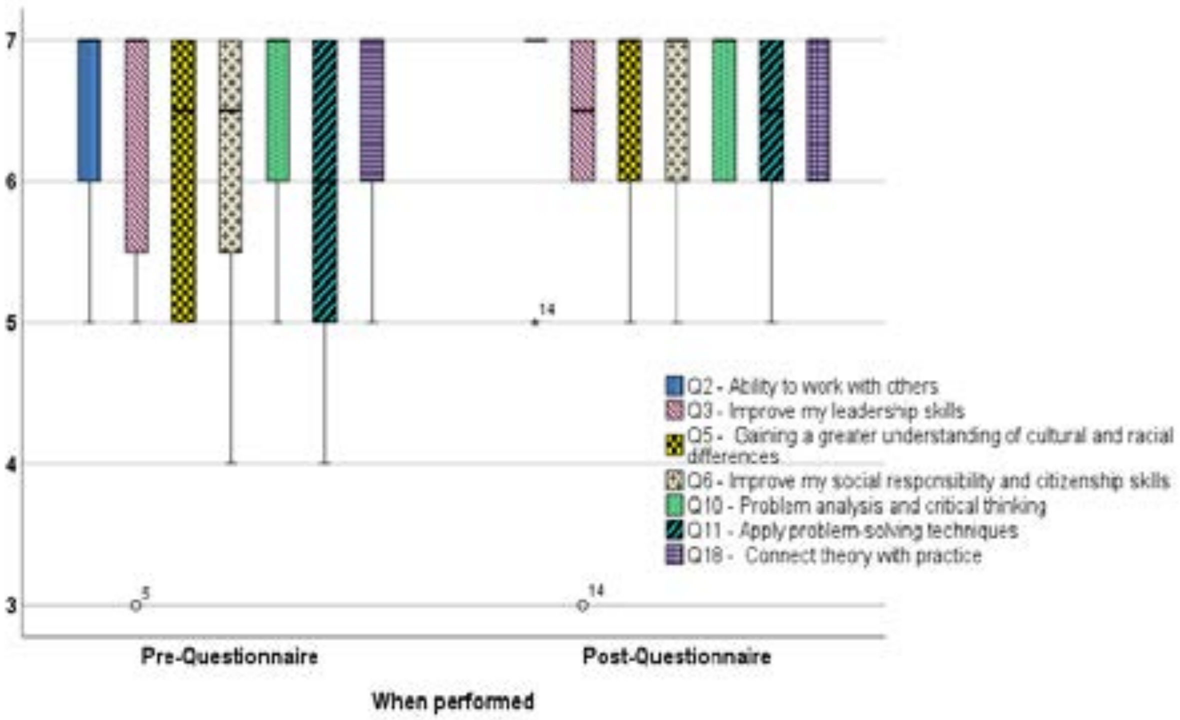

Fig. 2. Pre- and post-questionnaire results comparison

For questions not depicted in Figure 2 above, students' answers indicate that either their proficiency remained unchanged from the beginning of the activity, or the Service-Learning (SL) projects followed did not align with the referred competencies they anticipated, as illustrated in Figure 3,

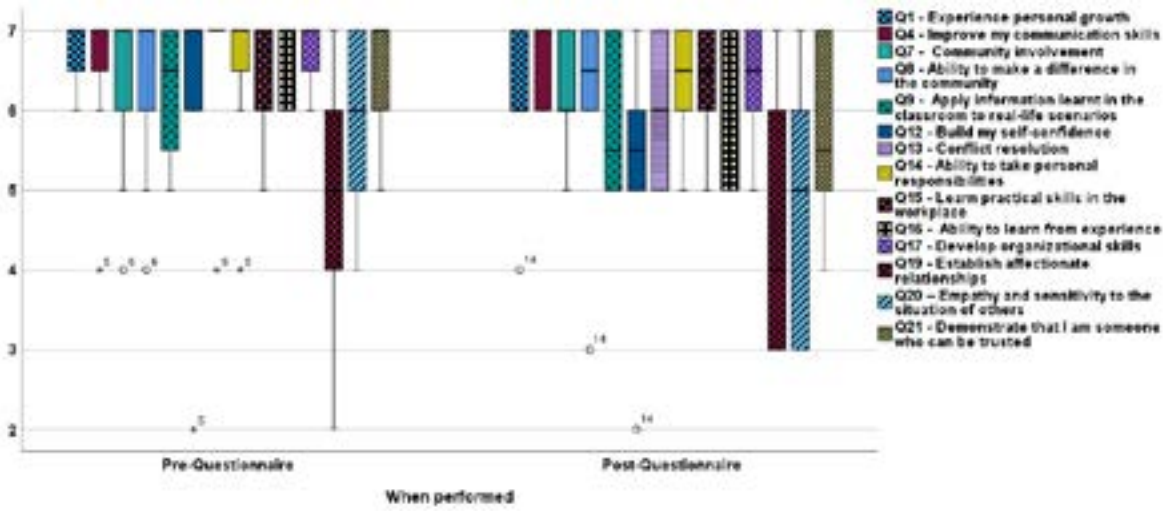

Fig. 3. Pre- and post-questionnaire questions where there were no competencies improvement

4 SUMMARY

With the proposed SL activity, competence improvements were observed in students' ability to work well with others, improve leadership skills, gain a greater understanding of cultural and racial differences, enhance social responsibility and citizenship skills, engage in problem analysis and critical thinking, apply problem-solving techniques, and connect theory with practice. Data analysis indicates that students perceived notable developments in collaborative skills, leadership abilities, cultural understanding, social responsibility, problem-solving proficiency, and theoretical application. These findings underscore the efficacy of SL in fostering teamwork, enhancing social competencies, and bridging theoretical and practical knowledge. Furthermore, the results confirm that SL is a valuable pedagogical approach for facilitating comprehensive student development within the curriculum. However, for some of the competencies covered by the questionnaires, students' responses suggested either unchanged proficiency or a misalignment between SL projects and anticipated competencies. It must be noticed that at the beginning students did not know which were the needs of the NPO institution and neither the service they were going to do. Still, these findings encourage authors to continue promoting the integration of SL initiatives into the curriculum to promote holistic student growth and learning outcomes.

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REFERENCES

Alpers, B., et al. "A Framework for Mathematics Curricula in Engineering Education." In *SEFI*, Salamanca, Spain, 2013. http://sefi.htw-aalen.de/

Caridade, C. M. R., A. H. Encinas, J. Martín-Vaquero, A. Queiruga-Dios, D. M. L. D. Rasteiro. "Project-based teaching in Calculus courses: Estimation of the surface and perimeter of the Iberian Peninsula." *Computer Application in Engineering Education* volume 26 (2018): 1350–1361. https://doi.org/10.1002/cae.22032.

Hadlock, C. R. *Mathematics in Service to the Community: Concepts and models for service-learning in the mathematical sciences*. MAA Notes #66. The Mathematical Association of America, 2005

Joseph A. Allen, Kaitlin Fosler, and Kelly Prange, "*All Service-Learning Experiences Are NOT Created Equal! Effects of Service-Learning Quality on Self-Efficacy and Engagement*", Journal of Higher Education Outreach and Engagement, Volume 25, Number 4, p. 41, (2021)

Lawson, D., M. Grove, and T. Croft. "The evolution of mathematics support: a literature review." *International Journal of Mathematical Education in Science and Technology* volume 51, no. 8 (2020): 1224–1254. https://doi.org/10.1080/0020739X.2019.1662120

Niss, M. "Mathematical Competencies and the Learning of Mathematics: The Danish KOM Project." In *Proceedings of the 3rd Mediterranean Conference on Mathematics*

Education, Athens, Greece, 2003, 115-124: Hellenic Mathematical Society and Cyprus Mathematical Society.

Niss, M., and T. Højgaard. "Mathematical Competencies Revisited." *Educational Studies in Mathematics* volume 102 (2019): 9–28. https://doi.org/10.1007/s10649-019-09903-9

Queiruga-Dios, M., M. J. Santos Sánchez, M. Á. Queiruga-Dios, P. M. Acosta Castellanos, A. Queiruga-Dios. “Assessment methods for service-learning projects in engineering in higher education: A systematic review.” *Frontiers in Psychology* volume 12 (2021): 629231. https://doi.org/10.3389/fpsyg.2021.629231

Queiruga-Dios, A., M. J. Santos Sánchez, M. Queiruga Dios, V. Gayoso Martínez, and A. Hernández Encinas. "A Virus Infected Your Laptop. Let’s Play an Escape Game." *Mathematics* volume 8, no. 2 (2020): 166. https://doi.org/10.3390/math8020166.

Queiruga-Dios, A., D.M.L.D. Rasteiro, B. Sánchez Barbero, Á. Martín-del Rey, I. Mierlus-Mazilu. “Service-Learning Activity in a Statistics Course.” In: *Mathematical Methods for Engineering Applications. ICMASE 2023*, 2024 Springer Proceedings in Mathematics & Statistics, vol 439. Springer, Cham. https://doi.org/10.1007/978-3-031-49218-1_23

Rasteiro, D.M.L.D., C. M. R Caridade. Is Collaborative Learning a Voluntary Process? In: *Mathematical Methods for Engineering Applications. ICMASE 2023*, 2024 Springer Proceedings in Mathematics & Statistics, vol 439. Springer, Cham. https://doi.org/10.1007/978-3-031-49218-1_9

RStudio Team. *RStudio: Integrated Development for R*. Boston, MA: RStudio, PBC, 2020. http://www.rstudio.com/

Leveraging Collaborative Digital Platforms for Supervising Project-Based Learning Activities: A Case Study

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ABSTRACT

In contemporary engineering education, project-based learning (PBL) has emerged as a prominent pedagogical approach to foster transversal skills like collaboration and communication. However, effective supervision and guidance of student groups in PBL present challenges. This paper introduces an innovative approach to support student groups and teaching assistants (TAs) in PBL, utilizing a digital experience platform. The presented pedagogical scenario features a digital collaboration journal used by students to document their progress. Through the implementation of this scenario in an interdisciplinary course, data was collected via surveys and interviews. Results indicate that students perceived the collaboration journal as supportive for poster preparation and discussions with the TAs. While the scenario was well received, challenges persist in fostering online communication. Future iterations aim to enhance the platform's role in facilitating group-TA interactions and providing a comprehensive collaborative environment. This research contributes to the advancement of PBL methodologies by offering practical insights into leveraging

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digital platforms to enhance collaboration, communication, and feedback processes, ultimately enriching the learning experience for students and TAs alike.

1 INTRODUCTION

Engineering education of the last few decades has recognized the development of transversal skills as essential to the development of responsible and skilled engineers (Jalali et al. 2022). Among these transversal skills, collaboration and communication is of particular importance for future engineers to be able to tackle the large and ill-defined problems of the 21st century through collaboration and coordination (Ercan and Khan 2017). One of the most prominent pedagogical approaches to combine the development of collaboration and communication skills with discipline learning is project-based learning (PBL) (Granado-Alcón et al. 2020; Hussein 2021; Saldo and Walag 2020).

In spite of its benefits, PBL is hindered by the flexibility and amount of facilitation it requires (Shpeizer 2019; Vasiliene-Vasiliauskiene, Vasiliauskas, and Sabaityte 2020). Indeed, supervising and guiding small groups of students in PBL is a common challenge in engineering education. In projects that develop over multiple weeks, teachers must implement strategies to assess the progress of the groups and deliver timely feedback (Meng et al. 2023) which can represent a considerable challenge for teachers.

This challenge is exacerbated in courses with a large number of students. In such settings, teachers may rely on Teaching Assistants (TAs) to supervise and guide the groups of students. At our institution TAs are most often Ph.D or undergraduate students. Thus, they are not trained teachers and they don't have expert knowledge of the course material, nor complete mastery of the skills that are trained in the course. Because of that TAs must coordinate with the main teacher(s) and often report to them. Coordinating the work between multiple TAs can be a challenging task that requires time, energy, and method. Additional difficulties may arise when the pedagogical scenarios involve blended or online modalities. Strategies to develop and prepare TAs to teach and support these scenarios appears to have received little attention in the literature (Wadams and Schick-Makaroff 2022).

Finally, it is important to consider the challenge posed by the creation and management of assignments to the groups of students. The collaborative redaction of a small report can be a daunting task if the group does not follow a proper procedure backed by relevant technologies (Hussein 2021). In this case, the scenario deceives its purpose and the progress of the groups may be limited by collaboration issues and conflicts (Chan and Chen 2010).

In this paper, we present an innovative approach to the supervision and guidance of groups in PBL, leveraging a digital experience platform and real-time collaborative documents to structure and enhance the collaboration between all stakeholders. While the use of digital platforms to foster collaboration in PBL has already been explored (Balderas-Díaz, Guerrero-Contreras, and De Castro-Cabrera 2022; Ørngreen *et al.* 2021), our approach contributes to the understanding of this practice by exploring the participation of TAs. We present the evaluation of this scenario through a survey of the students and semi-structured interviews with the TAs.

2 PEDAGOGICAL DESIGN FOR SUPPORTING GROUPS OF STUDENTS AND TEACHING ASSISTANTS IN PROJECTS

Our design is the continuation of an ongoing work aiming to improve the scenario of the Communication course at our university. This course is part of an interdisciplinary program which was introduced in 2013 as a compulsory course for all first-year students, to develop transversal skills as early as possible in their curriculum (Gillet and Vonèche-Cardia 2021; Holzer *et al.* 2016). Teachers are assisted by TAs from our academic institution. The course is divided in two parts: the first one is a series of lectures, and the second one is dedicated to a collaborative project. In this second part, students form groups of five teammates and choose a topic related to communication. Groups have to prepare a poster which tackles a global issue related to communication. It has to include the definition of the selected issue, its technical and societal dimensions, as well as the current and potential future solutions to tackle it, with the relevant scientific references (Gillet and Vonèche-Cardia 2021). In the original scenario of the course, groups were required to submit short reports every week on one particular aspect of their global issue. These reports were read by the TAs who provided oral feedback to each group.

In previous iterations of the course, we attempted to improve this scenario by providing a simple digital task management application to the students and access to a collaborative platform to share files and create documents (La Scala *et al.* 2022). We hypothesized that the students would use the provided tools considering their potential added value. Nevertheless, we found that those tools were not perceived as helpful by most students. We also realized that we had overlooked the burden of integrating tools within the pedagogical scenario.

Building on these findings and observations, and considering the challenges mentioned in the introduction, we elicited some core design principles (DPs) to guide the design of our new pedagogical scenario that should provide support to all stakeholders (students, TAs, and teachers).

DP1: Centralization

All digital tools, artifacts, communication and collaboration tools should be available on a single platform. One should mention that the Moodle LMS used to detail the syllabus and distribute slides in the first part of the course is not suitable to support effective collaborative learning in its second part.

We assume that the multiplication of online services and applications constitute an additional barrier to the effective adoption by the students. Therefore, we postulate that a centralized environment removes the burden and the cognitive load due to the management of multiple independent services.

DP2: Integration of activities and technology

Learning activities and learning technologies should be integrated to each other. Activities should be adapted to draw from the full potential offered by the selected technologies.

This was motivated by the observation that tasks and processes irrelevant for learning may be removed or simplified. For example, we removed the need to submit a report by using collaborative document accessible to the teachers and TAs.

DP3: Feedback delivering process

TAs should have a well defined and easy process to deliver their feedback to the students.

The potential benefits of feedback systems in higher education (Figas, Bartel, and Hagel 2017) motivates this DP.

DP4: Logs of the progress of the groups

All feedback delivered to the groups should be consigned in a document on the central platform. TAs should be able to use this document to assess the progress of the groups.

This is motivated by the current lack of visibility on the progress of the group. We assume that those logs will provide a clear overview on the advancement of each project and facilitate the delivery of useful and accurate feedback.

DP5: Promote connection and coherence between assignments

The different assignments of the project should build on each other. Moreover, this building process should be flexible and allow students to revise previous assignments to align them with the development of their project and allow for their reuse in the final deliverables.

We consider the project as an iterative design process. Thus, and for the feedback to benefit future assignments, those must be coherent.

Following these DPs, we designed and implemented a new approach relying on Graasp[2], a learning experience platform used to create collaborative online spaces. Graasp aims at building rich and interactive learning experiences in blended learning scenarios which integrate face-to-face and online activities (Gillet *et al.* 2022). The platform provides collaborative spaces that are built with **folders**, similarly to a conventional file system. Each folder can be shared with other users and access rights can be fine-tuned to control who can read or edit the content.

Graasp is a collaborative platform where users can exchange files, use built-in collaborative tools and elaborate documents. This collection of features was instrumental to the implementation of structured collaborative activities. It allowed us to centralize all the required features in one platform (*DP1*). In our scenario, we created a folder for each group. Each group was provided with a space where they could exchange files and collect references for their poster. In this space, we provided a **Collaboration Journal** (CJ) based on Etherpad[3], a real-time collaborative text editor integrated to Graasp (“Etherpad: A Real-Time Collaborative Editor for the Web” [2011] 2023). This application can be used in teamwork activities to jointly elaborate documents or share notes. The CJ was a template document in Etherpad to support the collaboration and the elaboration of the poster. In the CJ, the text written by each student is highlighted in a different color, allowing users to distinguish individual contributions as shown in Fig 1.

The template of the CJ contains three sections, each dedicated to one part of the poster, matching a dimension of a global issue. Every week, groups must fill a

[2] https://graasp.org
[3] https://etherpad.org/

section to complete the assignments summarized in Table 1. TAs will provide feedback to the groups after reviewing their assignment. The feedback is provided directly in the CJ, following *DP3*, and additional comments can be sent to the whole group with the help of a chat integrated in Graasp.

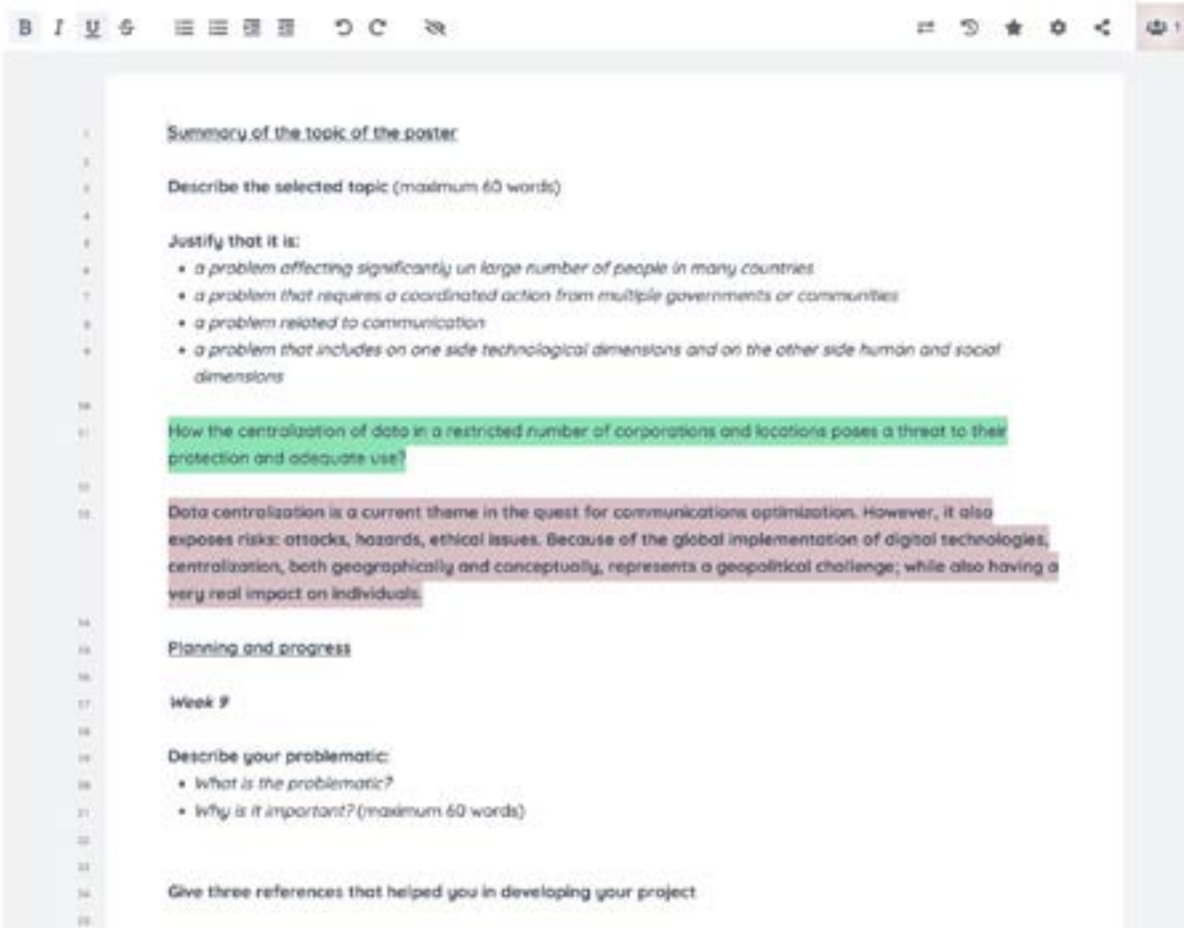

Fig. 1 A sample collaboration journal. The contributions of two students are highlighted with two different colors.

Table 1. Sections of the collaboration journal and corresponding assignments.

	Section	Assignment
1	Problem statement	Describe the problematic and justify its importance.
2	Technical and human dimensions	Describe the technical and social/human challenges.
3	Context and interest	Describe the context and show the interest of the selected topic.

After reviewing the assignments and having provided a written feedback to the groups, the TAs will also put their feedback in the **progress journal**. The latter is also an Etherpad that is provided to TAs to help them track the progress of the groups, implementing *DP4*. These journals are located at a level of the hierarchy in Graasp that is not accessible to the students but can be read by all TAs and teachers. Thus, teachers can get a quick overview of the work of all groups without having to read each CJ.

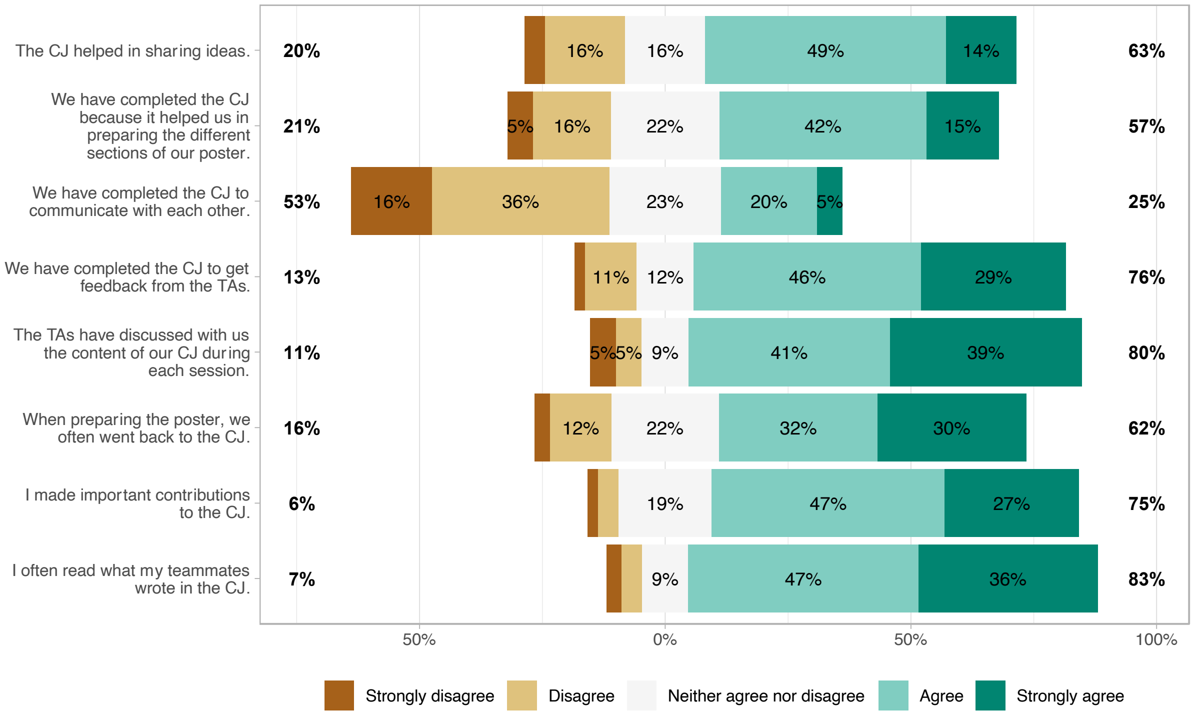

Fig. 2. Answers of the students to the survey items on the Collaboration Journal.

Overall, this process leads to the elaboration by each group of a complete document containing the essence of the poster that the students have to co-design and submit at the end of the project. By uniting all these sections in a single document, we aim at bringing the attention of the students on incoherence and discrepancies in the elaboration of their poster as early as possible, following *DP5*.

3 EVALUATION OF THE EDUCATIONAL SCENARIO

After implementing our redesigned scenario, we collected anonymous qualitative and quantitative data to build a first evaluation of our approach.

3.1 Data collection

At the end of the semester, we conducted an anonymous survey with the students and semi-structured interviews with the TAs. The survey was made of a unique paper questionnaire distributed to all the students after they presented their poster. The questionnaire was fully anonymous and did not require the students to provide any personal information. It contained 17 items to rate on a 5-point Likert scale and three open questions. The first ten items were related to the CJ. The survey was administered by the first author who briefly explained its purpose to the students. It was also clearly stated in the introduction to the questionnaire that all answers are anonymous and that participation to this survey is optional and not part of the course. This was also explained again during the administration of the survey. Overall, we transcribed **98** answers to the survey (n=98) selected randomly for analysis. More answers were collected but not transcribed as we had reached data saturation (Fusch and Ness 2015). The paper questionnaire was transcribed to an anonymous dataset and analyzed with R (R Core Team 2024).

To grasp the perception of the TAs, semi-structured interviews were conducted with all the TAs in the two weeks following the end of the course. Each interview was audio recorded. The TAs were informed that they would be recorded and that their participation to the interviews was optional. After the interviews, the audio files were transcribed automatically using Whisper ("Whisper" [2022] 2024; Radford *et al.* 2022). The transcripts were manually edited to correct transcriptions mistakes. Finally, the transcripts were imported in Taguette (Rampin and Rampin 2021) for coding and analysis.

3.2 Perception of the Students

As shown in Fig. 2, most students perceived the purpose of the CJ in supporting the preparation of the poster (57%) and getting feedback from the TAs (76%). The majority of the students agreed on having contributed to the CJ (75%) and having participated in the group work by reading the contributions of others (83%). These positive results highlight a good understanding of the scenario. Conversely, it appears that the CJ was not perceived as a communication tool.

3.3 Perception of the Teaching Assistants

With the objective to elaborate a comprehensive picture of the perception of the TAs, we followed an emergent coding strategy to identify the main themes of the interviews and the opinions of the TAs on those themes. The coding process was conducted by the first author and focused on identifying mentions of the behavior of the students, the communication between the students and the TAs, the interactions among the TAs, and the use of the CJ.

The analysis was done in two phases. First, a definition the main codes based on the guiding questions used during the interview. Second, the transcripts were coded by one researcher. During this process, new codes were created to encompass new themes and subthemes that were not foreseen in the preparation of the interview.

This analysis allowed for the identification of the main themes regarding the previously mentioned points. In the following subsections, we will focus on two themes that were extensively discussed by the TAs.

Delivering Feedback on the Collaboration Journal

Five TAs described how they delivered the feedback to the students using the CJ. All of them explained that they did not write their feedback directly in the CJ but mostly using the chat integrated to Graasp. They sent their comments using the chat but most of the time did not receive an answer from the students. They mentioned, however, discussing the feedback with the students during the course session and one TA explained he provided more detailed feedback when meeting the groups.

Following the Progress of the Groups

All TAs made positive comments on the use of the CJ to assess the progress of the students. They explained that it was convenient and one TA said he could not imagine how they would have followed the progress of the groups without such a tool. Nevertheless, two limitations were mentioned:

1. The instructions given in the CJ were not clear for all students. They asked many clarification questions on the length of the text they should produce and the style they should adopt.

2. The feature of Etherpad that highlights each piece of text with a color corresponding to its author impaired the readability of the CJ. Some students complained to the TAs about this feature and had created another collaborative document to elaborate their text before copying and pasting it in the CJ, despite the fact that the color highlighting feature can be disactivated in Etherpad (a fact that was probably not known by the TAs).

Nevertheless, one TA reported having observed the flexible and evolutive possibilities offered by the CJ. She described a group who did modify the previous section of their work to maintain the coherence of the whole journal after receiving the feedback from the TAs.

4 CONCLUSIONS

In this paper, we have presented our design principles to support the interaction and the work of TAs and students. We have then shown how we followed these design principles to enhance the pedagogical scenario of an interdisciplinary course. Finally, we evaluated this scenario after having implemented it in the course given in spring 2023, based on insights drawn from an anonymous survey of the students and interviews conducted with the TAs.

The communication between students and with TAs is always a challenge due to the channels they are using and their integration in their personal digital ecosystem. Chats in LMS are not used, discussions associated to documents (like in Google Drive or Graasp) are only used when they actually access these resources. Apps, like WhatsApp (used daily by 84% of the students of the course), are always preferred, but the associated discussions are invisible for assessing the actual interactions.

Our evaluation leads us to conclude that our pedagogical scenario was well received by the students and the TAs. The CJ was considered as helpful by the TAs in following the work of the groups. However, they preferred to use the chat or other channels, such as instant messaging apps, to deliver their feedback to the students. In addition, communications on the platform appear to have been limited in general, most discussions having happened face-to-face during the course sessions. This is also shown in the feedback from the students, most of them having not considered the CJ for communicating among group members.

The choice of Graasp was motivated by the flexibility and openness of the platform which was very much aligned with the need for the course. Moreover, we are involved in its development and had previous experience in using it for similar collaborative scenarios (La Scala *et al.* 2022; La Scala, Vonèche-Cardia, and Gillet 2023).

In 2024, we will continue to improve this pedagogical scenario, focusing on the CJ as a guiding tool to foster exchange between the groups and the TAs. We will strengthen the structure of the scenario to ensure that feedback is always delivered in a timely fashion. Finally, we dedicate more time to showing the possibilities of Graasp for communication among the students (chat, shared files, and collaborative documents) with the objective of providing them with a complete and easy-to-use collaborative environment.

5 ACKNOWLEDGEMENTS

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REFERENCES

Balderas-Díaz, Sara, Gabriel Guerrero-Contreras, and M. Del Carmen De Castro-Cabrera. 2022. "Collaborative Learning through PBL and Virtual Monitoring." In *2022 International Symposium on Computers in Education (SIIE)*, 1–6. https://doi.org/10.1109/SIIE56031.2022.9982317.

Chan, Lim Ha, and Ching-Huei Chen. 2010. "Conflict from Teamwork in Project-Based Collaborative Learning." *Performance Improvement* 49 (2): 23–28. https://doi.org/10.1002/pfi.20123.

Ercan, M. Fikret, and Rubaina Khan. 2017. "Teamwork as a Fundamental Skill for Engineering Graduates." In *2017 IEEE 6th International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 24–28. https://doi.org/10.1109/TALE.2017.8252298.

"Etherpad: A Real-Time Collaborative Editor for the Web." (2011) 2023. JavaScript. The Etherpad Foundation. https://github.com/ether/etherpad-lite.

Figas, Paula, Alexander Bartel, and Georg Hagel. 2017. "Feedback-Based Learning Through Online Feedback Systems in Higher Education." In *Third International Conference on Higher Education Advances*. http://ocs.editorial.upv.es/index.php/HEAD/HEAD17/paper/view/5388.

Fusch, Patricia, and Lawrence Ness. 2015. "Are We There Yet? Data Saturation in Qualitative Research." *Walden Faculty and Staff Publications* 20 (9). https://scholarworks.waldenu.edu/facpubs/455.

Gillet, Denis, and Isabelle Vonèche-Cardia. 2021. "Promoting Critical and Design Thinking Activities to Tackle Sustainable Development Goals in Higher Education." In *2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC)*, 224–30. Madrid, Spain: IEEE. https://doi.org/10.1109/WEEF/GEDC53299.2021.9657466.

Gillet, Denis, Isabelle Vonèche-Cardia, Juan Carlos Farah, Kim Lan Phan Hoang, and María Jesús Rodríguez-Triana. 2022. "Integrated Model for Comprehensive Digital Education Platforms." In *2022 IEEE Global Engineering Education Conference (EDUCON)*, 1587–93. https://doi.org/10.1109/EDUCON52537.2022.9766795.

Granado-Alcón, María del Carmen, Diego Gómez-Baya, Eva Herrera-Gutiérrez, Mercedes Vélez-Toral, Pilar Alonso-Martín, and María Teresa Martínez-Frutos. 2020. "Project-Based Learning and the Acquisition of Competencies and Knowledge Transfer in Higher Education." *Sustainability* 12 (23): 10062. https://doi.org/10.3390/su122310062.

Holzer, Adrian, Isabelle Vonèche Cardia, Samuel Bendahan, Alexis Berne, Luca Bragazza, Antonin Danalet, Ambrogio Fasoli, *et al.* 2016. “Increasing the Perspectives of Engineering Undergraduates on Societal Issues through an Interdisciplinary Program.” *International Journal of Engineering Education*.

Hussein, Bassam. 2021. “Addressing Collaboration Challenges in Project-Based Learning: The Student’s Perspective.” *Education Sciences* 11 (8): 434. https://doi.org/10.3390/educsci11080434.

Jalali, Yousef, Helena Kovaks, Siara Isaac, and Jessica Dehler Zufferey, eds. 2022. “Bringing Visibility to Transversal Skills in Engineering Education: Towards an Organizing Framework.” *[Proceedings of the 50th Annual Conference of the European Society or Engineering Education (SEFI)]*.

La Scala, Jérémy, Graciana Aad, Isabelle Vonèche-Cardia, and Denis Gillet. 2022. “Developing Transversal Skills and Strengthening Collaborative Blended Learning Activities in Engineering Education: A Pilot Study.” In *2022 20th International Conference on Information Technology Based Higher Education and Training (ITHET)*, 1–8. Antalya, Turkey: IEEE. https://doi.org/10.1109/ITHET56107.2022.10031948.

La Scala, Jérémy, Isabelle Vonèche-Cardia, and Denis Gillet. 2023. “Digital Intervention for Collaborative and Human-Centered Activities in Design-Based Learning Scenarios.” In *2023 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)*, 1–8. Auckland, New Zealand: IEEE. https://doi.org/10.1109/TALE56641.2023.10398356.

Meng, Nanxi, Yan Dong, Dorian Roehrs, and Lin Luan. 2023. “Tackle Implementation Challenges in Project-Based Learning: A Survey Study of PBL e-Learning Platforms.” *Educational Technology Research and Development* 71 (3): 1179–1207. https://doi.org/10.1007/s11423-023-10202-7.

Ørngreen, Rikke, Sara Paasch Knudsen, Ditte Kolbæk, and Rune Hagel Skaarup Jensen. 2021. “Moodle and Problem-Based Learning: Pedagogical Designs and Contradictions in the Activity System.” *Electronic Journal of E-Learning* 19 (3): pp133-146. https://doi.org/10.34190/ejel.19.3.2218.

R Core Team. 2024. “R: A Language and Environment for Statistical Computing.” Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Radford, Alec, Jong Wook Kim, Tao Xu, Greg Brockman, Christine McLeavey, and Ilya Sutskever. 2022. “Robust Speech Recognition via Large-Scale Weak Supervision.” arXiv. https://doi.org/10.48550/arXiv.2212.04356.

Rampin, Rémi, and Vicky Rampin. 2021. “Taguette: Open-Source Qualitative Data Analysis.” *Journal of Open Source Software* 6 (68): 3522. https://doi.org/10.21105/joss.03522.

Saldo, Ian Jay P, and Angelo Mark P Walag. 2020. “Utilizing Problem-Based and Project-Based Learning in Developing Students’ Communication and Collaboration Skills in Physics.” *American Journal of Educational Research*.

Shpeizer, Raz. 2019. “Towards a Successful Integration of Project-Based Learning in Higher Education: Challenges, Technologies and Methods of Implementation.” *Universal Journal of Educational Research* 7 (8): 1765–71. https://doi.org/10.13189/ujer.2019.070815.

Vasiliene-Vasiliauskiene, Virgilija, Aidas Vasilis Vasiliauskas, and Jolanta Sabaityte. 2020. “Peculiarities of Educational Challenges Implementing Project-Based Learning.” *World Journal on Educational Technology: Current Issues* 12 (2): 136–49.

Wadams, Morgan L., and Kara Schick-Makaroff. 2022. “Teaching Assistant Development and Contributions in Online, MOOC and Blended Synchronous Settings: An Integrative Review.” *Journal of Further and Higher Education* 46 (8): 1023–39. https://doi.org/10.1080/0309877X.2022.2038100.

“Whisper.” (2022) 2024. Python. OpenAI. https://github.com/openai/whisper.

DESIGNING AN ENGAGING FIRST-YEAR ENGINEERING EXPERIENCE: A CASE STUDY

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ABSTRACT

First-year engineering subjects play an important role in setting up a solid foundation for the ongoing development of technical and professional engineering skills. However, these subjects are not easy to design, as they must tackle the challenge of introducing students to the world of engineering while helping them navigate the difficult transition from high school to university. This paper presents a case study of one such first-year engineering subject: "Engineering Technology and Society". The subject's structure and delivery is discussed with reference to social constructivist and constructionist learning theories, as well as a framework of four dimensions identified as being critical in the design of first-year subjects. The most recent round of student feedback on the subject is also presented, identifying the development of time management, organisational, and teamwork skills as a key area of focus for future improvements to the subject. This case study provides a specific example of how an engaging first-year engineering experience can be designed for both small

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and large student cohorts, providing elements that can potentially be adapted by other tertiary institutions seeking to improve their first-year engineering offerings.

1 INTRODUCTION

Engineers are characterised by their ability to harness scientific principles in creative ways to design effective solutions for the benefit of society. Engineers therefore play a crucial role in working towards – and even beyond – the Sustainable Development Goals adopted by the United Nations in 2015. It is therefore essential that our future engineers be equipped with robust technical and professional skills, and also a keen awareness of the importance of sustainability. This foundation should be laid down early, through the effective design of first-year engineering subjects that can simultaneously teach new concepts, inspire and motivate students to push boundaries, and facilitate the transition from secondary to tertiary education (Burton 2007). In this paper, we present a case study of one such first-year engineering subject offered at the University of Melbourne: “Engineering Technology and Society” (ETS).

2 CHALLENGES, CONSTRAINTS, AND FRAMEWORKS

At the University of Melbourne, engineering qualifications are awarded at the postgraduate level. To qualify as professional engineers, students must first complete a three-year undergraduate degree (typically the Bachelor of Science) before commencing a two-year Master’s degree in their chosen engineering discipline. While this provides undergraduates with more flexibility in subject choice and thus the opportunity to develop a greater breadth of knowledge, it imposes constraints on the undergraduate engineering experience. More specifically, it does not allow as large a footprint for engineering representation in the first year, differing from a traditional Bachelor of Engineering. In fact, ETS is one of only first-year engineering subjects offered at the University. As such, it has had to take an integrated approach to curriculum design: its content spans multiple engineering disciplines, and incorporates basic programming and collaborative project work. In contrast, other institutions typically offer multiple first-year subjects that each focus on foundational concepts aligned with specific engineering disciplines. As ETS is offered in Semester 1, when most students start out their university journey, it also faces the challenge of helping first-years navigate the challenging transition from high school to university.

In this context, Trautwein and Bosse (2017) have presented a framework of four critical dimensions that should be considered when designing first-year subjects:

1. **Personal Dimension.** First-years should begin to identify learning styles and specific study skills that they find effective. The hands-off nature of university relative to secondary education means that students should be assisted in developing time management and organisational skills that will aid them in balancing their academic and non-academic commitments.
2. **Organisational Dimension.** First-years should begin familiarising themselves with university regulations, policies, and expectations. These encompass how teaching and learning is organised (e.g. lectures/tutorials/workshops, learning management systems, etc.), different approaches to teaching, rules around

assessment submissions, as well as the various university facilities and support services available to them.

3. **Content-related Dimension.** The rapid pace of university learning, along with the generally low learner maturity of first-years (Tomas et al. 2019), means that content should be appropriately chunked and scaffolded. Students should be introduced to conventions and rules-of-thumb common in their chosen field of study. They should also start developing assessment literacy: this includes familiarity with various assessment types, as well as the ability to use constructive feedback for improvement.
4. **Social Dimension.** First-years should be assisted in building peer relationships and networks, as well as navigating the social climate in class and on campus. This dimension aligns closely with Vygotsky's (2012) social constructivist views on learning, whereby the knowledge is best internalised by working together with peers or with "more knowledgeable others". These social interactions provide first-years with the scaffolding and confidence to push the boundaries of their knowledge and explore their zones of proximal development (Amani and Asl 2015), and to develop effective communication and teamwork skills.

First-year subjects should also be designed to maximise student engagement, as this has been shown to correlate positively with learning, satisfaction, and retention. The incorporation of active learning approaches is one way of doing this. These promote conceptual understanding by involving students in interactive "heads-on" and "hands-on" activities that generate closed feedback loops with their peers or instructors (Hake 1998). As with Trautwein and Bosse's Social Dimension, active learning is closely aligned with social constructivism, as it stresses the importance of peer-to-peer and peer-to-teacher interactions in the learning process. Project-based learning is a specific active learning approach that additionally draws on Papert's constructionist theory, whereby knowledge development is facilitated by the hands-on manipulation and construction of physical, shareable artefacts (Harel and Papert 1991).

ETS has been offered at the University of Melbourne since 2021, inheriting much of the philosophy of its spiritual predecessor "Engineering Systems Design 1", which ran from 2018 to 2020. Its current structure, which involves weekly lectures and workshops, a strongly-scaffolded assessment structure, and a heavy emphasis on collaborative project-based learning, is the culmination of years of iterative improvements informed by student feedback and best practice in teaching. It is worth noting that this structure has proven scalable from 100 to 700 students per semester, with similar experiences and outcomes for both small and large student cohorts. The authors, who make up the current ETS teaching team, continue to make adjustments to the subject in line with a design-based research methodology (McKenney and Reeves 2020). In this paper, we discuss ETS's current curriculum and how its design addresses the previously described challenges, constraints, and frameworks.

3 CURRICULUM DESIGN

Only two first-year engineering subjects are offered at the University of Melbourne, running in separate semesters. This small footprint has meant that between them, both subjects have to represent the breadth of engineering disciplines offered at the

University. ETS does this by embracing the growing transdisciplinarity of engineering. The subject revolves around a semester-long real-world design project: students collaborate in teams of four to design a water pumping, disinfection, monitoring, and distribution system to supply potable water sourced from an underground well to a remote village. Key concepts required for the design project are delivered via lectures, with the core content divided into four modules: professional engineering skills, fluid mechanics, water disinfection, and image processing. Here, a just-in-time learning approach is taken, where ideas developed in lectures one week are applied by students in hands-on workshop-based activities the following week. This general structure is visualised in Figure 1, and is elaborated upon in the following sub-sections.

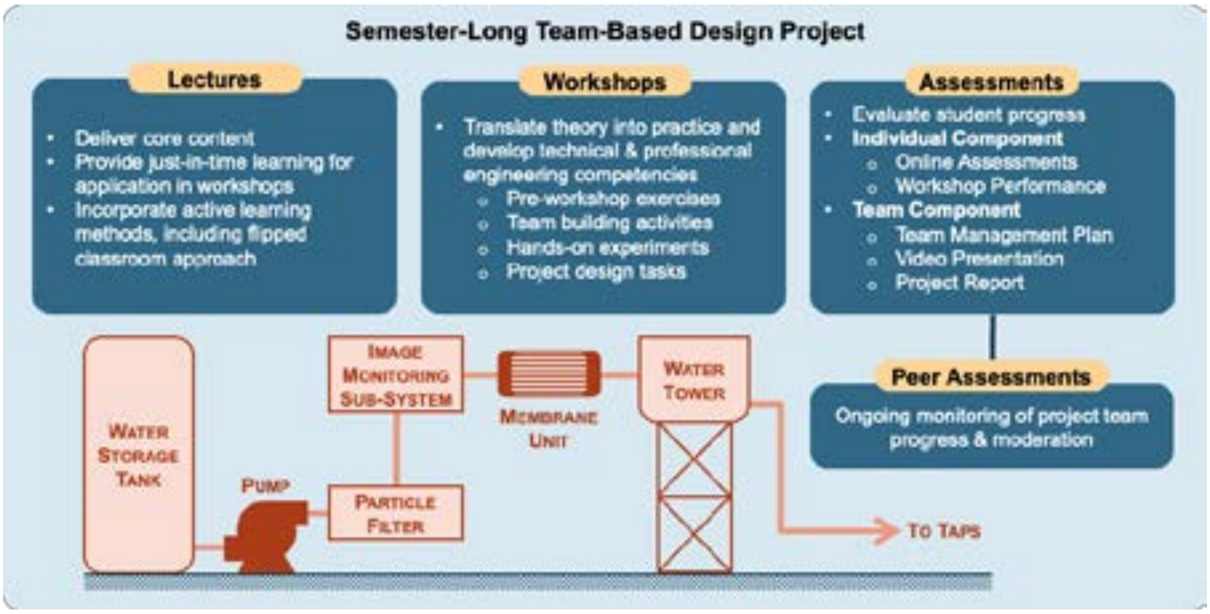

Figure 1: General structure of Engineering Technology and Society.

3.1 Lectures

Lectures run three times per week with each lasting an hour. These provide just-in-time learning of key concepts, which are applied by students in their workshops the following week. This staggered arrangement means that lectures only run from Weeks 1 to 11 in a regular 12-week semester. The lecture content by week and its relevance to the design project are summarised in Table 1.

Table 1: Summary of lecture content in Engineering Technology and Society.

Weeks	Module	Topics	Relevance to Design Project
1	**Professional Engineering Skills**	Subject structure, diversity of engineering disciplines, contributions of engineers to society, teamwork & communication skills, project & time management skills	Appreciation for the importance of interdisciplinary collaboration, communication, and project management skills in engineering projects
2 to 4	**Fluid Mechanics**	Pipe flow, the mechanical energy balance, pump design & scale-up, CAD & 3D printing of pump impellers, pipe networks,	Design of pumping & water distribution sub-systems

		introductory MATLAB programming skills	
5 to 6	Water Disinfection	Membranes, diffusive mass transfer, mass balances, log inactivation credits, the Chick-Watson Law, further development of MATLAB programming skills	Design of water disinfection sub-system (ozone infusion via membranes)
7 to 10	Image Processing	Digital images as matrices, image filters, convolution, for & while loops, if-else statements (programming flow control in MATLAB), video processing	Design of image monitoring sub-system (particle detection algorithm)
11		Subject summary	

Active learning methods are incorporated into lecture delivery to boost student engagement and learning. In fact, the entire Image Processing module is delivered using a flipped classroom approach. Here, students are assigned about 15 minutes of pre-lecture video content which cover key technical concepts. This frees up lecture time for more hands-on collaborative problem-solving and instructor-facilitated live coding sessions (Lam and Chan 2023). It also has the advantage of providing early exposure to our first-years of alternative teaching modalities that they might encounter at university, in line with Trautwein and Bosse's Organisational Dimension.

The subject also features three guest lectures delivered by industry-linked experts. These expand on the core content with topics that align closely with one of the four modules: product development and start-ups (Professional Engineering Skills module), industrial applications of membrane technology (Water Disinfection module), and medical imaging (Image Processing module). The Content-related Dimension is addressed here, as these provide first-years with some exposure to the norms and expectations of the engineering profession. In addition, an "Engineering Student Club Showcase" is held in Week 1, during which various engineering student clubs and societies are invited to talk about their activities and initiatives, and how first-years can get involved. This aligns with the Social Dimension, as it introduces first-years to existing on-campus networks that they can tap into to start building connections early.

3.2 Workshops

Weekly workshop sessions are an integral part of ETS, as these allow students to apply the theoretical concepts covered in lectures in practice. They also address Trautwein and Bosse's Social Dimension by providing students with an environment to engage in cooperative learning, and to actively collaborate with their teammates on a series of progressive tasks leading up to their final project outcome. Each three-hour workshop session consists of at most 56 students and is facilitated by two demonstrators. Demonstrators are typically more senior students who have previously completed ETS, and are selected to represent the breadth of engineering disciplines offered at the University. This allows them to act as "more knowledgeable others" in accordance with a social constructivist learning framework.

Prior to attending each workshop session, students must complete pre-workshop exercises deployed as online H5P-based interactives. In line with the Content-related Dimension, these scaffold relevant concepts and ensure that students are familiar with the operational procedures for each week's workshop. The workshops themselves consist of three categories of activities that collectively develop students' technical and professional engineering skills, and reinforce and supplement lecture content:

1. **Team Building Activities.** These short activities are conducted at the beginning of workshop sessions and focus on professional skills. Student teams are presented with a variety of activities over the semester, including physical Lego construction activities, virtual "Escape Room" scenarios, as well as reflective and discussion-based activities. These are all designed to promote engagement and encourage team bonding in a relaxed setting, allowing for the development of teamwork and communication skills (Chan and Lam 2023).
2. **Hands-on Experiments.** Drawing on constructionism, students work in teams to conduct hands-on experiments on scaled-down versions of the design project's sub-systems. This process of collaborative hands-on experimentation allows students to develop their teamwork and verbal communication skills.
3. **Project Design Tasks.** Towards the end of each workshop session, students are given time to work on their project-related tasks and deliverables such as the Team Management Plan, Video Presentation, and Project Report. Any collected experimental data is also analysed in MATLAB, providing students with a basis on which to scale-up and design the real-world version of their project. Through this process, students improve their programming skills and gain an appreciation for computational tools in technical engineering design and problem-solving applications. They also develop professional engineering skills around planning and project management by working together as a team.

3.3 Assessments

ETS has an assessment structure consisting of two equally-weighted components:

- The **Individual Component** includes numerous assessments spread over the semester that recognise students' individual progress and achievements. These assessments are largely low-stakes and function to scaffold student learning while providing exposure to a range of assessment types, in line with the Content-related Dimension.
- The **Team Component** consists of three major deliverables that are core to the progress of the semester-long design project. These are spaced out strategically over the semester, building up towards the final project outcome. The scale of these assessments means that collaborative teamwork is necessary, in line with the Social Dimension.

Both components also address the Personal and Organisational Dimensions of Trautwein and Bosse's framework by promoting the development of time management and organisational skills in the context of expectations around assessment quality and submission processes. The assessment structure in ETS is summarised in Table 2, with finer details on the assessments that make up each component.

3.4 Student Support

ETS is also designed to provide students with support beyond its regularly scheduled lectures, workshops, and assessments. As with all other subjects offered at the University, all subject content is accessible via the Canvas Learning Management System. As one of the first subjects students will encounter during their time at university, the Canvas page for ETS has been optimised for ease of navigation, and time is spent in Week 1 to demonstrate to students how Canvas works. The Discussion Boards on Canvas are a key feature of the subject, and are constantly monitored by the teaching team and demonstrators. Students are strongly encouraged to post questions about the subject content and to engage in discussions, drawing on social constructivism and addressing Trautwein and Bosse's Social Dimension.

In line with the Organisational Dimension, students are also introduced to various on-campus facilities, services, and networks that they will likely make use of as they progress through their degrees. These include the Telstra Creator Space, the University's makerspace that students use to 3D print custom-designed pump impellers for experimental testing. Various technical workshops and events (both academic and social) organised by the Faculty and student clubs are also advertised to students over the course of the semester.

Table 2: Assessment structure in Engineering Technology and Society.

Component	Assessments	Descriptions
Individual (50%)	**Online Assessments (25%)**	**Weekly Homework (5%)** • 9 problem sets deployed as Canvas Quizzes or with the MATLAB Grader platform • Low-stakes formative assessment: best 5 of 9 scores considered, unlimited attempts with automated marking and immediate feedback allows students to build confidence (Chan et al. 2022)
		Mid-Semester Quiz (10%) • Mid-semester summative assessment deployed as Canvas Quiz • More challenging with imposed time limits to assess students' technical knowledge
		End-of-Semester Quiz (10%) • End-of-semester summative deployed with the MATLAB Grader platform • More challenging with imposed time limits to assess students' technical knowledge
	Workshop Performance (25%)	**Health & Safety Training Modules (1%)** • Required for participation in workshop activities • Promote culture of safety in engineering
		Pre-Workshop Exercises (8%)

		• Provide scaffolding & relevant knowledge around hands-on workshop activities
		In-Workshop Tasks (14%) • Test competencies in engineering practice e.g. following experimental procedures, MATLAB-based data analysis, and reporting of outcomes
		Peer Assessments (2%) • Provide feedback on team health & contributions of team members • Used to moderate marks for the Video Presentation & Project Report (Team Component)
Team (50%)	**Team Management Plan (5%)**	• Helps establish project goals, expectations, and member responsibilities, as well as to distribute tasks and assess risks (Chan and Lam 2023)
	Video Presentation (10%)	• Motivates students to reflect on & summarise their project progress to date • Students develop skills around video production & presentation e.g. scripting, storyboarding, recording, video editing, and verbal communication • Marks moderated using peer assessment
	Project Report (35%)	**Draft Report (5%)** • Motivates students to start their report early • Critically assessed by markers to provide feedback students can use to improve their final report
		Final Report (30%) • 40-page technical report summarising the team's final design & project outcomes • Students develop written communication skills & experience with formal language & referencing

4 FEEDBACK & REFLECTIONS

Anchoring content to a semester-long team-based design project has proven to be an effective means of introducing engineering fundamentals to first-years, and this has been a constant feature of ETS since its inception. However, its structure has undergone numerous rounds of improvements to keep abreast of evolving student expectations, pedagogies, and learning technologies. These have previously been described in detail (Chan et al. 2022, Chan and Lam 2023, Lam and Chan 2023), and so here we present instead our high-level reflections on the ETS's current structure.

The most recent round of feedback involved discussions with student representatives to identify aspects of the subject that were working well versus those that could be improved. In general, students found the subject well-structured and well-taught, with the majority in agreement that the real-world design project provided an effective introduction to engineering. Students particularly appreciated the integration of MATLAB and other software-based tools with engineering design, as well as the opportunity to bridge theoretical knowledge and practice via collaborative hands-on workshop activities. Despite this, some students found the sheer volume of subject content and the fast pace of content delivery quite challenging. This was particularly evident in the workshop sessions, where a significant amount of tasks must be completed within a three-hour duration. Future adjustments to ETS will focus on identifying the right balance between pacing and subject content, and providing more support around developing time management and organisational skills in line the Content-related and Personal Dimensions, respectively.

In terms of assessments, the consensus was that regular low-stakes assessments spread over the semester (i.e. weekly homework, pre-workshop exercises, and in-workshop tasks) were helpful in ensuring students keep on track with the subject content. Students also expressed relief that the subject does not have a final examination, as this meant that they could focus on developing technical and professional engineering skills instead of rote-learning and regurgitating knowledge. There was, however, some level of discontent with the high weighting associated with team-based assessments, predominantly from students in teams with uncooperative member(s) and/or with mismatched achievement goals. In past runs of the subject, measures such as peer assessments and manual interventions have been enacted to ensure the fair moderation of marks for such teams. Building strong teamwork and collaboration skills – including effective conflict management strategies – continues to be a primary focus in ETS, in line with social constructivism and the Social Dimension.

5 SUMMARY

In this paper, we have discussed the current structure of ETS in the context of social constructivist and constructionist learning theories, as well as the Personal, Organisational, Content-related, and Social Dimensions identified as being critical in the design of first-year subjects. The authors will continue to review the curriculum of the subject based on feedback gathered via surveys, informal discussions with student representatives, and general class observations, in line with an iterative design-based research methodology. All feedback will be considered in the context of the subject’s objective of introducing first-years to the world of engineering while helping them successfully transition from secondary to tertiary education.

REFERENCES

Amineh, R.J., and Asl, H.D. "Review of Constructivism and Social Constructivism". *Journal of Social Sciences, Literature and Languages*, 1, 1 (2015): 9-16.

Burton, P. "The Challenge Of Teaching Large First Year Engineering Classes." Paper presented at *2007 ASEE Annual Conference & Exposition, Honolulu, HI, USA, 24-27 June 2007*. https://doi.org/10.18260/1-2--1994

Chan, H.Y., Lam, L., and Souza, R.A. "MATLAB Grader for Flexible Automated Assessment and Feedback in Large-Scale Engineering Subjects". *Proceedings of the AAEE 2022 33rd Annual Conference, Parramatta, NSW, Australia* (2022).

Chan, H.Y., and Lam, L. "Development of Teamwork Skills in a Project-based First-year Engineering Subject: A Comprehensive Framework". *Proceedings of the AAEE 2023 34th Annual Conference, Gold Coast, QLD, Australia* (2023).

Hake, R. "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics,* 66, 1 (1998): 64-74. https://doi.org/10.1119/1.18809

Harel, I., and Papert, S. *Constructionism*. Norwood, NJ: Ablex Publishing, 1991.

Lam, L., and Chan, H.Y. "Implementation of the Flipped Classroom Model in a Large-scale First-Year Engineering Subject". *Proceedings of the AAEE 2023 34th Annual Conference, Gold Coast, QLD, Australia* (2023).

McKenney, S., and Reeves, T.C. "Educational design research: Portraying, conducting, and enhancing productive scholarship". *Medical Education*, 55, 1 (2020) 82-92. https://doi.org/10.1111/medu.14280

Powell, K.C., and Kalina, C.J. "Cognitive and social constructivism: Developing tools for an effective classroom". *Education*, 130, 2 (2009): 241-250.

Prendergast, L., and Etkina, E. "Review of a First-Year Engineering Design Course." Paper presented at *2014 ASEE Annual Conference & Exposition, Indianapolis, IN, USA, 15-18 June 2014.* https://doi.org/10.18260/1-2--22987

Tomas, L., Evans, N., Doyle, T., and Skamp, K. "Are first year students ready for a flipped classroom? A case for a flipped learning continuum." *International Journal of Educational Technology in Higher Education*, 16, 5 (2019). https://doi.org/10.1186/s41239-019-0135-4

Trautwein, C. and Bosse, E. "The first year in higher education – critical requirements from the student perspective." *Higher Education* 73 (2017): 371-387. https://doi.org/10.1007/s10734-016-0098-5

Vygostky, L.S., translated by Hanfmann E., and Vakar G. *Thought and Language*. Cambridge, MA: MIT Press, 1965.

EXPLORING JOURNEYS FROM SUSTAINABLE DESIGN TO DESIGN FOR SUSTAINABILITY

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ABSTRACT

During the past two decades, educating students about sustainability issues has been a concern when designing engineering schools' curricula. One could think that nowadays students are trained to take into account the multiple dimensions of sustainability when addressing a project-based design challenge. Is this really the case? This paper presents an explorative qualitative study on the understanding and perspectives of engineering students regarding sustainability in the framework of such a course. The dataset consists of more than 200 reflexive notes gathered over a period of 3 years. The preliminary results of the study indicate that despite their previous knowledge and training about sustainability, engineering students still have an initial tendency to limit their perspectives and understanding to their own field of study. This points to the need to address the potential bias towards techno-centric perspectives and understanding of sustainability in engineering education by integrating or strengthening additional dimensions, including but not limited to social desirability or economic viability.

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1 INTRODUCTION

Our societies are facing increasingly pressing sustainability issues encompassing many different environmental and human dimensions, as reflected through the six planetary boundaries crossed (Richardson et al. 2023), and the many societal challenges to face (United Nations 2015). Educating responsible engineers implies transferring knowledge about these issues, but also transferring competences on how to appropriately act on such complex problems (Beagon et al. 2023).

'Design for sustainability', as defined by Ceschin and Gaziulusoy (2016), proposes to design systemic interventions, aiming at addressing sustainability issues in adequation with their inherent complexity. Design for sustainability takes roots in the observation that usual approaches to sustainable (engineering) design are "not sustainable" (Egenhoefer 2024). In sustainable design, the framing of the design problem as well as the design interventions towards sustainability are regularly limited to the technical dimension of the product (e.g., materials, processes), which fails to address the sustainability issues in their complexity.

Design for sustainability invites to address sustainability-related issues with design tools in a systemic way and at different scales. It includes the usual sustainable design interventions (e.g., on materials, components or products), but also invites to consider larger scales, regarding both design problem framing (ranging from product-service systems to local communities or even to socio-technical systems) and scope of design interventions (consumption habits, community practices, or even socio-technical systems dynamics). This opens the floor to a variety of additional design intervention types, such as design for sustainable behavior, design for social innovation, or design for sustainability transition, which act beyond the product scale and therefore offer a better grasp on sustainability dimensions which cannot be addressed at this scale only.

The 'Design for sustainability' course we present in this study, echoing other similar initiatives (Ceschin 2024), was created with the intention to train our students to act effectively on complex sustainability issues. This course brings together engineering and industrial design students from two separate institutions. It aims at training them to work in interdisciplinary teams and to define and execute a practical design project. This project should propose an economically viable design intervention while effectively addressing a sustainability issue. The class is taught by an industrial designer, a design strategist, an economist and an engineer specialized in sustainability. One third of the course[2] is dedicated to introductory classes covering theory and practical tools useful for the project work, as well as introductory exercises related to the three dimensions of the course (design, sustainability and economic viability). The remaining of the course is dedicated to the definition and execution of a practical design project in teams of 4 students (1-2 industrial design students and 2-3 engineering students from various disciplines). During this phase, regular consultations with all four teachers take place, to ensure project follow-up on the three dimensions covered by the course. The assessment is performed through multiple deliverables over the two semesters (see Table 1).

[2] The course runs over 2 semesters and is credited overall with 6 ECTS.

Table 1. Course assessment

Semester	Assessment elements	Sub-elements
Fall	Design process (40%)	Design (50%), Viability (50%)
	Project proposal (40%)	Design (33%), Sustainability (33%), Viability (33%)
	Reflexivity (20%)	Reflexive note (100%)
Spring	Project (80%)	Design (50%), Sustainability (30%), Viability (20%)
	Reflexivity (20%)	Reflexive note (100%)

As part of the assessment, students have to hand in a reflexive note (around 1000 words) at the end of the first semester (i.e., after having completed an introductory part of 60 hours and about 30 hours of actual project work). In the note, students are asked to reflect on cross-boundary collaboration in their team, as well as "[their] journey from sustainable design to design for sustainability"[3]. Prior to this reflexive note, students are asked to think about the issue of design for sustainability through a number of in-class and out-of-class activities. These include the re-design of an everyday object to make it more sustainable, as well as the integration of sustainability into a company's business model. Moreover, a guideline inspired from Hatton and Smith (1995) is provided to help students structure their reflexive practice.

In this framework, the question we set out to answer is: how do students understand and integrate the multiple dimensions of sustainability provided in the course? The purpose is to assess whether the proposed pedagogical setup, including many different dimensions (project-based learning, teamwork, cross-boundary collaboration beyond engineering, integration of social desirability and economic viability, etc.), manages, unlike other 'sustainable design'-centered initiatives, to equip our students with a complex multi-dimensional vision of sustainability, and would therefore be a relevant contribution to the improvement of the sustainability education in engineering.

To do so, the study explores the semantic content of the reflexive notes to gain insights as to the kind of sustainability understanding and perspectives students display. The content of reflexive notes on sustainability produced within design studio classes has already been analyzed in the literature, but from a reflexivity standpoint, rather than the sustainability understanding students are displaying (Gulwadi 2009). In parallel, several systematic frameworks have been established to assess the sustainability perspectives of students (e.g., Birdsall 2014) in different kinds of deliverables, but generally with a manual coding methodology and not directly based on reflexive notes. The exploration is conducted with MAXQDA, a qualitative lexical analysis software.

[3] The analysis presented hereafter only covers the "design for sustainability" part.

2 METHODOLOGY

2.1 Overview

The study involves students from two Swiss academic institutions (an engineering school and a design school) over a period of 3 years (2021-2023). The data gathered is based on the production of reflexive notes by the students at the end of the semester. As part of their reflexive note, students have to write about the following sub-theme: “My journey from sustainable design to design for sustainability”. While the course is taught in English, students can write their note either in French or in English. The sample is (n=223).

Table 2. Summary of dataset

	Design school		Engineering school		Total by language		Total
Year	French	English	French	English	French	English	
2021-2022	23	6	2	27	25	33	**58**
2022-2023	19	7	19	40	38	47	**85**
2023-2024	20	6	10	44	30	50	**80**
Total	**62**	**19**	**31**	**111**	**93**	**130**	**223**
as a %	**36.32%**		**63.68%**		**41.70%**	**58.30%**	

Note: enrollment was capped at 60 for 2021-2022 and 90 for the following 2 years.

2.2 Data analysis and coding process

For the preliminary study we applied an inductive thematic analysis approach to the dataset. The following coding process was used. In the first phase, both authors read the totality of the reflexive notes (n=223) and created separate lists of words related to the perspectives and understanding of sustainability (e.g., environment, complexity, etc.). These lists were then compared and discussed to flesh out frequent and salient keywords. Once merged, the list was then matched with a word frequency analysis on the entire dataset using MAXQDA. The rationale behind this was that we made the hypothesis that some words may appear less frequently than others but « weigh » more for the coders. Put differently, the word frequency analysis would potentially reduce our subjectivity and/or bias towards certain words while the subjective listing of words would prevent « salient » words from falling through the frequency trap. This led to a first list of 10 codes (see Table 3).

In the second phase, the dataset was auto-coded using MAXQDA on the basis of the ensuing list[4]. One author then identified a second set of words pertaining to the understanding and perspectives on sustainability based on the sentences surrounding the words from the first list. This led to a second list of 9 codes (see Table 4).

[4] Since the reflexive notes in the dataset are both in French and in English, the dataset was coded in both languages. Only the codes in English are presented here.

Table 3. Frequency of codes from first list (single, percentage and multiple counts)

	Single counts	**as % of notes**	**Multiple counts**
impact	138	61.88%	297
viable / viability	117	52.47%	212
need / needs	116	52.02%	194
question / questions	101	45.29%	208
environment	95	42.60%	168
economic / economy	92	41.26%	137
social	92	41.26%	164
value	62	27.80%	96
complex / complexity	61	27.35%	89
responsible / responsibility	52	23.32%	81
SUM	926		1646
N = Reflexive notes	**223**	**100.00%**	**223**

Table 4. Frequency of codes from second list (single, percentage and multiple counts)

	Single counts	**as % of notes**	**Multiple counts**
understanding / understand	171	76.68%	427
important importance	168	75.34%	394
aspect / aspects	147	65.92%	328
future	84	37.67%	141
change	77	34.53%	116
role	50	22.42%	61
conscious / consciousness	33	14.80%	53
justice	15	6.73%	17
coherent / coherence	12	5.38%	14
SUM	757		1551
N = Reflexive notes	**223**	**100.00%**	**223**

3 RESULTS AND DISCUSSION

Figure 1 shows how the 19 codes are distributed among the reflexive notes. More than 50% of the notes contain between 6 and 10 codes (this increases to 80% when one extends this to 4 and 11 codes). Going back to some of the earlier studies

(Azapagic, Perdan, and Shallcross 2005), one can wonder to what extent the knowledge and understanding of engineering students has deepened. On the one hand, the content analysis indicates that some high-level concepts (e.g., SDGs) are well integrated in students' perspectives and understanding on sustainability. Whereas Lozano et al. (2019) find that the social dimension of sustainability was the least addressed in European higher education institutions (below 20%), our dataset shows that more than 40% of the notes explicitly address this dimension. The same can be said for the economic and environmental dimensions. At this stage, it is hard to attribute this increase to any given factor. Several hypotheses can be put forward including an overall awareness increase in the student population, the fact that a course on sustainability attracts students already aware of such dimensions and/or that the content of the course helps raising such awareness.

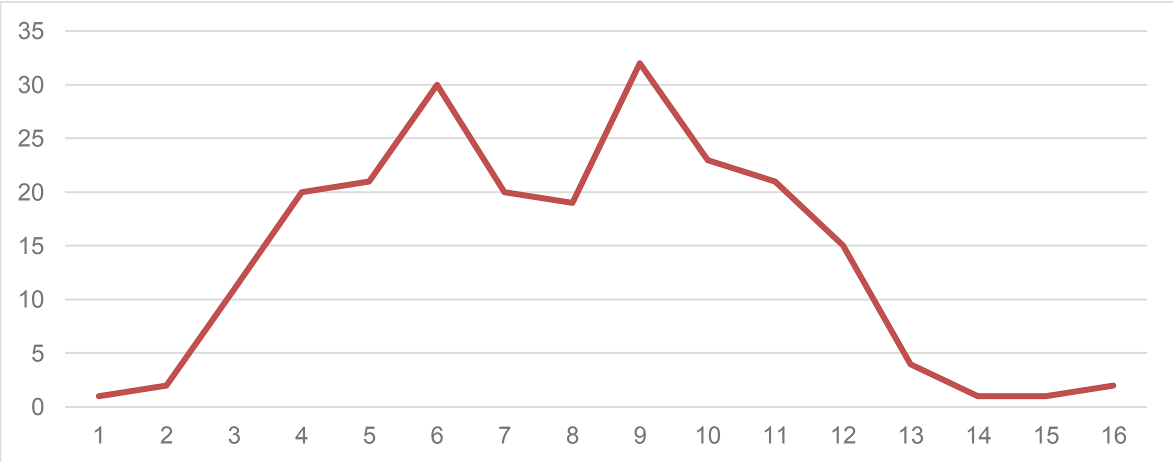

Fig. 1. Distribution of codes among reflexive notes (max=19)

On the other hand, the analysis shows that concepts related to inclusivity or justice feature much less prominently in students' reflections. The same can be said for concepts related to responsibility, as they are featured in less than 25% of the notes.

Given the interdisciplinary nature of the course, we also ran a frequency analysis comparing keywords found in the reflexive notes from engineering and design students (see Table 5).

Table 5. Comparison between engineering and design students (first list of codes)

	Design students	**Engineering students**	**Total**
impact	45.70%	71.10%	61.90%
viable / viability	55.60%	50.70%	52.50%
need / needs	38.30%	59.90%	52.00%
question / questions	58.00%	38.00%	45.30%
environment	37.00%	45.80%	42.60%
economic / economy	45.70%	38.70%	41.30%
social	37.00%	43.70%	41.30%
value	22.20%	31.00%	27.80%
complex / complexity	23.50%	29.60%	27.40%

responsible / responsibility	33.30%	17.60%	23.30%
N = Reflexive notes	81	142	100.00%

One cannot fail to notice some large discrepancies between engineers and designers in the use of certain words (e.g., impact, responsibility), something that we will need to further investigate by conducting a number of interviews with students both from the dataset and outside of the dataset to control for a selection bias.

The analysis of the reflexive notes has also fed our reflexivity as teachers. For instance, it helped us to identify if the students' understanding and perspectives of sustainability match the learning outcomes that we defined, and to what extent the teaching and learning strategies we developed actually help students reach these outcomes. Additional teaching material focusing on some of the "forgotten" dimensions (e.g., inclusivity) will be included in the course. Last but not least, the study also prompted us to initiate a discussion on how to refine the rubric used to assess the reflexive notes.

3.1 Limitations

The current study suffers from a number of limitations. A first one relates to the open-ended nature of the reflexive note. Elements of the reflexive process aside, no specific structure was imposed, which may have led students to comment only on a selected number of aspects rather than cover the whole span of their learning journey. Asking students to comment on their *journey* could also push them to express something they may not have experienced. This could even have been reinforced by the fact that the reflexive note is graded. To our knowledge, this has not been the case. For instance, some students clearly indicated that their journey had not taken them very far since they were already very much aware of sustainability-related questions. Other students provided substantial evidence on how their understanding regarding sustainability had broadened and the questions this raised (e.g., integration of multiple constraints, personal responsibility or professional identity). The following quote from an engineering student illustrates this point: "*Before taking this course, my understanding of sustainability was very techno-centric, which means that as a material engineer, I only thought of sustainable design and how to find a solution for questions like 'How to reduce the energy consumption for producing a specific material'*". Similar quotes can be attributed to designers: "*In the past, I approached the question of the sustainable object with the gaze of a designer who took care of its characteristics using the tools at my disposal, but my approach was limited to this. I now understand that the object is intrinsically linked to a larger network of relationships and impacts*".

A second limitation relates to the fact that at the time of the writing of the reflexive note, students have only spent 4 weeks working on their final project. To overcome this problem, we have added an element to the second reflexive note (due at the end of the second semester) pertaining to the practical work. This will hopefully shed additional light on the students' journey throughout the entire course.

A third and growing concern relates to the potential use of generative AI (GAI) for producing the individual reflexive note. This issue regards both the actual grading of the assignment and the core of this study. While it is for now impossible to check with high levels of reliability whether or not the note has been produced or 'enhanced' by ChatGPT or another GAI, we have checked the notes that appeared too ‘polished’ and believe that less than a handful fall in this category. To limit the use of GAI, students were asked to provide concrete examples from their actual project and experience with group work.

A final limitation relates not to the study itself but to the transferability of the set-up. Since the course is built around the bringing together of engineering and design students and instructors, not all academic institutions are in a position to propose such an interdisciplinary learning environment. We believe that a project-based approach around designing for sustainability can nonetheless be achieved in an “engineers-only” environment, provided that students are trained and challenged on issues beyond engineering issues (e.g., social and economic dimensions) and that the projects are assessed equally on their technical and non-technical merits. In our experience with project-based courses, students tend to “overinvest” in the artefact (the “hardware”), which often comes at the expense of other dimensions (e.g., theoretical content or transversal skills).

4 FUTURE WORK AND CONCLUSION

Future work needs to be carried out on at least two fronts. First and foremost, we need to refine and enhance the current analytical approach. This can be achieved by looking at the co-occurrence of codes and supplementing the quantitative analysis with more qualitative insights (e.g., conducting in-depth interviews). Second, we plan to compare our results with existing theoretical frameworks (Birdsall 2014; Brundiers et al. 2021; Lönngren et al. 2016; Wiek, Withycombe, and Redman 2011) and/or by applying a SOLO analysis (Carew and Mitchell 2002), thus moving from an inductive approach to a deductive one. Further comparisons could be run between our sample and students not enrolled in the course. This would provide some insights as to the general understanding and perspectives on sustainability among engineering students. Given some of the inherent limitations encountered with the frequency analysis, one could also imagine borrowing tools from sentiment analysis (Liu 2020) to gain further insights.

The preliminary analysis has allowed us to get a glimpse of engineering and design students’ journey towards design for sustainability. So far, we can conclude that in comparison with recent studies their perspectives and understanding of sustainability integrates slightly more social, economic and environmental dimensions. At the same time, more indirect concepts like justice or inclusivity feature less prominently in students’ reflections. In our view, this calls for strengthening the non-engineering component of the course while finding an equilibrium between the expectations of engineering students in a project-based course and the opportunity such a course provides to explore the responsibilities that come with design and engineering. Following the study, the teaching team will need to reflect on how to bring early on the non-technological elements pertaining to the broad understanding of sustainability we aim to foster. This would need to be reflected in the course content (knowledge, skills and attitudes), the learning activities and the assessment modalities.

REFERENCES

Azapagic, Adisa, Slobodan Perdan, and David Shallcross. 2005. "How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum." *European Journal of Engineering Education* 30 (1): 1-19. https://doi.org/10.1080/03043790512331313804.

Beagon, Una, Klara Kövesi, Brad Tabas, Bente Nørgaard, Riitta Lehtinen, Brian Bowe, Christiane Gillet, and Claus Monrad Spliid. 2023. "Preparing engineering students for the challenges of the SDGs: what competences are required?" *European Journal of Engineering Education* 48 (1): 1-23. https://doi.org/10.1080/03043797.2022.2033955.

Birdsall, Sally. 2014. "Measuring student teachers' understandings and self-awareness of sustainability." *Environmental Education Research* 20 (6): 814-835. https://doi.org/10.1080/13504622.2013.833594.

Brundiers, Katja, Matthias Barth, Gisela Cebrián, Matthew Cohen, Liliana Diaz, Sonya Doucette-Remington, Weston Dripps, Geoffrey Habron, Niki Harré, Meghann Jarchow, Kealalokahi Losch, Jessica Michel, Yoko Mochizuki, Marco Rieckmann, Roderic Parnell, Peter Walker, and Michaela Zint. 2021. "Key competencies in sustainability in higher education—toward an agreed-upon reference framework." *Sustainability Science* 16 (1): 13-29. https://doi.org/10.1007/s11625-020-00838-2.

Carew, A. L., and C. A. Mitchell. 2002. "Characterizing undergraduate engineering students' understanding of sustainability." *European Journal of Engineering Education* 27 (4): 349-361. https://doi.org/10.1080/03043790210166657.

Ceschin, Fabrizio. 2024. "Teaching Design for Sustainability from Product Design to Design for Sustainability Transitions: A New Programme at Brunel University London." In *Routledge handbook of sustainable design*, edited by Rachel Beth Egenhoefer, 605-608. Abingdon, Oxon: Routledge.

Ceschin, Fabrizio, and Idil Gaziulusoy. 2016. "Evolution of design for sustainability: From product design to design for system innovations and transitions." *Design Studies* 47: 118-163. https://doi.org/https://doi.org/10.1016/j.destud.2016.09.002.

Egenhoefer, Rachel Beth. 2024. "Sustainable design is not sustainable." In *Routledge handbook of sustainable design*, edited by Rachel Beth Egenhoefer, 5-13. Abingdon, Oxon: Routledge.

Gulwadi, Gowri Betrabet. 2009. "Using reflective journals in a sustainable design studio." *International Journal of Sustainability in Higher Education* 10 (1): 43-53. https://doi.org/10.1108/14676370910945918.

Hatton, Neville, and David Smith. 1995. "Reflection in teacher education: Towards definition and implementation." *Teaching and Teacher Education* 11 (1): 33-49. https://doi.org/10.1016/0742-051X(94)00012-U.

Liu, Bing. 2020. *Sentiment analysis : mining opinions, sentiments, and emotions*. Second edition. ed.*Studies in natural language processing*. Cambridge ; New York: Cambridge University Press.

Lönngren, Johanna, Magdalena Svanström, Åke Ingerman, and John Holmberg. 2016. "Dealing with the multidimensionality of sustainability through the use of multiple perspectives – a theoretical framework." *European Journal of Engineering Education* 41 (3): 342-352. https://doi.org/10.1080/03043797.2015.1079811.

Lozano, Rodrigo, Maria Barreiro-Gen, Francisco J. Lozano, and Kaisu Sammalisto. 2019. Teaching Sustainability in European Higher Education Institutions: Assessing the Connections between Competences and Pedagogical Approaches. *Sustainability* 11 (6). https://doi.org/10.3390/su11061602.

Richardson, Katherine, Will Steffen, Wolfgang Lucht, Jørgen Bendtsen, Sarah E. Cornell, Jonathan F. Donges, Markus Drüke, Ingo Fetzer, Govindasamy Bala, Werner von Bloh, Georg Feulner, Stephanie Fiedler, Dieter Gerten, Tom Gleeson, Matthias Hofmann, Willem Huiskamp, Matti Kummu, Chinchu Mohan, David Nogués-Bravo, Stefan Petri, Miina Porkka, Stefan Rahmstorf, Sibyll Schaphoff, Kirsten Thonicke, Arne Tobian, Vili Virkki, Lan Wang-Erlandsson, Lisa Weber, and Johan Rockström. 2023. "Earth beyond six of nine planetary boundaries." *Science Advances* 9 (37): eadh2458. https://doi.org/10.1126/sciadv.adh2458.

United Nations. 2015. *Transforming Our World: The 2030 Agenda for Sustainable Development.* Accessed 11th June 2024 https://sdgs.un.org/publications/transforming-our-world-2030-agenda-sustainable-development-17981.

Wiek, Arnim, Lauren Withycombe, and Charles L. Redman. 2011. "Key competencies in sustainability: a reference framework for academic program development." *Sustainability Science* 6 (2): 203-218. https://doi.org/10.1007/s11625-011-0132-6.

EXPERIENCING ENGINEERING – INCREASING THE ATTRACTIVENESS OF ENGINEERING THROUGH PERIOD OF WORK EXPERIENCE FOR LOWER SECONDARY SCHOOL PUPILS

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Keywords: work experience, secondary school, gender, second-generation migrant, industry involvement

ABSTRACT

This practice paper presents a novel way of designing a work experience program for lower secondary school pupils, combining university and company activities. The program aims to broaden pupils' understanding of engineering jobs and the educational pathways that lead to them. To highlight and illustrate the need for a diverse engineering workforce, the program was specifically targeted at young women and students from immigrant backgrounds. The experience of the first pilot was positive for both the students and the university and company personnel. However, it was also found that communicating the expert nature of the engineering work can be a challenging task.

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1 INTRODUCTION

In Finland, like in many other countries, occupational gender segregation persists despite efforts to promote gender equality. The fields of technology, engineering, and construction are still strongly male-dominated (Statistics Finland 2022). Segregation begins in childhood and continues throughout individuals' education and into their careers (Keski-Petäjä and Witting 2018). In addition to gender segregation, the Finnish education system is experiencing a continuously strengthening segregation according to social background (Bernelius and Huilla 2021). Family background more strongly guides some young people into higher education and some away from it. Young people with immigrant backgrounds, for example, seek higher education far less often than the general Finnish population (Nori et al. 2021).

Periods of work experience (a.k.a. TET) refer to the opportunities offered to lower secondary school pupils in Finland to familiarize themselves with various fields and professions, as well as to learn workplace practices. This may include short internship periods in companies or organizations, visits to workplaces, and tasks simulating real work situations. The collaboration between schools and working life is designed to offer pupils opportunities to discover their areas of interest, enhance their work-seeking skills, develop an understanding of entrepreneurship, and gain insights into working life in general (OPH 2014). TET is a compulsory part of the lower secondary school curriculum, but the format of execution may vary according to the municipality and school (Mayer et al. 2022).

LUT University’s project *TechnoTET South Karelia* establishes pathways for lower and higher secondary school students to familiarize themselves with the technology sector education and labor market. The project utilizes different concepts of working life cooperation, which are included in the lower and upper secondary education curriculum in Finland. The project aims to reach especially young females and young people with immigrant backgrounds in order to broaden their educational opportunity horizons and interests. The goal is to attract more young people to pursue studies in technology while simultaneously alleviating the segregation between different fields of education and professions. This practice paper describes and analyzes the first *TechnoTET* pilot from the fall of 2023.

2 PERIODS OF WORK EXPERIENCE AS A MEANS TO ATTRACT MINORITIES TO TECHNOLOGY

Periods of work experience are typically conducted during the upper grades of lower secondary school when the pupils are 14-16 years old. The most typical way to offer the experience to pupils is to do it in 1–2-week periods, during which they visit companies or other organizations and familiarize themselves with working life practices, various professions, and tasks. Even though this concept has existed in the Finnish lower secondary schools for several decades it is, unfortunately, an underutilized opportunity for several reasons.

Firstly, organizations’ shortage of resources can limit the opportunities to offer diverse and high-quality workplace orientation experiences (Mayer et al. 2022). In many cases, employers recognize the value, but cannot offer a wide enough range of tasks or guidance for the trainees. Another significant challenge is a regional imbalance (Mayer et al. 2022). Some areas in Finland have limited availability of companies and organizations, making it difficult for pupils to gain diverse workplace experiences. Furthermore, in some schools, there is very little collaboration with any employer organizations, which leads to an unbalanced situation where some pupils have a wide selection of companies and other organizations to choose from while others have significantly less (Mayer et al. 2022).

Additionally, in certain fields such as the technology industry, arranging work experience periods is difficult due to reasons such as occupational safety and lack of time resources. Minors cannot be allowed to familiarize themselves with production tasks, as legislation alone prohibits it (Occupational Safety and Health Act 2002). On the other hand, it would be possible to introduce them to expert tasks without significant occupational safety risks, but simulating expert tasks is challenging without proper preparation, which in turn would require time and commitment from employees.

All the aforementioned reasons have led pupils to typically gravitate towards places that are easily accessible and where simple tasks such as cleaning, stocking shelves, dishwashing, etc., are available to them. While these work experiences are valuable and important, they may not necessarily broaden pupils' horizons regarding further studies or career opportunities. Companies and professions in the field of technology, especially, are such that pupils typically haven't had the opportunity to familiarize themselves with. The young people’s lack of familiarity and knowledge of vocations, activities, and opportunities of STEM fields was identified by van Tuijl and van der Molen (2016) as one of the three factors driving young people away from STEM careers.

Various reach-out activities have shown that technology-related hands-on activities are an effective way to evoke adolescents' interest in technology and engineering regardless of their age or gender (Naukkarinen and Ikonen 2018; Naukkarinen et al. 2019; Naukkarinen et al. 2021). Their effectiveness is further enhanced by connecting the experiences to youngsters’ world spheres (Naukkarinen and Ikonen 2018). Vennix et al. (2018) discovered that a positive attitude toward STEM careers was positively associated especially with activities that enhanced the autonomous-motivation. This was best achieved with workshop-format out-of-school activities suggesting that *“the out-of-school component is important to get a more complete picture of the implications of STEM and of possible career opportunities”* (Vennix et al. 2018, 1280).

Linking the activities to the demonstrations of the positive effects that technology can have on society can be beneficial, especially in evoking girls’ interest in technology (Naukkarinen et al. 2021). As girls are less likely to have technology-related hobbies and are less often encouraged to act with technology at school and home (Naukkarinen et al. 2021), a period of work experience in a technology company can provide the much-needed opportunities to gain technology-related concrete experiences with real-life connections that girls easily otherwise lack. These experiences also increase the adolescents’ science capital, by conveying knowledge about STEM-related jobs and the transferability of science in working life, as well as giving the opportunity to get to know people in science-related roles (Moote et al. 2019). As science capital is known to positively correlate with engineering aspirations (Moote et al. 2019), period of work experience in a technology company can be expected to increase pupils’ interest in engineering careers.

Secondary schoolers with immigration backgrounds are generally not identified as a distinct group (Airas et al. 2019) hence little is known about their experiences in choosing educational paths. An evaluation of students with an immigrant background in Finnish higher education recognized marketing cooperation between companies, higher education institutions, and the public sector as a good practice that can both advance the employment of graduates with immigration backgrounds and make higher education opportunities better known to those with no prior experience of it (Airas et al. 2019). A period of work experience in a technology company coupled with information about the educational paths leading to respective professions serves these objectives well.

The spectrum of STEM outreach activities is vast yet work placement does not seem to be common among them (see e.g. Tillinghast et al. 2020). Hence little is also known about its effectiveness in attracting young people to engineering.

3 TECHNOTET SOUTH KARELIA PROJECT

LUT University has long been aware of the segregation of different fields of education based on gender, as well as the significant influence of young people's social background on whether they choose to pursue higher education or not. For years, LUT has also been an organization offering periods of work experience (a.k.a. TET) to lower secondary school pupils, like many other employer organizations. However, LUT's TET periods have not been conceptualized. Thus, their full potential has not been utilized. A solution to these challenges arose in the form of the *TechnoTET South Karelia* project.

In the early stages of the project, various options were considered for constructing a TechnoTET period for lower secondary school pupils. The first decision was that TechnoTET would be aimed at 9th graders because they are the ones most actively considering their further education options. In local lower secondary schools, 9th graders have a two-week work experience period, so the TechnoTET period also had to be designed as a two-week package.

The project also aimed to involve companies from the technology sectors because the goal was to show young people what kinds of tasks are carried out in technical expert roles and what opportunities the technology sectors offer in general. It was decided that during the two-week TechnoTET period, pupils would spend the first week at LUT getting acquainted with the different education opportunities, academic work environment, and researcher's work. During the second week, pupils would familiarize themselves with expert tasks in companies for the first four days. On the final day, all pupils would gather again at LUT, where experiences would be shared and feedback collected.

Since this is a local project and pupils need to be able to easily access the companies, it made sense to invite tech companies that operate in Lappeenranta region and are located close enough to the pilot school. Another selection criterion was that the companies had to have technical expert positions that the young people could observe. Approximately 25 companies were contacted, and it was found that it was generally very difficult to reach company representatives. Once contact was established, the companies liked the idea of the project but were not willing to take in TET trainees due to workload and the lack of meaningful tasks for the trainees. The project schedule was also very tight, which made it difficult to engage the companies. However, negotiations were successful with a few, and the first pilot involved four partner companies: Metso, Roxia, UPM and Yaskawa. Each company was able to offer 2-4 internship positions.

The selection process also included a visit from a LUT representative to each company at least once. Internship contracts were signed with all partner companies to make sure that the young people would have meaningful tasks and a supervisor during the company days, too. Based on the discussions, it was clear that the companies selected for the pilot were suitable because they were genuinely motivated to participate in the project and recognized its value in terms of social responsibility. Additionally, the company representatives were willing to put effort into planning the program and wanted to leave the young people with a positive impression of the company, its operations, and employees.

Sammonlahti School, a comprehensive school with approximately 900 students served as a partner school in the first TechnoTET pilot. During the 2023-2024 academic year, there were around 100 ninth graders at Sammonlahti School. TechnoTET was promoted to them during student counseling classes in September 2023, with each 9th-grade class having a TechnoTET-themed lesson where the concept was introduced, and pupils were encouraged to consider the significance and opportunities of technology education and careers. During the lesson, pupils rotated in small groups to stations where they discussed, among other things, gender segregation in various professions, read career stories from the field of technology, and familiarized themselves with the partner companies.

After the lessons, pupils were invited to apply for the TechnoTET period. A total of 27 applications were received but there were only 15 positions available. The selections were made in collaboration with Sammonlahti school student counselors. In line with the project's objectives, priority was given to females and pupils with immigrant backgrounds. Following these principles, a group of 15 pupils was formed, consisting of a total of 8 females and 7 males. Two out of 15 were pupils with an immigrant background.

3.1 The program

The two-week pilot was carried out between October 9th and 20th, 2023. During the first week, pupils were introduced to educational opportunities in technology fields and the academic work at the university. The aim was to create a program that was as varied as possible to keep the pupils' interest alive throughout the entire week. The week included, among other things, an escape room game related to environmental technology, an introduction to researcher's work, making sorbet in the chemical engineering laboratory, and delving into electrolysis under the guidance of an electrical engineering student. The theme of gender segregation was also addressed. Additionally, the pupils familiarized themselves with partner companies and pondered what kind of skills are required in the workplaces. The program for the first week is illustrated in Figure 1.

Time	Monday 9.10.	Tuesday 10.10.	Wednesday 11.10.	Thursday 12.10.	Friday 13.10.
09.00-10.00	Getting to know each other, Team-building activities	ABB classroom: electrolysis	Introduction to the work of a researcher	Introduction to gender segregation	TEK: science and technology education
10.00-11.00	Familiarization with partner companies	*Draw an Engineer* assignment	Introduction to the academic library	*Shaking up Tech Stream*	
11.00-12.00	Lunch	Lunch	Lunch	Lunch	Lunch
12.00-13.00	Creating a written or video presentation about oneself and sending it to company	Campus orienteering: study programmes	Chemical engineering Making sorbet: heat transfer and phase change Thin-layer chromatography Analytical balances, SEM	Preparing for the following week: TET report, working life skills, strengths	TEK: science and technology education
13.00-14.00	Guild room tour	13.00-13.30 Orienteering: right answers			
14.00-15.00	Introduction to Jamie Hyneman Center	13.30-15.00 Environmental engineering escape room game		Gender segregation: addressing the topic interactively	xxxxxxx

Fig. 1. TechnoTET schedule, 1st week

During the second week, the pupils were at partner companies from Monday to Thursday. The aim was to provide them with insights into expert tasks in technology fields by simulating real expert work. At UPM, for example, pupils manufactured laboratory sheets, tested them, and wrote a report on the entire process. At Metso, interns engaged in tasks such as equipment engineering using SolidWorks and identifying different types of rock. At Roxia, interns had their own small project during which they interviewed employees, wrote career stories, and updated them on the company's website. At Yaskawa, students were introduced to different departments of the company through various tasks. They became familiar with areas such as occupational safety, quality, design, project management scheduling and management of production facility instructions.

On the Friday of the second week, all pupils gathered once again at the university to share experiences and to give feedback. As the pupils had spent four days in different companies, it was important to bring the group together one more time. The morning was mainly spent exchanging experiences and giving feedback. Additionally, the pupils recorded short videos describing their experiences and created a thank-you message to the company they had been in. After lunch, the pupils familiarized themselves with LUTES, which is a student-driven entrepreneurship society based at the university. In the afternoon, they played with VR glasses and consoles before it was time to bid farewell to the TechnoTET experience.

4 EXPERIENCES AND FEEDBACK

The pupils' experiences from the TechnoTET period were generally very positive and they liked the training. Discussions with the participants revealed that pupils who wouldn't have otherwise pursued a technical field for work experience participated in the internship. It also became apparent that before TET, most of the pupils had had limited knowledge about the possibilities in technology-related fields and the various tasks that can be undertaken in expert roles. Additionally, the partner companies had not been familiar to everyone, especially regarding what is done in the companies and why. Furthermore, the pupils' perceptions of engineers as a professional group had been somewhat incomplete and, in some cases, biased. However, all of this changed somewhat during the internship, as the pupils' understanding of the technology sector and the people working in it increased.

For example, at the beginning of the TechnoTET period, pupils were asked to draw an engineer and describe them along with their working conditions. Only one drawing depicted a female, while the rest were of males. Many figures had helmets on their heads and tools in their hands, implying a perception of work as primarily hands-on installation and repair tasks. Many pupils also described engineers as working alone and being introverted. In the discussions on the final day, however, the pupils mentioned a better understanding of the diverse working field of engineers and the variety of people involved in engineering tasks.

At the end of the period pupils were administered a short survey about their TechnoTET encounters. The survey aimed at gauging different aspects of student experience: attractivity, perspicuity, efficiency, dependability, stimulation, and novelty (Laugwitz et al. 2008). The feedback was altogether very positive but foremost the pupils evaluated the experience as pleasant (as opposed to unpleasant), modern (as opposed to old-fashioned), innovative (as opposed to conventional), and organized (as opposed to chaotic). One out of thirteen respondents stated to be slightly disappointed with the experience, whereas all the rest regarded it as meeting their expectations on positive terms.

When asked about potential changes to the TechnoTET concept, the pupils unanimously expressed a desire for more hands-on experiences both at the university and in the companies. The company representatives also noticed the same preference. They mentioned that although the pupils had the opportunity to try out real expert tasks, they did not perceive them as actual work. For example, at Yaskawa, students had worked on project scheduling but, according to their own words, did not consider it real work but more like playing with Excel.

However, the companies were generally very pleased with the experience and praised the behavior and actions of the young participants. A common improvement point highlighted by both the university and the companies was the need to simulate expert tasks at an even more concrete level. Despite this, all four partner companies were so satisfied with the experience that they expressed their willingness to continue participating in the project and host TechnoTET interns in the future as well.

The university was also very satisfied with the first TechnoTET experience. Thirteen university employees participated in implementing the program, and their experiences with the internship were very positive. Interns are welcomed as long as the responsibility is distributed enough among different units and as long as the coordination of the program functions well. Employees are happy to participate when they know what is required of them in their respective roles and as long as it is closely related to their own work and expertise. The coordination responsibility is gladly given to a coordinator who is responsible for organizing the whole program and ensuring that the youth are in the right place at the right time.

Additionally, it was observed that organizing a TechnoTET period is more efficient than receiving individual TET interns. Since the university has now done both, it was easy to compare the two alternatives. Through the conceptualized internship, a broader group of young people can be reached, and it is easier to build 1-2 high-quality programs per academic year than constantly tailor individual programs for a few interns.

5 CONCLUSIONS AND CONTINUATION

Overall, the first TechnoTET pilot was a very positive experience that encouraged continuing the work and expanding the TechnoTET concept to high school and vocational school students in the spring semester of 2024. In autumn 2024 the lower secondary school TechnoTET internship will be repeated, but this time it will be expanded to include a total of three schools and twelve partner companies.

Although collecting longitudinal data to assess the effectiveness of the program is not possible due to data protection regulations, we will collect research data on the effects of the TechnoTET program next academic year. For example, pupils' perceptions of engineering, their understanding of engineer's work and their aspirations toward engineering will be examined.

So far, the narrow data from the project has not allowed us to evaluate the attractiveness and effectiveness of the activities from the viewpoint of the targeted minorities. However, a new round of pilots coupled with a growing number of participants allows us to examine the concept and its impact on a deeper level and hopefully enables us to evaluate the possible differences related to participants' gender and ethnic background, too.

While awaiting research evidence, we base our current thoughts on discussions and feedback from the different stakeholders. As expected, they seem to confirm the value of out-of-school activities (Vennix et al. 2018) and of first-hand experience and knowledge in increasing the pupils' science capital (Moote et al. 2019) and in increasing the attractiveness of engineering as a possible career (van Tuijl and van der Molen 2016).

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REFERENCES

Airas, M., Delahunty, D., Laitinen, M., Saarilammi, M-L., Sarparanta, T., Shemsedini, G., Stenberg, H., Vuori, H., and H. Väätäinen. *Taustalla on väliä. Ulkomaalaistaustaiset opiskelijat korkeakoulupolulla [Background matters. Students with an immigrant background in higher education]*. Finnish Education Evaluation Centre (FINEEC), Publications 22:2019, 2019.

Bernelius, V., and H. Huilla. *Koulutuksellinen tasa-arvo, alueellinen ja sosiaalinen eriytyminen ja myönteisen erityiskohtelun mahdollisuudet [Educational equity, social and spatial segregation and opportunities for targeted support]*. Publications of the Finnish Government 2021:7, 2021.

Keski-Petäjä, M., and M. Witting. 2018. ”Alle viidennes opiskelijoista opinnoissa joissa tasaisesti naisia ja miehiä – koulutusalojen eriytyminen jatkuu [Less than one fifth of students in studies where women and men are evenly distributed - the disciplinary segregation of fields continues].” *Statistics Finland: Tieto & trendit*. Accessed March 1, 2024. https://www.stat.fi/tietotrendit/artikkelit/2018/alle-viidennes-opiskelijoista-opinnoissa-joissa-tasaisesti-naisia-ja-miehia-koulutusalojen-eriytyminen-jatkuu/

Laugwitz, B., Held, T., and M. Schrepp. 2008. Construction and Evaluation of a User Experience Questionnaire. In: Holzinger, A. (eds) *HCI and Usability for Education and Work.* USAB 2008. Lecture Notes in Computer Science, vol 5298. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-89350-9_6

Mayer M., Lahtinen J., Aapola-Kari S., Pietarinen A., Kallio A., Jänkälä J.-P., and M. Hakanen. *Työelämään tutustumisjaksojen toteutus, yhdenvertaisuus, tasa-arvo ja saavutettavuus perusopetuksen aikana [The implementation, equality and accessibility of work practice program TET during basic education].* Publications of the Government's analysis, assessment and research activities 2022:33, 2022.

Naukkarinen, J. and L. Ikonen. “Reaching out for girls. Raising interest and self-efficacy in engineering with ‘girls only’ workshops at a technical university.” In *Proceedings of the 46th SEFI Annual Conference, Copenhagen, 17-21 Sep., 2018*, pp. 338 –348.

Naukkarinen, J., Korpinen, K., and P. Silventoinen. ”High-School Students' Gendered Interests in Electronics and Electrical Engineering.” *Research in Science & Technological Education* 41, no. 4 (2021): 1412–1432. https://doi.org/10.1080/02635143.2021.2008342

Naukkarinen, J., Kuisma, M., and H. Järvisalo. ”Hands-on work in a web-based Basic Electronics course”. *Proceedings of the 47th SEFI Annual Conference, Budapest, 16-19 Sep., 2019*, pp. 817–824.

Nori H., Lyytinen A., Juusola H., Kohtamäki V., and J. Kivistö. *Marginaaliryhmät korkeakoulutuksessa: opiskelemaan hakeutuminen, opiskelukokemukset ja tulevaisuuden suunnitelmat. [Marginalised groups in higher education: seeking education, learning experiences and plans for the future]*. Publications of the Ministry of Education and Culture, Finland 2021:26, 2021.

Occupational Safety and Health Act. 2002. Accessed March 1, 2024. https://www.finlex.fi/fi/laki/kaannokset/2002/en20020738

OPH. *Perusopetuksen opetussuunnitelman perusteet 2014. [National Core Curriculum for Basic Education 2014]*. Finnish National Agency for Education, Regulations and Guidelines 2014:96, 2014.

Statistics Finland. 2022. “Employed labour force by industry, occupational status, sex and year”. Accessed March 1, 2024. https://pxdata.stat.fi/PxWeb/pxweb/en/StatFin/StatFin__tyokay/statfin_tyokay_pxt_115m.px/table/tableViewLayout1/

Tillinghast, R.C., Appel, D.C., Winsor, C., and Mansouri, M. STEM outreach: A Literature review and definition. *Proceedings of the 2020 IEEE Integrated STEM Education Conference (ISEC), Virtual Conference, 1 Aug., 2020*, pp. 1–20.

van Tuijl, C, and van der Molen, J.H.W. Study choice and career development in STEM fields: an overview and integration of research. *International Journal of Technology and Design Education* 26, no. 2 (May 2016): 159–183. https://doi.org/10.1007/s10798-015-9308-1.

Vennix, j., den Brok, P., and Taconis, R. Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM?, *International Journal of Science Education* 40, no. 11 (2018): 1263–1283. https://doi.org/10.1080/09500693.2018.1473659.

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Responsible Research and Innovation in Higher Education– An Approach to Strengthen the Social Responsibility of Engineering Students

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ABSTRACT

Engineering and technology are necessary for handling global challenges that encompass technological, environmental, economic and social dimensions. However, there can be unintended consequences if technological solutions are not aligned with societal needs or ethical considerations. This paper emphasizes the need for engineering students to understand social, economic and environmental responsibilities associated with their profession. The paper highlights the importance of fostering the concept of Responsible Research and Innovation (RRI) within higher education institutions and positioning universities as stakeholders in promoting socially responsible innovation. At RWTH Aachen University, the institutionalization of a RRI Hub underscores the commitment to embedding RRI principles in research, teaching, and collaboration efforts.

By introducing the concept of RRI, engineering students can develop an understanding of socially responsible technological development. The article outlines the conception and implementation of a seminar at RWTH Aachen University that aims to awaken students' sense of responsibility towards societal challenges. The

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seminar integrates different dimensions of RRI, including multi-stakeholder involvement, reflective approaches, and responsiveness and adaptability. Through a structured course design, students explore topics such as ethics, gender equality and public engagement while developing solutions to local sustainability problems. Reflecting on the seminar's outcomes, the paper identifies areas for further development, including interdisciplinary collaboration and the integration of external expertise.

1 INTRODUCTION

Engineering and technology can offer sustainable and responsible solutions for global challenges, which includes technological, ecological, economic and social effects. However, technical and engineering solutions can also cause social and environmental problems if, technological innovations are used for unintended purposes or if unexpected and undesirable impacts occur. With their technical expertise, future engineers contribute essentially to achieving the sustainable development goals (Steuer-Dankert et al. 2019; UNESCO 2021; Tabas et al. 2019). Engineering students have to recognize this social and environmental responsibility of their profession und have to know what responsibility means and how they can deal with itself in their engineering practice (Rulifson und Bielefeldt 2019). This contrasts with a trend towards depoliticization within engineering (Cech und Sherick 2019; Cech und Sherick 2015; Henderson 2022; Hughes und Kothari 2021). Depoliticization in engineering reinforces the attitude that political, social and ethical aspects can be separated from technical aspects and are not part of the scope of engineering (Cech und Sherick 2015). Studies show that awareness of social responsibility decreases with the duration of engineering education and that the consideration of social values and needs is not considered by students as a relevant part of professional identity (Cech 2014).

The concept of Responsible Research and Innovation (RRI) provides engineering students an opportunity to develop an understanding of the need for socially responsible research and innovation and to receive orientation for their work as engineers in the development of technical solutions to cope with societal challenges. Technical universities and institutions involved in engineering education have thereby an important role in the implementation of RRI in research and innovation processes, particularly through the training of students. Prospective engineering students must be prepared for their role as developers of responsible technological innovations and equipped with the relevant competencies (Tassone et al. 2018). For this purpose, this paper presents the concept of the seminar “Selected Aspects of Responsible Research and Innovation” and discusses how the various dimensions of the RRI concept can be integrated into the conceptual design of a seminar for engineering students. In the sense of responsiveness and adaptability, we analyze the feedback of the students at the end of the course and reflect how engineering students perceive the discussion of the RRI concept as well as outline possibilities for the further development based on the reflection and evaluation of the seminar.

2 BACKGROUND

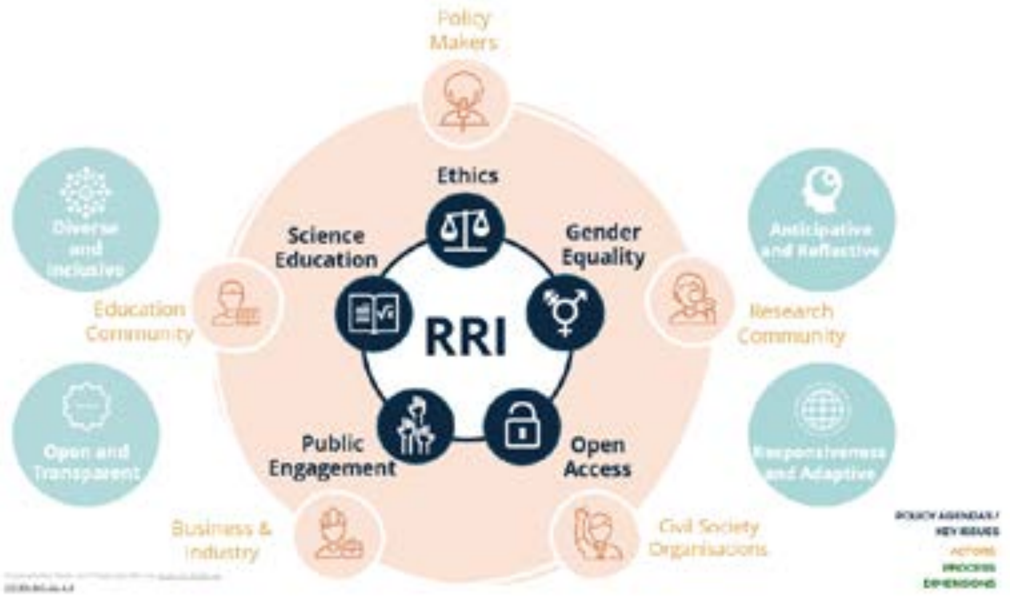
2.1 Responsible Research and Innovation

Schomberg´s (2013) often cited definition of RRI explains responsible innovation as

> a transparent, interactive process by which societal actors and innovators become mutually responsive to each other regarding the ethical acceptability, sustainability and social desirability of the innovation process and its marketable products. (von Schomberg 2013, S. 63).

The ethical acceptance of innovations (products) and the innovation process means compatibility with fundamental values and rights of society as well as the alignment of these processes with the social needs and perspectives of diverse societal groups (Sutcliffe 2011; Burget et al. 2017). In addition to technical or economic aspects, current and future social, ethical and ecological effects, risks and opportunities are anticipated and a response is made to changing knowledge and circumstances (Sutcliffe 2011).

Figure 1. Dimensions of the RRI concept (illustration in Berg-Postweiler et al. in press based on RRItools)



“Multistakeholder involvement” (von Schomberg 2013, S. 67) refers to the shared responsibility for an ethically acceptable, sustainable and socially desirable orientation of research and innovation by different actors from academia, industry, government and society. The EU commission named different dimensions of RRI (Figure 1, dark blue): All stakeholders assume responsibility for research and innovation processes and their results (engagement), which also includes science education and open access to research findings, as well as consideration of gender equality and ethical issues. The EU-funded program “RRItools” formulates four process dimensions (Figure 1, light green) for the collaboration of society, research and education sector, politics as well as industry and business. Diversity and inclusiveness - as a process dimension - is related to the involvement of a broad spectrum of stakeholders and society in research and innovation. The requirement to be open and transparent includes communicating the findings of methods, results, conclusions and effects openly and transparently. Third, research and innovation must be viewed in an anticipatory and reflexive manner in order to predict important implications and consider appropriate opportunities for action. The last dimension, responsive and adaptive, aims to be able to adapt research processes and the necessary structural requirements to changing conditions, needs or new scientific findings (RRI Tools 2016).

3.1 Fostering RRI at RWTH Aachen University

Universities and other higher education institutions are relevant stakeholders in the implementation of the RRI concept (Nulli und Stahl 2018). On the one hand, the fostering of science education is one dimension of the RRI framework and, on the other hand, it is necessary for the implementation of RRI in research and innovation processes that the involved persons are familiar with the concept and acquire competencies to implement RRI in the sense of the four process dimensions described.

With around 45,000 students 550 professors and 6500 scientific employees RWTH Aachen University is one of the largest technical universities in Germany. And one of Germany´s Universities of Excellence. In the excellence strategy of the German state and federal governments RWTH formulates 2019 under the title “The Integrated Interdisciplinary University of Science and Technology. Knowledge. Impact. Networks” the goal “to further grow beyond a unique integrated, interdisciplinary university by embracing the convergence of knowledge, approaches and insights from the humanities, economics, engineering, natural and life sciences, i.e. biology and medicine” (RWTH Aachen University o.J., S. 11). The RRI concept serves as a “guiding principle” (RWTH Aachen University o.J., S. 47) for shaping the process described in the Excellence Strategy. The Responsible Research and Innovation Hub (RRI Hub) has been institutionalized for the implementation and fostering of RRI at RWTH Aachen University. The aim of the RRI Hub is to “anchor responsible research and innovation as one of the central guiding ideas in research, teaching, and transfer, and become a nucleus for a socially responsible orientation of the university” (Berg-Postweiler et al. 2024). The RRI Hub operates in the three areas of research, teaching and transfer. It promotes cooperation and the joint action of various stakeholders from science, industry, politics and civil society. The assumption of social responsibility is seen as the basis and objective of an excellent university. In addition to responsibly oriented research and cooperation with civil society, this also includes the training of responsible future engineers (Berg-Postweiler et al. 2024).

3 COURSE DESIGN

Within the teaching area of the RRI Hub, the seminar “Selected Aspects of Responsible Research and Innovation (RRI)” is offered annually in the winter semester for master students of the study programs, Civil Engineering, Environmental Engineering and Business Administration and Engineering specializing in Civil Engineering at RWTH Aachen University. The seminar was conceptualized and implemented for the first time in the winter semester 2023/2024. Because the course is offered in German, we translated all material into English.

3.1 Learning Outcomes

The aim of the seminar is for students to reflect on the relevance of a responsible orientation of research and innovation and their own responsibility in the concept of science and research and to apply the RRI concept to current societal challenges.

Following the concept of constructive alignment (Biggs und Tang 2011), there a several learning outcomes, which students should attain after completing the course. Students should first of all **describe** the position of the RRI concept in the European context, **characterize** the RRI concept as well as **explain** its various dimensions and content areas. Furthermore, after the course students are able to **explain** the relevance of a responsible orientation of research and innovation and to **discuss** current challenges in selected subject areas of the RRI context. Through the analysis of selected examples of technical or engineering examples, students are able to **reflect** on the consideration of different dimensions of responsible research and innovation. Students should **reflect** on their own responsibility in a scientific or research context, particularly within their own discipline. Through the knowledge and competencies they acquire, students **develop** a concept for an activity that deals with a current societal challenge and integrates various aspects of RRI.

3.2 Course Structure

The presented policy agendas, actors and process dimensions of RRI (section 1) are taken into account in the conceptualization of the course.

The course structure (Table 1) attempts to address the various policy agendas. After the introductory session explains the course and examination concept, presents the RRI Hub and introduces the SDGs as a context for responsible technical developments and innovations, the following session introduces the approaches of RRI. Initially, the development of the RRI concept in the European research context is presented and then the principles of responsible research and innovation are elaborated on the basis of different administrative and scientific definitions. Students develop the process dimensions of RRI and reflect on relevant actors in research and innovation processes. The exploration of the RRI framework is the basis for the subsequent seminar sessions. In individual sessions, the policy agendas Ethics, Gender Equality, Open Access and Public Engagement are examined from the perspective of the various stakeholders and connections to the four process dimensions are established. Table 1 shows the content covered in each session. In the "RRI and Gender Equality" session, for example, students discuss the gender balance in research and innovation teams as well as the relevance of gender aspects in research and innovation. Based on the question “How must the mobility infrastructure in Aachen be designed to consider the needs of women and men”, students discuss the impact of the needs and requirements of different genders on the development and design of infrastructure. To promote the students' ability to adopt perspectives, this is done with the help of the Disney method, in which ideas are generated by the participants adopting the roles of dreamer, realist and critic in turn (Schawel und Billing 2014).

The content sessions are complemented by an interactive seminar session on public engagement methods, in which students have the opportunity to practice selected methods (i.e. fishbowl discussion or World Café) with the seminar group and reflect on the opportunities and challenges of these methods. In preparation for this session, students deal with the Action Catalogue (http://actioncatalogue.eu/) and briefly present a method of their choice. In the session they reflect together on the purposes for which the methods are suitable, which stakeholders are addressed, and what strengths and weaknesses the methods have. In a workshop session, students get to know Living Labs and discuss their significance for the implementation of RRI. In the conclusion session, students reflect on their own expectations and learning progress. Together with their fellow students and the course supervisor, they discuss on which topics have addressed, which challenges have arisen and which possibilities for improvement would be appropriate.

Table 1. Course Structure

	Topic	Content	Individual Reflection
1	Introduction	Course concept and examination Introduction RRI Hub SDGs, Societal challenges	x
2	RRI as a Framework	Definitions RRI policy agendas, actors and process dimensions	x
3	RRI and Gender Equality	Gender Equality in the world Gender Balance in Research, Leaky Pipeline Gender aspects in research and innovation Gender Mainstreaming & Planning	x
4	RRI and Ethics	Ethics in Research, Scientific Integrity Science communication Open Access, Open Science	x
5	RRI and Public Engagement	Participation, Civic Engagement Citizen Science Methods of Public Engagement	x
6	Methods of Public Engagement	Interactive session, Methods of Public Engagement in Practice	x
7	Living Labs	Definition, Types of Living Labs Living Labs and RRI	
8	Pitch-Session	Short Presentations of the elaborated concepts	
9	Conclusion & Reflection	Reflection seminar concept, own expectations	

After each seminar session, students could reflect on one aspect of the session in writing and discuss their thoughts on this aspect. For example, after the session on RRI and public engagement, students reflect on structural and individual barriers or ethical challenges, such as distribution of power and the use of influence. The individual written reflection papers serve to deepen the discussion of the RRI concept.

3.3 Examination

The examination consists of the task to develop a concept for a sustainability week organized by the RRI Hub, where students work together with various stakeholders from research, business and industry, politics and civil society to elaborate solutions for the challenges to mastered by the city of Aachen to achieve the SDGs. Table 2 shows how the four process dimensions of RRI are taken into account in the design of the examination.

Table 2. Addressing RRI process dimensions in the examination

Diverse & Inclusive	- Sustainability week for students and different stakeholders/actors - Impact and effects of the challenge for different actors and social groups
Open & Transparent	- Presentations/Pitchs - Documentation of the Concept
Anticipative & Reflective	- Analyse of the challenge in term of positive and negative developments - Effects of the challenge for different actors and social groups
Responsiveness & Adaptive	- Feedback from fellow students and the course supervisor during the pitch session - Reflection on the group work - Peer feedback and self-assessment of social competencies in group work

The task is divided into two parts that build on each other. The students are given guiding questions for both parts to provide orientation. In the first part, the students identify a challenge that Aachen has to master to achieve sustainable development by 2030. This challenge should address an SDG. The students decide independently in their groups how to identify the challenge. In doing so, the students should also speak with different stakeholders in the city. They analyse the challenge in terms of positive and negative development opportunities, connections with other challenges as well as the extent to which the challenge affect different actors and social groups. Based on the challenge they have identified, they develop a concept for a sustainability week, which will work out and discuss possible solutions to this challenge. As part of the concept, students work out how the various policy agendas, actors and process dimensions of RRI (s. section 1) can be integrated into their concept.

The students present their concept for a sustainability week in the pitch session in the format of a five-minute pitch. The pitch should be created in such a way that potential organizers of the sustainability week are convinced of the concept. In the pitch session, the students receive feedback on the concepts from their fellow students and the course supervisor. In the subsequent written documentation, students explain certain aspects in more detail and incorporate feedback from their fellow students and the course supervisor. The aim is not to revise the concept, but to explain how to respond to the feedback.

In addition to reflecting on the concept as part of the documentation, the documentation should also include a joint reflection of the group on the work processes. This is supported by the following key questions: What worked well? What worked less well - and why? In the winter semester 2023/2024, students identified open communication, clear objectives and coordination as elements of successful group work. Each group member should take responsibility, while at the same time tasks need to be distributed and regular coordination is necessary. In addition to jointly reflecting on the group work, the students give each group member anonymous feedback on their communication and teamwork skills as well as their commitment within the group. The students receive an evaluation of this feedback, including a comparison with their own personal rating.

4 REFLECTION AND FURTHER DEVELOPMENT

In terms of the RRI process dimensions “anticipative and reflective” and “responsive and adaptive”, the last seminar session "Conclusion and Reflection" (Table 1) serves to evaluate the seminar and review the students' expectations. In preparation for the session, students can note down their thoughts on a digital Miro board with the help of six key questions on the seminar topics, acquired competencies, challenges and suggestions for improvement. In the session, the students discuss these first in small groups and then in plenary. In general, the students indicated their satisfaction with the seminar concept and underlined the relevance of the RRI concept for future engineers during the discussion and reflection. In addition to the positive feedback, the students criticized only a few aspects. The students were missing more seminar participants.

The students emphasize the need to make research and innovation processes more transparent. This is an elementary component of the RRI concept through the described process dimension "open and transparent" as well as the topics of public engagement and open access. They mention the reflection on their responsibility as engineers and a member of the civil society as a learning gain from the seminar. Reflection is an important part of the RRI concept and therefore also plays a relevant part in the seminar. Reflection is considered holistically in the seminar, by critically examining the RRI concept and its elements, by students writing individual reflections on individual aspects of the sessions, by fellow students and course supervisors giving feedback on the concepts and pitches, by the groups reflecting on the feedback in their documentation, by students thinking about their group work, by giving each other feedback on the social skills within the group work (peer feedback) and by receiving detailed feedback from the course supervisor during the assessment.

In line with the RRI process dimension "Responsiveness and Adaptive", research and innovation have to react to changing needs and conditions as well as new knowledge. This also applies to the seminar concept and therefore some changes, adaptations and improvements are already planned for the next cycle of the seminar.

As we did only have a small amount of students, we are expecting more students in the next round of the seminar. For example, the structures of the RRI Hub could be used to attract students. In addition to the university's course evaluation, a pre-post survey on student motivation and satisfaction as well as the development of RRI-related competencies is planned for the next semester. This quantitative data will allow further insights about the effectiveness of the teaching and learning approach presented.

In the winter semester 2023/2024, the students independently selected a challenge of sustainable development in the city of Aachen and developed a concept for an event (Sustainability Week) based on this. The next time the seminar is conducted, the cooperation between different stakeholders that is necessary in terms of the RRI concept will also be practically implemented, in that students will work together with stakeholders from the city of Aachen and the surrounding region to develop challenges for sustainable development in Aachen. This can then be followed by the planning of a living lab or a citizen science project in the form of group work. The stakeholders will be recruited through the network structures of the RRI Hub (e.g. contacts to the city administration, civil organizations or entrepreneurs).

The diverse involvement of a broad spectrum of stakeholders (diverse & inclusive) is to be achieved through various components. The intention of the seminar is to strengthen the exploration of inter- and transdisciplinary perspectives on RRI. For this purpose, students of political science will participate in the next cycle of the seminar alongside students of the engineering study programs. For the group work interdisciplinary groups will then be arranged. In a further step, the seminar can be supplemented by additional input from experts from the partner universities of the ENHANCE Alliance. With the Massive Open Online Course "Responsible Innovators of Tomorrow", the RRI Hub already has a teaching and learning offer that is available to the students at the ten ENHANCE universities. The integration of this content into the seminar, a subsequent discussion and reflection of this content and the processing of a case study are possibilities for expanding the concept.

This practice paper shows that the institutionalization of a structure such as the RRI Hub at RWTH Aachen University enables the implementation of RRI as a guiding principle of a technical university by practically integrating the RRI concept into engineering education and the interaction of science, business and industry, politics and civil actors. Dealing with RRI allows the trend towards depoliticization within engineering (Cech und Sherick 2015; Cech und Sherick 2019) to be countered and encourages students to reflect on their social responsibility as future engineers.

REFERENCES

Berg-Postweiler, Julia; Decker, Marie; Leicht-Scholten, Carmen (2024): Academia as a Key Factor in Fostering Responsible Research and Innovation with and for Society: The Case of the RRI Hub at RWTH Aachen University. In: Peter Letmathe, Christine Roll, Almut Balleer, Stefan Böschen, Wolfgang Breuer, Agnes Förster et al. (Hg.): Transformation towards Sustainability - A Novel Interdisciplinary Framework from RWTH Aachen University (the "Work"): Springer Nature Switzerland AG.

Biggs, J.; Tang, C. (2011): Teaching for Quality Learning at University. Maidenhead: McGraw-Hill and Open University Press.

Burget, Mirjam; Bardone, Emanuele; Pedaste, Margus (2017): Definitions and Conceptual Dimensions of Responsible Research and Innovation: A Literature Review. In: *Science Engineering Ethics* 23, S. 1–19. Online verfügbar unter 10.1007/s11948-016-9782-1.

Cech, Erin A. (2014): Culture of Disengagement in Engineering Education? In: *Science, Technology, & Human Values* 39, S. 42–72.

Cech, Erin A.; Sherick, H. M. (2019): Depoliticization as a Mechanism of Gender Inequality among Engineering Faculty. In: *ASEE Annual Conference & Exposition, Tampa, Florida*.

Cech, Erin A.; Sherick, H.M. (2015): Depoliticization and the Structure of Engineering Education. In: *Philosophy of Engineering and Technology* 20, S. 203–216. Online verfügbar unter https://doi.org/10.1007/978-3-319-16169-3_10/COVER.

Henderson, T. (2022): Development and Validation of a Depoliticization in Engineering Scale. In: *ASEE Annual Conference & Exposition, Minneapolis, MN*. Online verfügbar unter https://peer.asee.org/41091.

Hughes, Bryce E.; Kothari, Shriyansh (2021): Don't Be Too Political: Depoliticization, Sexual Orientation, and Undergraduate STEM Major Persistence. In: *Journal of Homosexuality* 70 (4), S. 632–659. Online verfügbar unter https://doi.org/10.1080/00918369.2021.1996101.

Nulli, Margherita; Stahl, Bernd (2018): RRI in Higher Education. In: *The ORBIT Journal* 1 (4), S. 1–8. Online verfügbar unter https://doi.org/10.29297/orbit.v1i4.78.

RRI Tools (2016): A practical guide to responsible research and innovation. Key lessons from RRI Tools. Hg. v. "la Caixa" Foundation. Online verfügbar unter https://rri-tools.eu/documents/10184/16301/RRI+Tools.+A+practical+guide+to+Responsible+Research+and+Innovation.+Key+Lessons+from+RRI+Tools/a90c882f-f260-4398-891e-bc55a384b11b, zuletzt geprüft am 25.11.2022.

Rulifson, Greg; Bielefeldt, Angela (2019): Learning Social Responsibility: Evolutions of Unergraduate Students´ Predicted Engineering Futures. In: *International Journal of Engineering Education* 35 (2), S. 572–584.

RWTH Aachen University (o.J.): The Integrated Interdisciplinary University of Science and Technology. Knowledge. Impact. Networks.

Schawel, C.; Billing, F. (2014): Walt-Disney-Methode. In: Christian Schawel und Fabian BIlling (Hg.): Top 100 Management Tools. Wiesbaden: Gabler Verlag, S. 273–275. Online verfügbar unter https://doi.org/10.1007/978-3-8349-4691-1_91.

Steuer-Dankert, Linda; Gilmartin, Shannon K.; Muller, Carol B.; Dungs, Carolin; Sheppard, Sheri; Leicht-Scholten, Carmen (2019): Expanding Engineering Limits: A Concept for Socially Responsible Education of Engineers. In: *International Journal of Engineering Education* 35 (2), S. 658–673. Online verfügbar unter https://www.ijee.ie/contents/c350219.html.

Sutcliffe, H. (2011): The Report on Responsible Research & Innovation. Online verfügbar unter https://ec.europa.eu/research/science-society/document_library/pdf_06/.

Tabas, Brad; Beagon, Una; Kövesi, Klara (2019): Report on the Future Role of Engineers in Society and the Skills and Competences Engineering will Require. A-STep 2030 - Report 1 Literature Review.

Tassone, Valentina C.; O'Mahony, Catherine; McKenna, Emma; Eppink, Hansje J.; Wals, Arjen E. J. (2018): (Re-)designing higher education curricula in times of systemic dysfunction: a responsible research and innovation perspective. In: *High Educ* 76 (2), S. 337–352. DOI: 10.1007/s10734-017-0211-4.

UNESCO (2021): Engineering for sustainable development: delivering on the Sustainable Development Goals. Online verfügbar unter https://unesdoc.unesco.org/ark:/48223/pf0000375644.

von Schomberg, René (2013): A Vision of Responsible Research and Innovation. In: Richard Owen, John R. Bessant und Maggy Heintz (Hg.): Responsible Innovation. Managing the Responsible Emergence of Science and Innovation in Society. Chichester, UK: John Wiley & Sons, Ltd, S. 51–74.

CAN A ROBOT TEACH DESIGN? LARGE LANGUAGE MODEL BASED FEEDBACK TOOL FOR ENGINEERING DESIGN COURSES

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ABSTRACT

This practice paper report the use of by Inflection AI's Pi chatbot and Azure OpenAI GPT-3.5-Turbo and GPT-4 APIs to provide insightful and timely feedback across written, oral, project-based and team-based assessment tasks in a level 2 capstone engineering design course. The Large Language Model (LLM) driven AIs can text and audio based artefacts submitted by students, including short written tasks, draft reports, pitch presentations and meeting transcripts. This in turn allows course instructors to address students' learning needs more efficiently and effectively. The present work further demonstrated there are still limitations and barrier to full implementation of AI-assisted feedback in the classroom. Unless trained on specific content, LLM-driven AI lacks nuanced contextual understanding. For some students, the AI generated feedback did not appear to develop or improve the student's metacognitive abilities or their self-regulation of learning. At the time, use of LLM-driven AI for feedback was hindered by an absent of toolchain for data capture and processing, as well as the lack of an institutional level AI strategy and roadmap, partnerships to bridge capability and capacity gaps, robust guiderail and policies around the use of AI in the classroom. The final section of this paper outlines strategies that can be used to address these limitations and how the needs of academics who intent to apply LLM-driven AI in feedback practice should be supported.

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1 INTRODUCTION

Design is generally considered a core competency in undergraduate engineering education and a main component in value creation. The modern engineer is also expected to possess the necessary technical, project management, communication, and teamwork skills needed to deliver the best design solution. As such, many engineering schools have introduced project-based design courses into their curriculum to better align engineering theory with practice. Students are given opportunities to work on authentic problems, and some recent developments include the teaching of user-centred approach such as design thinking (Charosky et al. 2022).

While authentic, real-world based design courses have been reported to engage and motivate students more effectively, their implementation in large class remains a challenge (Heller et al. 2010). Engineering students often have difficulty conceptualising and contextualising user-centred problems solving, particularly if it is their first exposure to the approach. Some students also had the tendency to switch immediately to solution mode, skipping or rushing through the user research stage of the design. Teaching strategies that are based on project and collaborative learning are also vulnerable to the students' lack of project management and teamwork skills. The issues that can hampered a student progress in a design course are also difficult to detect and address, particularly in large classes with high student to staff ratio.

A way to overcome the abovementioned issues and improve the learner experience in project-based design courses is to provide timely feedback that is aligned with the course learning outcomes and learner needs (Gülbahar and Tinmaz 2006). In recognition of this fact, engineering educators have embraced various feedback tools and strategies to improve student's feedback literacy in their practice (Coppens et al. 2023, Gilbuena et al. 2015). Peer feedback, for instance, have been shown to foster a culture of constructive criticism and continuous improvement among students, while enhancing their ability to provide and receive feedback effectively (Dong et al. 2023, Tai et al. 2018).

Another important development is the increase affordance of digital platforms. Learning analytics and educational data mining offer promises in enhancing students' learning in design courses through early intervention, individualized feedback mechanisms and improved workflow (Xing et al. 2023). Recent development in LLM-driven AI, as exemplified by ChatGPT, Open AI's widely accessible web based chatbot, further reshaped the landscape (Bauer et al. 2022).

Several investigators have reported the use of LLM-driven AI to generate feedback for written and programming tasks (Dong 2024; Escalante 2023; Mahapatra 2024; Husain 2024; Sun et al. 2024; Wilson et al. 2024; Xiao and Zhi 2023). Banihashem et al. (2024) found a statistically significant difference between the feedback generated by an AI and student peers for a written task. Using statistical methods, they showed the former was more descriptive while the latter was better at identifying deficiencies in the written task. Nonetheless, the quality of both types of feedback did not affect the quality of the written task. Instead, a positive correlation was found between the former and the affective features present in the AI-generated feedback.

So far, the consensus in the literature was that LLM-driven AI has the potential to alleviate the challenge of providing feedback to large classes and to promote self-regulating skills such as feedback seeking, goal-setting, and progress monitoring (Guo 2023; Hopfenbeck et al. 2023; Li and Kim 2024). Subtle variations remain in how students and teachers perceive the trustworthiness of AI-generated feedback. Barrett and Pack (2023) noted a disagreement between students and teachers concerning the acceptable use of LLM-driven AI tools for generating feedback for written tasks. Ding et al (2023) found physics students held misconceptions about the capability of LLM-driven AI, with nearly half of the students trusting LLM-driven AI generated answers even though the AI only has 85% accuracy. Contrarily, Tossell et al (2024) found students were not confident in the feedback generated by LLM-driven AI and did not trust its' use as an independent evaluation and feedback tool. Darvishi et al. (2024) found students tended to rely on, rather than learn from, AI. Moreover, supplementing AI assistance with self-regulated strategies did not yield significant advantages over relying solely on AI assistance.

Taken together, these findings suggest a complex dynamics between the use of LLM-driven AI to generate feedback, attainment of learning outcomes, and student's perception of the tool which requires further exploration and elucidation, and for learning tasks other than writing or programming. The present study examine how LLM-driven AI can be employed to monitor or evaluate the quality of formative written and oral assessment tasks, as well as team interactions and contributions in a 10-week long project based design course. The course was taught to level 2 chemical engineering students with the aims of developing the students' design thinking and professional skills. Outputs from the LLM-driven AI were also used to provide tailored and immediate feedback to individual students (class size = 54 students). The use of AI generated feedback as a complement to instructor and peer feedback was also explored.

2 METHODOLOGY

Due to the rapidly evolving nature of LLM-driven AI technologies in 2023, a design-based research methodology was applied in this study (Holland et al. 2019). Instead of pre-defining and controlling all variables in the study, a variety of LLM-driven feedback mechanisms were introduced to support students in different formative tasks at various stage of the course delivery (see Figure 1). The outcome of each intervention which were then used to guide subsequent feedback mechanisms design.

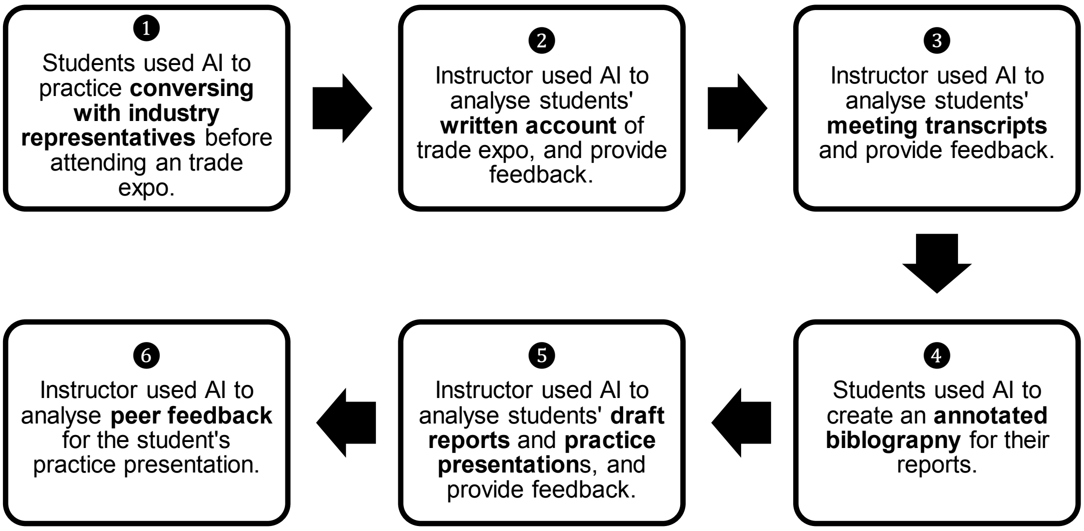

Fig. 1. Schematic of the design-based approach.

At the start of the course, students role-play conversation with industry representative at a trade show with Pi, a chatbot by Inflection AI's, via a web interface (see text box marked '1' in Figure 1). Based on Inflection's proprietary LLM Inflection-1, Pi was designed to maintain an interactive text or voice-based dialogue with a human user in personable manner. It was for this reason which Pi was selected over other chatbot at the time.

The students then attend a trade show that is related to the course. The students were assigned the task of sharing their experience, observations and conversations with industry representative at the trade show on Padlet, a virtual bulletin board. The instructor downloaded the student's accounts of their interactions at the trade show as a CSV file and summarised the submission using Azure Open AI's gpt-35-turbo model via the API (see text box marked '2' in Figure 1).

Throughout the course, the students who were assigned to teams of six students. The student teams held regular online meetings on Microsoft Teams outside of class time. In these meetings, collective sensemaking, brainstorming, planning and decision making about the design solution occurred. The meetings were setup to automatically record and generate a transcript at the end. The transcripts were analysed periodically using Azure Open AI's gpt-4 model via the API (see marked '3' in Figure 1).

Mid-way through the term, the students had to submit draft of their reports and practice pitching their design solution individually as formative tasks for end-of-term summative assessments that are worth 60% and 20% of the total mark, respectively. As part of the report writing process, the students were instructed on how to use elicit.org, an AI research tool which can create annotated bibliography from articles the students have found (see text box marked '4' in Figure 1). It should be noted here that the use of elicit.org is not mandatory, but students were evaluated based whether they can accurately gauge the quality and relevancy of the articles they have selected for their report. The draft reports were all written 'from scratch' on Microsoft Word documents that were saved to a SharePoint library.

The practice pitches were recorded during class time in the same way as the students' meeting. Both type of submissions were summarised by the instructor using Azure Open AI's gpt-35-turbo model via the API (see text box marked '5' in Figure 1). When a student was practicing their pitch in class, other students who were in the audience were required to provide peer feedback on the quality and content of the pitch on Padlet. The instructor downloaded the students' feedback as a CSV file and summarised them using Azure Open AI's gpt-4 model via the API (see text box marked '6' in Figure 1).

A survey with two sets of questions was developed for this study. The first set of questions, derived from the work of Brookhart (2017), Haughney et al. (2020), and Carless and Boud (2018) surveyed students' feedback literacy and experiences of feedback practice. The second set of questions explored students' experiences and perceptions of AI-assisted feedback. This includes comparing the perceived quality of feedback generated by or with the assistance of AI, to that of their instructor, and peers. A total of 17 students' responses were received (32% of cohort). This is typical in an academic setting, and is due to the fact that the students were only invited twice to complete the survey in order to reduce the number of inauthentic responses.

The survey data was complemented by autoethnographic account of the instructor's experiences of implementing the LLM-drive AI interventions in their course. Here, 'auto' relates to a focus on personal experience; 'ethno' relates to the study of a culture; and 'graphy', refers to a systematic process for describing and analysing both personal and cultural experience arising from the study (Ellis et al. 2011). The act of self-enquiry by an author-instructor who had designed the present design course from scratch and has good insight into the support needs of their students can lead t0 a deeper and more nuanced understanding of LLM-driven AI use in teaching practice (Mao et al. 2023).

3 RESULTS

3.1 Instructor's Account of Developing AI Feedback Tools for a Design Course

In an essay on constructionism, Harel and Papert (1991) described two styles of solving problems. One is the methodical and analytical method of problem solving that is familiar to many engineers. The other is 'bricolage', which is a way to learn and solve problems by tinkering, that is, trying, testing, learning, and iterating. More recently, the term bricolage was used when referring to an innovation practice that is based on using the least amount of immediately available resources, usually in a resource-constrained context (Bouvier-Patron, 2021).

The instructor was first exposed to LLM-driven AI in early December of 2022, immediately after ChatGPT was launched. The disruptive and somewhat unpredictable nature of LLM tools has generated excitement and academic integrity concerns among the education community on social media. The ensuring Christmas break afforded time for the author-instructor to tinker with ChatGPT and Open AI's APIs. At this stage, the instructor found their prior expertise in the subject matter, experience in learning design, and intuition on what will or will not work in the classroom is critical. For instance, the instructor soon realise some of the response generated by the LLM-driven AI is superficial and unreliable. The instructor experience at this stage is akin to traditional bricolage as defined by Papert.

It later became clear that the toolchain needed to deploy AI tools and apps in a manner that met the institution’s data, privacy, cybersecurity policies are not immediately unavailable to teaching staff. The cost of Open AI’s premium subscription and APIs needed to process large volume of input is also prohibitive. Through their professional network, the instructor was able to secure access to non-production Azure Open AI GPT-3.5-Turbo and GPT-4 APIs via their institution’s Microsoft O365 tenancy. Using a citizen development approach, i.e. simple Python scripts and in-built speech-to-text (STT) function of the Office suite applications (e.g. meeting transcript in Teams), the instructor deployed basic LLM-driven feedback tool in their course (McHugh et al. 2023). Here, the instructor felt their experience aligns more with contemporary bricolage where resource constrain necessitate the use of resource that are already available.

Towards the end of the development cycle, it became clear to the author-instructor that any LLM-driven AI tools developed in-house for education purposes or otherwise will not scale easily. For innovation around LLM-driven AI to thrive, the institution will have to develop the following: (1) Short and long term AI strategy and roadmap; (2) internal or external partnerships that bridges the institution’s capability and capacity gaps; (3) robust guiderail and policies around the use of AI in the classroom; (4) program to identify and upskill teaching staff wanting to upskill; and (5) process for scaling and translating successful implementations.

3.2 Student Experience and Perception of AI Assisted Feedback

Figure 2 shows students’ responses on a Likert scale to questions on receiving (top-left) and giving feedback (bottom-left). Both chart shows in general, students are comfortable with giving and receiving feedback. The more negative response appeared to be related to managing affect.

The responses to the open question “**Can you describe your experiences with giving feedback?**” contained a mixture of positive and challenging experiences. Most individuals expressed difficulty and anxiety over the process, highlighting concerns about the time required, difficulty in evaluating tasks against guidelines, and potential negative outcome for the reviewee due to incorrect feedback. Only one individual was appreciative of peer feedback, noting the mutual learning aspect as an inherent benefit.

The open question “**Can you describe your experiences with receiving feedback?**” resulted in a range of responses. Some individuals reported the feedback they received was beneficial, aiding in improvement and learning. There are also instances where feedback is seen as non-constructive or substandard. Complaints include feedback being vague, shallow, too brief, not enough justification for marks given, or that it didn't align with the student’s expectations.

The responses to the open questions “**What guidance have you received to date on giving feedback?**” indicate students have received inconsistent levels of guidance on how to give feedback. The response ranging from “none” to needing to several individuals noting that they were instructed to adhere to a rubric, and to provide feedback that were actionable, specific, and constructive.

Taken together, these response suggested the negative affect maybe due to quality of feedback received by the students. Carless and Boud (2018) reported that feedback can have varied affective effects depending on the student's self-confidence, motivation, and emotional management skills. The feedback's tone and feedback provider expressed care for students also significantly influences student reaction. Here, the student may have perceived a lack of care after receiving poor quality feedback, i.e. feedback that are generic or unconstructive. This in turn maybe due to poor instruction received by students and graders on how to give constructive feedback.

Figure 2 further shows student’s responses on a Likert scale to questions around receiving AI assisted feedback (top-right), and perception of the feedback quality relative to feedback provided by course instructor and peers (bottom-right).

It is interesting to note in that while the responses to AI generated feedback is generally positive, the students did not perceive the feedback to be better (or worst) than feedback provided by their instructor or peers. This response can be explained by the fact that most of the feedback produced by the LLM-driven AI will lack nuanced contextual understanding is unless it is trained on specific content (which it is not in this study). Hence, the utility of the feedback is similar to that produced by a human.

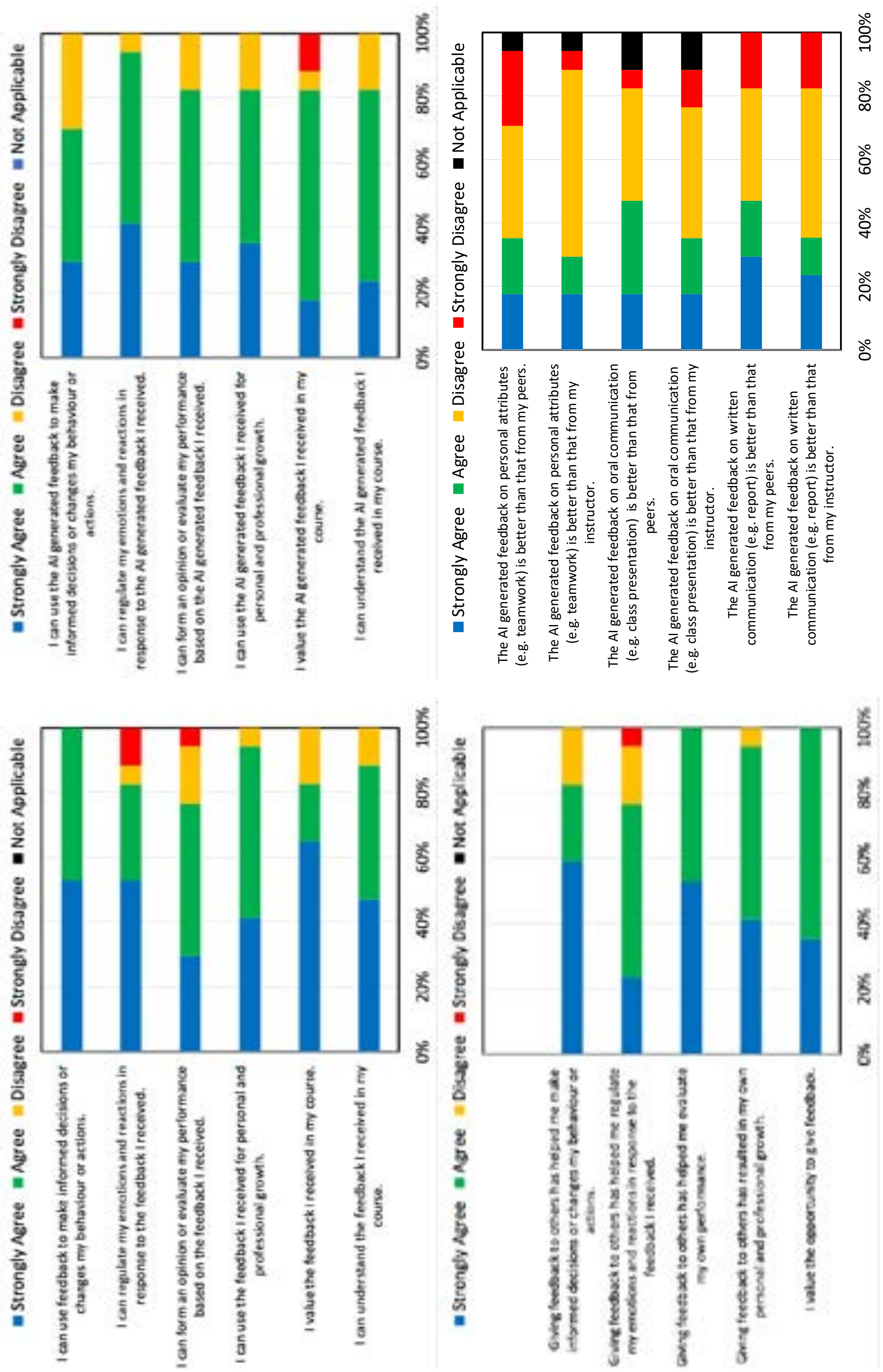

Fig 2. Students' responses on a Likert scale to questions around receiving feedback (top-left), giving feedback (bottom-left), receiving AI assisted feedback for different formative task (top-right), and their perception of the feedback quality relative to feedback provided by course instructor and peers (bottom-right).

The responses to the open question "**What guidance have you received to date on AI generated feedback?**" was peculiar in the sense that there was huge variability in experiences with guidance on AI-generated feedback. Some student indicated that they have received no direction at all. Other student noted that they have been advised by the instructor to view AI feedback critically, not to take the AI generated feedback too seriously, which suggest the student was aware of the limitations of AI and the need for human judgment.

Finally, the responses to the open question "**Can you describe your experiences with AI generated feedback?**" provide insights into the student's varied experiences involving AI-generated feedback. Some students found AI feedback valuable, helping them enhance their work through recommendations. Others, however, reported negative experiences where the AI failed to accurately assess their work, as discussed previously. There appeared to be a recurring theme in the response regarding how the AI had failed to recognise some sections of reports, or failed to capture certain aspects of team contribution.

4 SUMMARY AND ACKNOWLEDGEMENTS

LLM-driven AI can improve student learning in design courses by offering tailored and immediate feedback on written, oral, and team-based formative tasks. However, integrating AI-generated feedback into courses presents some challenges. It involves an ongoing process of tinkering, iterating and adapting, often within a resource-constrained context. Expertise in the subject matter and experience in learning design are important factors for successful implementation. Moreover, scaling the use of AI in feedback practices would require an institution-wide strategic approach. This includes developing an AI strategy and roadmap, forming partnerships and innovation pathways to bridge capability gaps, establishing robust policies and guardrails for AI use in classrooms, identifying and upskilling teaching staff, and creating processes for scaling and translating successful implementations.

Students' experiences with AI-generated feedback further reveal a complex interplay of factors influencing their perceptions and reactions. While students generally have good feedback literacy, and are comfortable receiving AI-generated feedback, the quality of the AI-generated feedback can significantly impact their experiences. Future development should include fine-tuning the LLM-based AI to produce more nuanced feedback.

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REFERENCES

Banihashem, S.K., N. T. Kerman, O. Noroozi, J. Moon and H. Drachsler. "Feedback Sources in Essay Writing: Peer-Generated or AI-Generated Feedback?" *International Journal of Educational Technology in Higher Education* 21, no. 23 (2024). https://doi.org/10.1186/s41239-024-00455-4

Barrett, A. and A. Pack. “Not Quite Eye to A.I.: Student and Teacher Perspectives on the Use of Generative Artificial Intelligence in the Writing Process.” *International Journal of Educational Technology in Higher Education* 20, no. 59 (2023). https://doi.org/10.1186/s41239-023-00427-0

Bauer, E., M. Greisel, I. Kuznetsov, M. Berndt, I. Kollar, M. Dresel, M. R. Fischer and F. Fischer. “Using Natural Language Processing to Support Peer-Feedback in the Age of Artificial Intelligence: A Cross-Disciplinary Framework and a Research Agenda.” *British Journal of Educational Technology* 54, no. 5 (2023):1222-1245. https://doi.org/10.1111/bjet.13336

Bouvier-Patron, P., “Bricolage – From Improvisation to Innovation: The Key Role of ‘Bricolage’”. In *Innovation Economics, Engineering and Management Handbook: Vol. 2 Special Themes*, edited by D. Uzunidis, F. Kasmi and L. Adatto, 67-73. John Wiley & Sons, New York. https://doi.org/10.1002/9781119832522.ch6

Brookhart, S. M., *How to Give Effective Feedback to Your Students*. 2nd ed., Alexandria, VA: ASCD, 2017.

Carless, D. and B. David. “The Development of Student Feedback Literacy: Enabling Uptake of Feedback.” *Assessment & Evaluation in Higher Education* 43, no. 8 (2018): 1315-25. https://doi.org/10.1080/02602938.2018.1463354

Charosky, G., L. Hassi, K. Papageorgiou and R. Bragós. “Developing Innovation Competences in Engineering Students: A Comparison of Two Approaches.” *European Journal of Engineering Education* 47, no. 2 (2022): 353-372. https://doi.org/10.1080/03043797.2021.1968347

Coppens, K., L. Van den Broeck, N. Winstone and G. Langie. “Capturing Student Feedback Literacy Using Reflective Logs.” *European Journal of Engineering Education* 48, no. 4 (2023): 653-66. https://doi.org/10.1080/03043797.2023.2185501

Darvishi, A., H. Khosravi, S. Sadiq, D. Gašević and G. Siemens. “Impact of AI Assistance on Student Agency.” *Computers and Education* 210 (2024): 104967. https://doi.org/10.1016/j.compedu.2023.104967

Ding, L., T. Li, S. Jiang, and A. Gapud. “Students’ Perceptions of Using ChatGPT in a Physics Class as a Virtual Tutor.” *International Journal of Educational Technology in Higher Education* 20, no. 1 (2023):63–18. https://doi.org/10.1186/s41239-023-00434-1

Dong, L. “‘Brave New World’ or Not?: A Mixed-Methods Study of the Relationship Between Second Language Writing Learners’ Perceptions of ChatGPT, Behaviors of Using ChatGPT, and Writing Proficiency.” *Current Psychology* 43, no. 21 (2024):19481-19495. https://doi.org/10.1007/s12144-024-05728-9

Dong, Z., Y. Gao and C. D. Schunn. “Assessing Students’ Peer Feedback Literacy in Writing: Scale Development and Validation.” *Assessment & Evaluation in Higher*

Education 48, no. 8 (2023): 1103-18. https://doi.org/10.1080/02602938.2023.2175781

Ellis, C., T. E. Adams and A. P. Bochner. "Autoethnography: An Overview." *Forum, Qualitative Social Research* 12, no. 1 (2011). http://nbn-resolving.de/urn:nbn:de:0114-fqs1101108

Escalante, J. "AI-Generated Feedback on Writing: Insights into Efficacy and ENL Student Preference." International Journal of Educational Technology in Higher Education, 20 no. 1 (2023). https://doi.org/10.1186/s41239-023-00425-2

Guo, K. and D. Wang. "To Resist It or to Embrace It? Examining ChatGPT's Potential to Support Teacher Feedback in EFL Writing." Education and Information Technologies, 29 no. 7 (2023):8435-8463. https://doi.org/10.1007/s10639-023-12146-0

Gülbahar, Y. and H. Tinmaz. "Implementing Project-Based Learning and e-Portfolio Assessment in an Undergraduate Course", *Journal of Research on Technology in Education* 38, no. 3 (2006): 309-327. https://doi.org/10.1080/15391523.2006.10782462

Gilbuena, D. M., B. U. Sherrett, E. S. Gummer, A. B. Champagne and M. D. Koretsky. "Feedback on Professional Skills as Enculturation into Communities of Practice." *Journal of Engineering Education* 104 (2015): 7-34. https://doi.org/10.1002/jee.20061

Haughney, K., S. Wakeman and L. Hart. "Quality of Feedback in Higher Education: A Review of Literature." *Education Sciences* 10, no. 3 (2020): 60. https://doi.org/10.3390/educsci10030060

Heller, R. S., C. Beil, K. Dam and B. Haerum. "Student and Faculty Perceptions of Engagement in Engineering." *Journal of Engineering Education* 99 (2010): 253-261. https://doi-org/10.1002/j.2168-9830.2010.tb01060.x

Holland, D. P., C. J. Walsh and G. J. Bennett. "A Qualitative Investigation of Design Knowledge Reuse in Project-Based Mechanical Design Courses." *European Journal of Engineering Education* 44, no. 1-2 (2019): 137-52. https://doi.org/10.1080/03043797.2018.1463196

Hopfenbeck, T. N., Zhang, Z., Sun, S. Z., Robertson, P., & McGrane, J. A. (2023). Challenges and opportunities for classroom-based formative assessment and AI: a perspective article. Frontiers in Education (Lausanne), 8. https://doi.org/10.3389/feduc.2023.1270700

Husain, A. "Potentials of chatgpt in computer programming: insights from programming instructors." *Journal of Information Technology Education Research*, 23 no. 002 (2024). https://doi.org/10.28945/5240

Li, L. and M. Kim. "It is Like a Friend to Me: Critical Usage of Automated Feedback Systems by Self-Regulating English Learners in Higher Education." *Australasian Journal of Educational Technology* 40, no. 1 (2024): 1–18. https://doi.org/10.14742/ajet.8821ya

Mahapatra, S. "Impact of ChatGPT on ESL Students' Academic Writing Skills: A Mixed Methods Intervention Study." *Smart Learning Environments* 11, no. 9 (2024). https://doi.org/10.1186/s40561-024-00295-9

Mao, J., E. Romero-Hall and T. C. Reeves. “Autoethnography as a Research Method for Educational Technology: A Reflective Discourse.” *Educational Technology Research and Development* (8 September 2023). https://doi.org/10.1007/s11423-023-10281-6

McHugh, Sally, N. Carroll and C. Connolly. “Low-Code and No-Code in Secondary Education - Empowering Teachers to Embed Citizen Development in Schools.” *Computers in the Schools* (2023), 1-26. https://doi.org/10.1080/07380569.2023.2256729

Papert, S. “Situating Constructionism”. In *Constructionism*, edited by I. Harel and S. Papert, 1-11. Norwood, NJ: Ablex Publishing, 1991.

Sun, D., A. Boudouaia, C. Zhu and Y. Li. “Would ChatGPT-Facilitated Programming Mode Impact College Students’ Programming Behaviors, Performances, and Perceptions? An Empirical Study.” *International Journal of Educational Technology in Higher Education*, 21 no. 1 (2024). https://doi.org/10.1186/s41239-024-00446-5

Tai, J., R. Ajjawi, D. Boud, P. Dawson and E. Panadero. “Developing Evaluative Judgement: Enabling Students to Make Decisions About the Quality of Work.” *High Education* 76 (2018): 467-481. https://doi.org/10.1007/s10734-017-0220-3

Tossell, C. C., N. L. Tenhundfeld, A. Momen, K. Cooley and E. J. de Visser, "Student Perceptions of ChatGPT Use in a College Essay Assignment: Implications for Learning, Grading, and Trust in Artificial Intelligence." *IEEE Transactions on Learning Technologies* 17 (2024):1069-1081. https://doi.org/10.1109/TLT.2024.3355015.

Wilson, J., C. Palermo and A. Wibowo. “Elementary English Learners’ Engagement with Automated Feedback.” *Learning and Instruction* 91, (2024):101890. https://doi.org/10.1016/j.learninstruc.2024.101890

Xiao, Y and Y. Zhi. “An Exploratory Study of EFL Learners’ Use of ChatGPT for Language Learning Tasks: Experience and Perceptions.” *Languages* 8 no. 3 (2024):212. https://doi.org/10.3390/languages8030212

Xing, W., B. Pei, S. Li, G. Chen and C. Xie. “Using Learning Analytics to Support Students’ Engineering Design: The Angle of Prediction.” *Interactive Learning Environments* 31, no. 5 (2023): 2594-2611. https://doi.org/10.1080/10494820.2019.1680391

PEER REVIEW EVALUATION IN 3D MODELING COURSE: SIMPLIFYING ASSESSMENT AND ENSURING QUALITY

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Keywords: *Peer review; massive course*

ABSTRACT

This paper discusses how peer review evaluations can simplify the assessment process and ensure quality in a 3D modelling course. The method was implemented in the second year of a bachelor's degree course in 3D modelling. Compared with other massive courses such as mathematics and physics, the evaluation of this 3D

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modelling course can only be done manually. Teachers provide an evaluation matrix, which students use to grade their peers' work. The average points from different reviews are then used as the final grade for the submission. During the evaluations, students can identify their own mistakes in their drawings and assess the quality of their peers' work. This peer review system saves teachers time on evaluations so that teachers can focus on answering questions during exercise sessions and giving more instructions. The statistics of students' grades in individual exercises over the past three academic years were collected and analysed. The results indicate that peer-review assessments can decrease teachers' workload without sacrificing course's quality. In addition, this peer review system can be also used in other course, especially when the exercise submission is fully online.

1. INTRODUCTION

A large body of research literature suggests that peer assessment is an effective way of promoting learning and optimising teaching resources (Double et al. 2020). As an assessment method, peer assessment has been shown to be reliable and to correlate well with teacher assessment (Chang et al. 2021, Power and Tanner 2023). In addition to improved learning outcomes, peer assessment has been found to improve students' critical thinking and tendencies towards collaboration, problem solving and meta-cognition (Chang et al. 2021), as well as their ability to make informed judgements and articulate those judgements (Nicol et al. 2014).

The benefits of peer assessment often focus on its ability to provide feedback to students in circumstances where this would not otherwise be possible, e.g. large class sizes. As a result, more attention has been paid to the learning support provided by feedback than to the benefits of assessing and providing feedback on the work of others. However, some studies suggest that students taking an active role in assessment by evaluating the work of peers can have a significant effect on evaluating and improving their own work (Nicol et al. 2014), even if they do not receive feedback in return (Culver 2023). Indeed, Culver's (2023) work found that assessing the work of others was more influential than receiving feedback, even though students did not perceive it to be of similar value.

Peer-review tasks have gained more attention in large university courses in the past decade. In the paper (Luckner and Purgathofer 2015), a peer review system was used in a course with up to 800 students. The objective was to provide students with personal feedback and support them in self-directed studies. Online courses have been adopted by many universities during the Covid-19 pandemic, and even before that. In paper (Knight and Steinbach 2011), a course was offered both on campus and online. The online course utilised a peer review system, which was found to be challenging without appropriate software. Peer-review tasks are adopted in the education system as well, for example, such system is used in the initial stage of the Covid-19 pandemic and approved to be robust (Pick. 2022). Oral peer review exercises in postgraduate students is presented in (Dickson et al. 2019), the results reveal that students' confidence increase and anxiety decrease in the whole process, and get good results in course.

This paper describes a course designed mainly for the second year bachelor's students in university level. Upon completion of the course, students will be proficient in using 3D modelling software, specifically SolidWorks, for 3D modelling and 2D drawing. Additionally, they will gain knowledge related to technical documentation, including general tolerance, geometry tolerance, surface roughness, standards, and welding symbols. This course runs from September to April each year and has approximately 600 students every year. The teaching method is hybrid and exercises are conducted in the classroom only. Due to the large number of students, exercise sessions are conducted in a question-and-answer format. Teachers provide guidance only when students have questions.

As 3D modelling exercises cannot be evaluated automatically, unlike mathematics or physics, this 3D modelling course always require human evaluation. Therefore, a peer-review system was considered as a tool. The course includes both individual and group exercises, but the peer-review system is only adopted for individual exercises, making the evaluation half-supervised. The evaluation of group exercises is always checked by teachers. Literature reviews (Mulder et al. 2014, Hew and Wing 2014) suggest that the peer-review system at the university level may be challenging and may not always meet the teacher's goals. However, the purpose of individual exercises in this course is to familiarise students with the software and enable them to design different models within the scope of the exercise requirements. As teachers, we provide students with a detailed evaluation matrix, and students should evaluate other's work based on the given criteria. The peer-review system in Moodle is actively used. Additionally, teachers randomly check exercises to ensure fair evaluation. This approach is a good choice for reducing teacher workload while maintaining the quality of students' work.

2. DESCRIPTION OF THE METHOD

2.1 Course setting

The course is a second-year bachelor level course in Technical Documentation and 3D Modelling that takes place in the autumn semester. However, it is noticed that some first-year students also take this course because there is no prerequisite. Before 2021 the course was organized in Finnish only. During 2021-2022, the course was organized as two separate course modules in Finnish and English. In 2023, the Finnish and English modules were merged, and the general instructions were in both Finnish and English, but all students were in the same classroom. Lectures are given online, but exercises are held on campus to ensure the quality of the course. The students in this course are divided between two campuses, so sometimes the teachers have to travel between the campuses, but there are permanent teaching assistants at both campuses who can give some general instructions to the students. In total there are about 600 students each year. All the exercises are held on campus because it is not efficient to instruct students on how to use software online. The course extends over the whole academic year with periods 1 and 2 in the autumn and periods 3 and 4 in the spring term. The course schedule is shown in the Fig. 1.

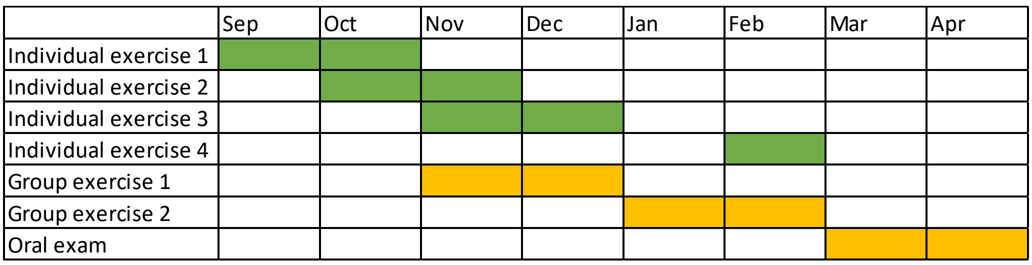


Fig. 1. Schedule of different exercises.

The learning tasks in the course consist of individual exercises, group exercises, and oral exam. In this paper, only the individual exercises will be introduced in detail since the peer review system is adopted only in individual exercises. There are altogether four individual exercises. Each individual exercise is worth 10% of the final course grade. The full grading scheme of the course is presented in Table 1.

Table 1. The grading scheme of the course

Assessment task	Description	Share of the final grade
Individual exercise	Four individual tasks (10% each) completed with SolidWorks.	40%
Group exercise	1st part: make 3D modelling using SolidWorks 2nd part: make technical drawings based on the model from 1st part	35%
Oral examination	Individual oral discussion with the teacher on the 2nd part of group exercise	25%

A step-by-step tutorial on how to use SolidWorks is provided to the students, and the students need to follow those steps, and complete the exercises, the aim is to motivate the students and activate their interest in this course, so the focus is on how to maximize their ability to use SolidWorks. The individual exercises are arranged in Periods 1 and 2. Over the years, there are minor changes on the instructions.

2.2 Improved method

When the course was organized for the third time in 2023-2024, there were some minor changes to the exercise, but major changes to the management based on the experience and feedback from the previous two years.

Firstly, the peer review system has been adopted in the Individual Exercise 1-3, the tasks require student to use SolidWorks software to create some 3D modelling, and the evaluation of this exercise can only be done by teachers. The aim is to motivate students to create a model based on their daily life and interests. In the peer review system, after the submission is closed, each student receives three submissions from three other students, and they have to evaluate each submission based on the provided evaluation matrix. By using this peer review system, the workload of teachers is dramatically reduced. Firstly, the peer review system follows the strict deadline, so there is no way that students can submit the exercise late. In the past, there have been some cases where students had various excuses and wanted to submit the exercise late. Secondly, when students are evaluating other people's work, they have to check the evaluation matrix so that they know what good work is, what is bad work and how their own work is. This will reduce the number of emails asking why they get certain grades. In addition, if students are not satisfied with the grades of the exercises, they will come to the exercise sessions and the responsible teachers will check the work and change the grades if necessary. This approach encourages students to come to class, discuss with teachers, learn more about the course, and drastically reduces the time spent answering emails, as these types of questions cannot usually be resolved by email.

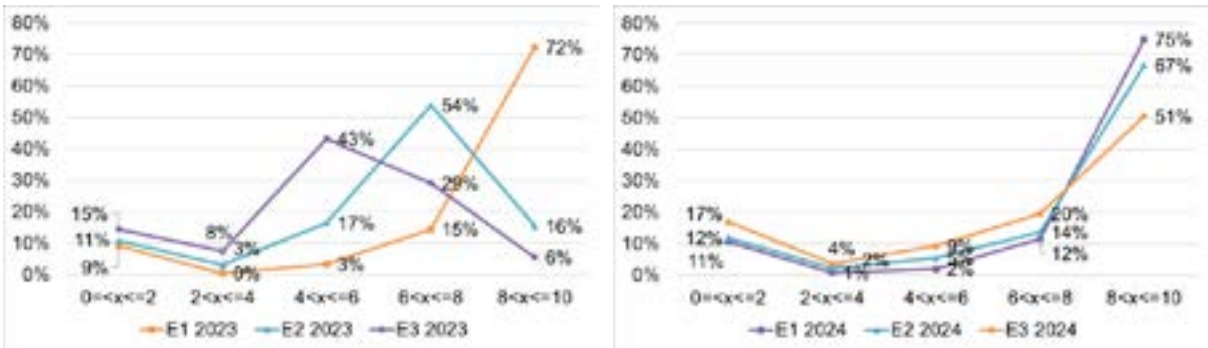
The duties of responsible teachers remain the same, but the duties of teaching assistants are only giving instruction during the exercise session, since we notice different teaching assistant has different level of knowledge, sometimes, it caused some confusion among students. To better control the teaching quality, the teaching assistants can only provide help, not give advice related to the grades.

In the next sections we compare the individual exercises in two consecutive academic years. In the academic year 2022-2023, the Individual Exercise 1/2/3 were evaluated by the teaching staff. In the academic year 2023-2024, the Individual Exercise 1/2/3 were evaluated using a peer review system. First, the grades of the exercises between two years are compared, which represents the quality of the students' work. Second, the estimated time for evaluation between two years is compared, which is considered as teacher workload. Finally, we elaborate the student experience of the peer feedback with excerpts from the course feedback.

3. RESULTS

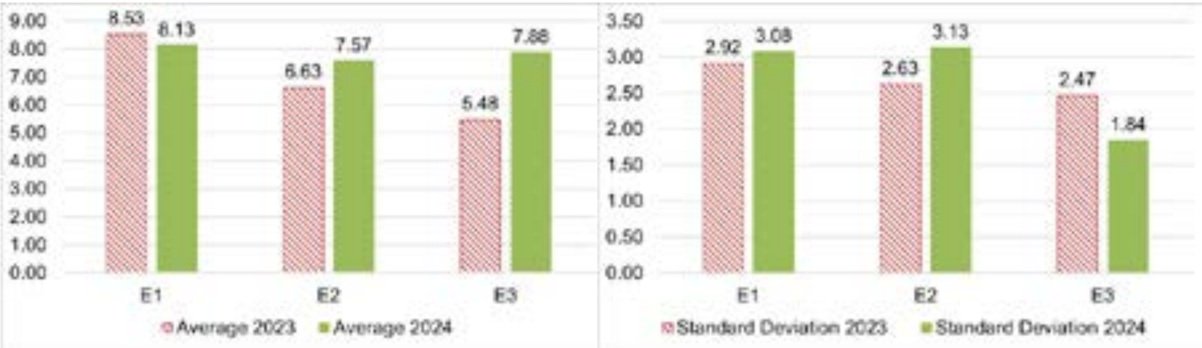
3.1 Student learning

The points of each exercise 1/2/3 are exported and then analysed. Firstly, the scale of the points of each exercise is from 0 to 10. The x-axis represents the grades, then these points are divided into five intervals: 1) 0⩽point⩽2; 2) 2<point⩽4; 3) 4<point ⩽6; 4) 6<point⩽8; 5) 8<point⩽10. The y-axis represents the percentage of students who received this score out of the total number of students. Different colours/markers represent different exercises in different years, details can be seen in the labels. Fig. 2 illustrates line charts showing the distribution of students' scores in individual exercises 1/2/3 in academic years (a) 2022-2023, and (b) 2023-2024. And Fig.3 illustrates students’ points statistics in individual exercise 1/2/3 in different academic years. Table 2 summarizes the frequencise of scores, average values, and standard devision in academic years 2022-2023 and 2023-2024.



(a) (b)

Fig. 2. Students’ points distributions in individual exercise 1/2/3 in academic year (a) 2022-2023 and (b) 2023-2024 (comparison between different exercise in the same academic year).



(a) (b)

Fig. 3. Students' points statistics in individual exercise 1/2/3 in academic years (a) average value x̄, and (b) standard deviation σ.

Table 2. Course grades' frequencies in different intervals, average value x̄, and standard deviation σ.

	2023							2024						
	0-2	2-4	4-6	6-8	8-10	x̄	σ	0-2	2-4	4-6	6-8	8-10	x̄	σ
E1	9%	0%	3%	15%	72%	8.53	2.92	11%	1%	2%	12%	75%	8.13	3.08
E2	11%	3%	17%	54%	16%	6.63	2.63	12%	2%	5%	14%	67%	7.57	3.13
E3	15%	8%	43%	29%	6%	5.48	2.47	17%	4%	9%	20%	51%	7.88	1.84

From the Fig. 2 (a), it seems that most of the students have a grade in the scale of 8<point≤10 in individual exercise 1. The distribution of individual exercise 2/3 are close to the normal distribution. From Fig. 2 (b), the trends of individual exercises 1/2/3 are similar. These trends follow the teachers' expectations, this year most of the students have higher scores, it may be that the tutorials are well developed, and more instructions are given in the exercises, in addition, teaching assistants were hired to assist students in the tutorial sessions. However, it could also be that students prefer to give relatively very low and very high scores to their peers, which could lead to unfair assessment.

In addition, from Fig. 2, there are 9%-24% students who got points on the scale of 0<point≤2. There might be different reasons, it might be military service that students have to leave the course for a while, or some students realise that the current workload is too much, they have to drop out this course, or some students forgot to submit previous exercises and they realise that they cannot reach high grades in this course no matter how hard they try.

Fig.3 and Table 2 show that the difference between the average scores between different years are not large when the total score of the course is 100. The aim of the individual exercises 1/2/3 is to motivate the students to be more creative in 3D modelling, instead of giving up at the beginning of the course, since the beginning of any software is always difficult.

3.2 Teacher workload

As mentioned previously, the goal of adopting peer review system in the course is to decrease teachers' workload without sacrificing the course quality. Considering the workload, in academic year 2022-2023, the evaluation of each individual exercise for each student is about 3 minutes, in total 90 hours for all individual exercises in each year. In academic year 2023-2024, all evaluations will be done by peer review system, if students have any questions about their scores, teachers will check with students during the exercise session. This saves time and encourages interaction between teachers and students. All the teachers in the course have the same feeling that workload is decreased. In additional, similar idea will be extended to MOOC course in the future. When talking about course quality, it can be reflected on the grades, in a course with total points of 100, the differences in all the individual exercises are not huge. And the goal of the individual exercises is to motivate students to use the 3D modelling software, so the evaluation is not very strict.

From students' perspective, the peer review systems allow students to check how other students are working on the exercise, they can see the error in their own work, and they do not need to send emails to teachers asking what is wrong. There are students who appreciate this approach very much because they take advantages of it, such as recognizing the mistake and learning new things by checking other's work. In traditional way, students cannot see their classmates' work, and do not know how well themselves have done. In some countries, there is ranking system, so students want to compete with each other somehow. In addition, they can recognize hard-working students, and choose them as potential group member in the future, since getting higher grade is their common goal.

3.3 Student experience

The course feedback contained one open question about the best features of the course and one open question about the aspects of the course needing most improvement. 219 out of 486 answered the survey.

Individual exercises were named as the best feature of the course by many students. Peer assessment of the individual exercises was mentioned by six students, with three students questioning the fairness or reliability of the peer assessment, two students calling for clearer criteria for assessment, and one student mentioning technical difficulties with peer assessment (problems with opening files). Relating the number of comments to the number of respondents shows that student have very few complaints or concerns regarding peer assessment, but a high appreciation for the individual exercises which are in part enabled by the use of peer assessment instead of grading by teachers. However, just like Culver (2023) noticed, students do not recognize that assessing the work of others can in fact also support their own learning process.

4. SUMMARY

The results from the statistics show that peer review assessment supports this course well, it reduces the workload of teachers without sacrificing the quality of the course. From exercise sessions, feedbacks are collected orally and in paper, both teachers and most of students are satisfied with the peer review systems. Some random exercises samples were taken after the assessment to check on the reliability of the peer-assessment, and teachers found the given grades to be mostly aligned with their expert opinions, just as expected from the literature (Chang et al. 2021, Power and Tanner 2023). It is true that some students do not give a fair mark, but it does not affect the final points much because average points from three students will be used as the final points. In addition, if students are not satisfied with the results, teacher will evaluate together with the students. The aim of the individual exercise is not to select the best students, but to motivate the students in this course because the group exercise will be more difficult. However, if peer review system will be used in other courses, the weight of this evaluation method must be considered carefully, as students may tend to give very high or very low results. Teachers must find a way to make this process fair.

A detailed evaluation matrix was given to the students and further guidance was given during the exercise so that students take responsibility and evaluate each other's work. The students were not, however, informed about the motives of the use or peer assessment and its potential benefits for student learning. In the future also these aspects should be communicated better, to enhance the motivation and increase the student effort put into peer assessment.

Some unexpected and interesting phenomenon was noticed during the statistical analysis, such as many students dropped out of the course at the very beginning before the individual exercise 1. The reasons behind this situation will be investigated in the future. If the reason is related to the teaching quality, the course should be improved. If the reason is related to enrolment system error, then the course selection tool should be developed.

REFERENCES

Chang, D., Hwang, G-J., Chang, S-C., and S-Y. Wang. "Promoting students' cross-disciplinary performance and higher order thinking: a peer assessment-facilitated STEM approach in a mathematics course". *Educational Technology Research and Development* 69 (2021): 3281–3306. https://doi.org/10.1007/s11423-021-10062-z.

Culver, C. "Learning as a peer assessor: evaluating peer-assessment strategies". *Assessment & Evaluation in Higher Education* 48, no. 5 (2023): 581–597. https://doi.org/10.1080/02602938.2022.2107167.

Double, K. S., McGrane, J. S., and T. N. Hopfenbeck. "The Impact of Peer Assessment on Academic Performance: A Meta-analysis of Control Group Studies". *Educational Psychology Review* 32 (2020): 481–509. https://doi.org/10.1007/s10648-019-09510-3.

Nicol, D., Thomson, A., and C. Breslin. "Rethinking feedback practices in higher education: a peer review perspective". *Assessment & Evaluation in Higher Education* 39, no.1 (2014): 102–122. https://doi.org/10.1080/02602938.2013.795518.

Power, J.R., and D. Tanner. "Peer assessment, self-assessment, and resultant feedback: an examination of feasibility and reliability". *European Journal of Engineering Education* 48, no. 4 (2023): 615–628. https://doi.org/10.1080/03043797.2023.2185769.

Mulder, R. A., Pearce, J. M., and C. Baik, "Peer review in higher education: Student perceptions before and after participation". *Active Learning in Higher Education* 15, no. 2 (2014): 157-171. https://doi.org/10.1177/1469787414527391.

Luckner, N., and P. Purgathofer. "Exploring the Use of Peer Review in Large University Courses". *Interaction Design and Architecture(s) Journal* 25 (2015): 21-38. https://doi.org/10.55612/s-5002-025-002.

Hew, K. F., and W. S. Cheung. “Students’ and instructors’ use of massive open online courses (MOOCs): Motivations and challenges”. *Educational Research Review* 12 (2014): 45-58. https://doi.org/10.1016/j.edurev.2014.05.001.

Dickson, H., Harvey, J., and N. Blackwood. “Feedback, feedforward: evaluating the effectiveness of an oral peer review exercise amongst postgraduate students”. *Assessment & Evaluation in Higher Education* 44, no.5 (2019): 692-704. https://doi.org/10.1080/02602938.2018.1528341.

Knight, L. V., and T. A. Steinbach. “Adapting Peer Review to an Online Course: An Exploratory Case Study”. *JITE-Research* 10, no.1 (2011): 81-100. https://www.learntechlib.org/p/111513.

Pick, L. T., Manda, K., Cole, J. S., McCartan, C., and J. P. Hermon. “A mathematics peer assessment process for flexible modes of delivery”. Paper presented at *the 50th Annual Conference of the European Society or Engineering Education, Barcelona, 19-22 September, 2022*. https://doi.org/10.5821/conference-9788412322262.1117.

RETRIEVAL-AUGMENTED GENERATION FOR FINDING RELEVANT LECTURES FROM QUIZZES IN A MULTILINGUAL STEM EDUCATIONAL ENVIRONMENT

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ABSTRACT

Understanding the semantic connections between the increasingly online-based offered educational content is becoming more relevant for educational institutions. The fast adoption of AI-based techniques and their application in semantic search offers new possibilities and challenges when working in an educational context.

In this paper, we explore the usage of broadly used text embedding models in Retrieval-Augmented Generation (RAG) systems for semantic retrieval when searching multilingual educational content from Massive Open Online Courses (MOOCs), a significant part of which belongs to engineering studies. More specifically, we analyse the performance of text embedding models when searching multilingual content and the impact of mathematical notation on the retrieval results. Furthermore, we introduce a series of developed prototypes and applications that

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inspect embedding models and utilise them to find semantically relevant lectures and courses.

1 INTRODUCTION

The last decade has seen an explosion of online courses being published by higher education institutions. These courses harbour a wealth of different learning materials that could serve multiple purposes beyond the entire course to which they belong: revising before an exam, pre-requisite check before starting a course, re-use in other courses or modules, etc. Offering elements of these courses individually allows learners to have more individualised experiences and increases the flexibility of an institution's educational offer. However, defining what constitutes an element and how to make those elements searchable and available is not trivial: what is the size of a meaningful course element? One quiz question or several? A chapter including text, video and assignments? And how can we 're-package' individual elements together to create meaningful elements? For example, students who revise before an exam may want to search for interactive quizzes to test themselves, receive meaningful feedback after answering and maybe watch an exploratory video, whereas, for re-use in another course, teachers need interoperable or "technically agnostic" files that contain questions, answers, explanatory texts and (links to) video files.

This paper presents the work done to make existing online quizzes from a collection (64) of open edX Massive Open Online Courses (MOOCs) available for learners. In particular, we focus on how we can enrich the individual quiz question with references to short video content to serve as feedback so that it can be presented together as a meaningful learning experience.

We study the potential of Retrieval-Augmented Generation (RAG) systems and embeddings-based semantic retrieval, using the transcriptions of video lectures and the quiz questions from the MOOCs as the educational resources indexed. We foresee two unique challenges in our indexing and enriching the MOOC elements, stemming from 1) the mathematical notations used in our STEM MOOCs (49) that may negatively impact retrieval rates (Gangwar et al. 2022) and 2) the multilingual content with courses in English (24) and in French (40) that may affect the performance of semantic retrieval.

After this introduction, section 2 introduces RAG systems and their components, how they are used in education, and the challenges we faced in our use case. We then discuss how we generated our dataset (section 3), and we introduce the metric used in the analysis of existing embedding models for our RAG (section 4). In section 5, we describe the prototypes and tools we developed with the goals of, on the one hand, inspecting further the semantic embedding space to understand better the semantic similarities between the different educational content and, on the other hand, to use these methods to conduct semantic search for finding relevant educational content, including lectures and courses. At last, we present our conclusions.

2 TEXT EMBEDDINGS AND RETRIEVAL-AUGMENTED GENERATION

Our aim is to index individual quiz questions, make them searchable, and enrich them with a video that provides an explanation. Text embedding models are efficient in indexing text and searching for related information (Jurafski and Martin 2024). These are machine learning models that have been trained with a large corpus of text. The underlying assumption is that words that occur in similar contexts tend to have similar meanings, the so-called distributional hypothesis (Harris 1954). Text embedding models receive a text fragment as an input and output a multidimensional vector with semantic properties.

When conducting a semantic search with embedding models, different text fragments (such as transcripts of video lectures in our case) are encoded into vectors stored in a database (vector store). Then, this database can be queried to retrieve the text fragments (transcripts from lectures in our case) closest to an input text (a quiz in our case). This similarity is based on the distance between the vectors (Fig. 1, Step 1). Text embedding models and vector stores are often used in RAG systems.

RAG systems have emerged (Lewis et al. 2020) as a paradigm that combines information retrieval from a provided knowledge source with large language models (LLMs). RAGs, by making use of verified external content (in our case a vector store), have the potential to mitigate one of the risks posed by LLMs: the presence of wrong facts in their answers, also known as hallucinations (Ji et al. 2023). In an educational setting, RAGs are being utilised for multiple tasks, such as Question Answering (Levonian et al. 2023; Abdulrahman et al. 2024; Liu et al. 2024), tutoring evaluation (Han et al. 2024) and exam generation (Guinet et al. 2024).

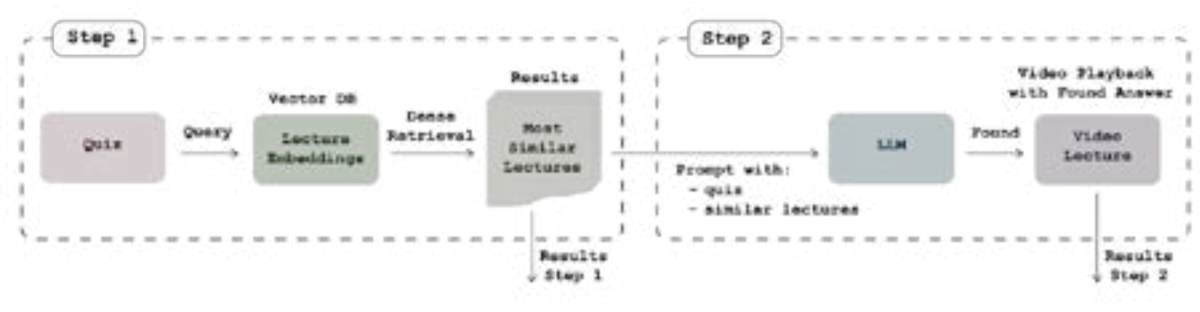

Fig. 1. Diagram of the components of our RAG system.

2.1 Challenges

2.1.1 Multilingual Content

As stated previously, the multilingual capabilities of our semantic search system are essential. Although information about the multilingual capabilities of certain text embedding models is available in the form of model cards (Mitchell et al. 2019), these are often incomplete, and it is not straightforward to find sources that evaluate embedding models under conditions similar to our use case. Therefore, evaluating the retrieval capabilities of widely adopted embedding models with our multilingual content was fundamental to increasing the retrieval performance of our system.

2.1.2 Mathematical Notation

Given that our dataset is constituted by a large part of courses in the realm of engineering, it was important for us to evaluate the impact (Gangwar et al. 2022) that mathematical formulas would have on the retrieval success rate.

An additional challenge in our study is the different representations of our mathematical content: many quizzes use LaTeX notation, whereas our transcripts contain natural language, as they are transcripts of spoken language. Therefore, we evaluate the impact of several options: 1) inclusion vs exclusion of mathematical content, 2) translating mathematical notation into natural language.

3 METHODOLOGY

3.1 Initial Dataset

First, we generated a dataset from the quizzes and transcribed video lectures. To evaluate the capability of the embeddings from different available models to retrieve meaningful lectures, we needed our dataset to have a ground truth. Determining the ground truth of every quiz manually would be unrealistic due to time constraints.

The majority of our MOOCs have an internal structure in which, in the same learning unit, a quiz, or a series of quizzes, comes right after a video lecture. Therefore, we discarded the MOOC content that does not follow this pattern, and we made the assumption that we could use a lecture as “ground truth” for the quiz (or quizzes) that come right after it (Fig. 2). This helped us to generate a dataset to evaluate the retrieval capabilities of text embedding models.

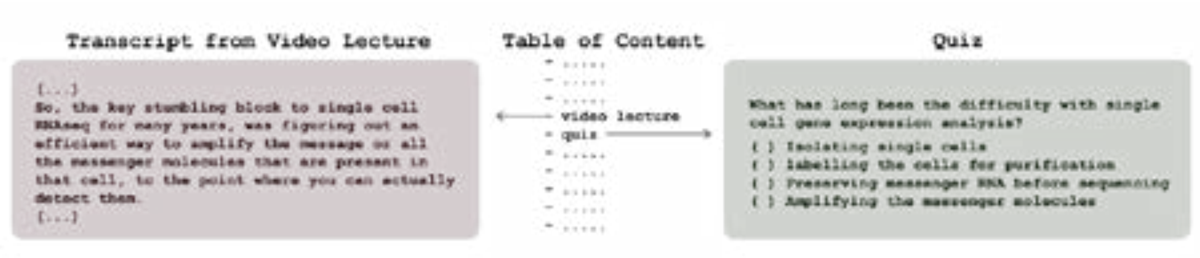

Fig. 2. Diagram that depicts the ground truth assumption followed to generate our dataset.

3.2 Languages

We initially created variants of our dataset for English and French content. For the base version, we randomly selected 300 pairs of quizzes with their “ground truth” lecture in French (“FR Base”) and the other three hundred in English (“EN Base”).

3.3 Mathematical notation

To evaluate the impact on the retrieval performance of different models with content including LaTeX notation, we generated French and English versions of our dataset with 300 randomly selected quizzes that contained LaTeX (“FR LaTeX”, “EN LaTeX”), 300 that did not (“FR No LaTeX”, “EN No LaTeX”).

We also created a fourth variant of our dataset (in English and French) in which we used an LLM to replace the LaTeX notation present in the dataset variants “FR LaTeX” and “EN LaTeX” with natural language (“EN Nat. Lg.”, “FR Nat. Lg.”). For example, \frac{5}{3} becomes ”5 divided by 3”.

3.4 Embeddings and Retrieval

Text embedding models used in RAG systems generate a maximum text length that can be encoded. When text is input into a model that is larger than its maximum input length, the rest of the input text will not influence the generated embedding. Multiple chunking strategies can be used to address this problem (Gao et al. 2023). When processing the transcripts from the lectures, we decided to use the longer chunk (fragment) of text containing complete sentences that do not exceed the model's maximum input length. For encoding the quizzes, due to their shorter length, we decided not to chunk them and to generate an embedding per quiz.

For retrieval, we employ a dense retriever (Karpukhin et al. 2020) and cosine distance as a metric to compute similarity. In our use case, the cosine distance between the input quiz embedding and all the embeddings from the lecture transcripts in the vector store will determine which lectures are the most similar to the input quiz.

3.5 Task and Performance Metric

The task consisted of finding a text fragment (chunk) from the "ground truth" lecture from a given quiz in the different variants of our dataset. We used Average Precision (AP), a widely used metric in ranking problems, as our metric for the analysis of how different text embedding models perform at this given task. The final performance for each text embedding model is measured by the mean of the AP of all quizzes in the variants of our dataset.

$$AP = \frac{1}{m}\sum_{k=1}^{n} P_k \ rel_k$$

(1).

Where:

n is the total number of video lectures.

m is the number of relevant items (in our case, it is always 1).

k iterates over all video lectures.

P_k is the precision at position k.

rel_k is the relevance at position k, a binary value indicating whether the video lecture at position k is relevant (1) or not (0), i.e. is part of the "ground truth" described in section 3.1.

4 RESULTS

For this evaluation (Table 1), we made a selection of openly available text embedding models. We chose models for English content (the four first rows of the table), French content (the last two rows of the table), and models that claimed to have been trained on multilingual content that includes English and French languages (the rest of rows).

As we could expect, the models for English content suffered a more accentuated drop in performance when used on French content than the top-performing model considered multilingual: "Multilingual-e5-large" (Wang et al. 2024).

In the French variants of our dataset, "Solon-embeddings-large-0.1" ("Solon") outperformed the other models for French content by a wide margin, with the multilingual model, "Multilingual-e5-large", the second top performer. Unexpectedly, “Solon” was not only very close in performance to the top English embedding models in three of the four variants of our dataset but outperformed them in the “EN Base” variant by a slight margin. Although the model claims to have some English capabilities, it is not advertised to be fully multilingual. These results made “Solon” and “Multilingual-e5-large” our top options for working with our English-French bilingual content.

We also observe in the table that across all models, unsurprisingly according to the literature (Gangwar et al. 2022), there are significant drops in performance when using the dataset variants that contained mathematical notation in the form of LaTeX (columns “EN LaTeX” and “FR LaTeX”) compared to the dataset variants that do not (columns “EN No LaTeX” and “FR No LaTeX”). However, the French model, “Sentence-camembert-large” (Martin et al. 2019), was the only model that had significantly improved results when replacing LaTeX with natural language in the “FR Nat. Lg.” dataset variant. Some models decreased in performance, with “Solon” and “Multilingual-e5-large” being the most affected ones (column “FR Nat. Lg.”). In the English variant of our dataset, the results were barely affected by replacing LaTeX with natural language. This disparity in performance across models in the natural language variants of our dataset stresses the need for further exploration before we can reach conclusions.

Table 1. Mean of the Average Precision scores for finding a text fragment (chunk) from the “ground truth” lecture (in English and French) for quizzes without restriction (“EN Base”, “FR Base”), quizzes that contain LaTeX (“EN LaTeX”, “FR LaTeX”), quizzes that do not contain LaTeX (“EN No LaTeX”, “FR No LaTeX”) and quizzes that contained LaTeX translated into natural language (“EN Nat. Lg.”, “FR Nat. Lg.”). Scores range from 0.0 to 1.0 (higher is better).

Model	EN Base	EN LaTeX	EN No LaTeX	EN Nat. Lg.	FR Base	FR LaTeX	FR No LaTeX	FR Nat. Lg.
all-mpnet-base-v2	0.514	0.360	0.605	0.360	0.394	0.337	0.489	0.302
all-MiniLM-L6-v2	0.536	0.388	0.619	0.388	0.338	0.283	0.446	0.287
UAE-Large-V1	0.576	0.391	**0.650**	0.403	0.347	0.322	0.469	0.293
bge-large-en-v1.5	0.558	**0.397**	0.639	**0.409**	0.368	0.331	0.473	0.295
distiluse-base-multilingual-cased-v2	0.434	0.251	0.519	0.251	0.294	0.191	0.417	0.211
paraphrase-multilingual-mpnet-base-v2	0.426	0.254	0.524	0.254	0.274	0.181	0.459	0.199
multilingual-e5-large	0.548	0.372	0.621	0.387	0.489	0.436	0.587	0.357
sentence-camembert-large	0.430	0.186	0.503	0.186	0.319	0.177	0.520	0.262
solon-embeddings-large-0.1	**0.579**	0.392	0.647	0.392	**0.498**	**0.460**	**0.601**	**0.364**

5 APPLICATIONS

We have developed a series of tools and prototypes that make use of the introduced RAG system and model embeddings. While the “Embeddings Explorer” and “Course

Retriever" target education administrators, curriculum designers, educators and researchers, the "Lecture Finder" is primarily oriented to students.

5.1 Embeddings Explorer for MOOCs

This web-based application[2] was developed as an internal tool to visualise the semantic connections between quizzes and lectures from MOOC courses when encoded with text embedding models. To reduce the dimensionality of the embeddings to a plottable two-dimensional space, we used the method for dimensionality reduction UMAP (McInnes et al. 2018).

The application has two main functionalities. Firstly, it allows the user to visualise the embedding space as an Interactive Scatter Plot (Fig. 3, Panel C) containing the quizzes (outline of a circle) and transcript from the video lectures (full circle) from all courses at once, providing a general overview of the semantic connections between the content from the different MOOC courses.

Secondly, the user can select a specific course and analyse its embeddings in more detail. The Course Structure Panel (Fig. 3, Panel B) visualises the hierarchical structure of the selected course. The user can expand and collapse the nodes from the different chapters and units. When a quiz or video lecture is selected (via the Course Structure Panel or the Interactive Scatter Plot), it is highlighted, its information is shown in the Metadata Panel (Fig. 3, Panel E), and its textual content, used to generate its embedding, is displayed in the Content Panel (Fig. 3, Panel F).

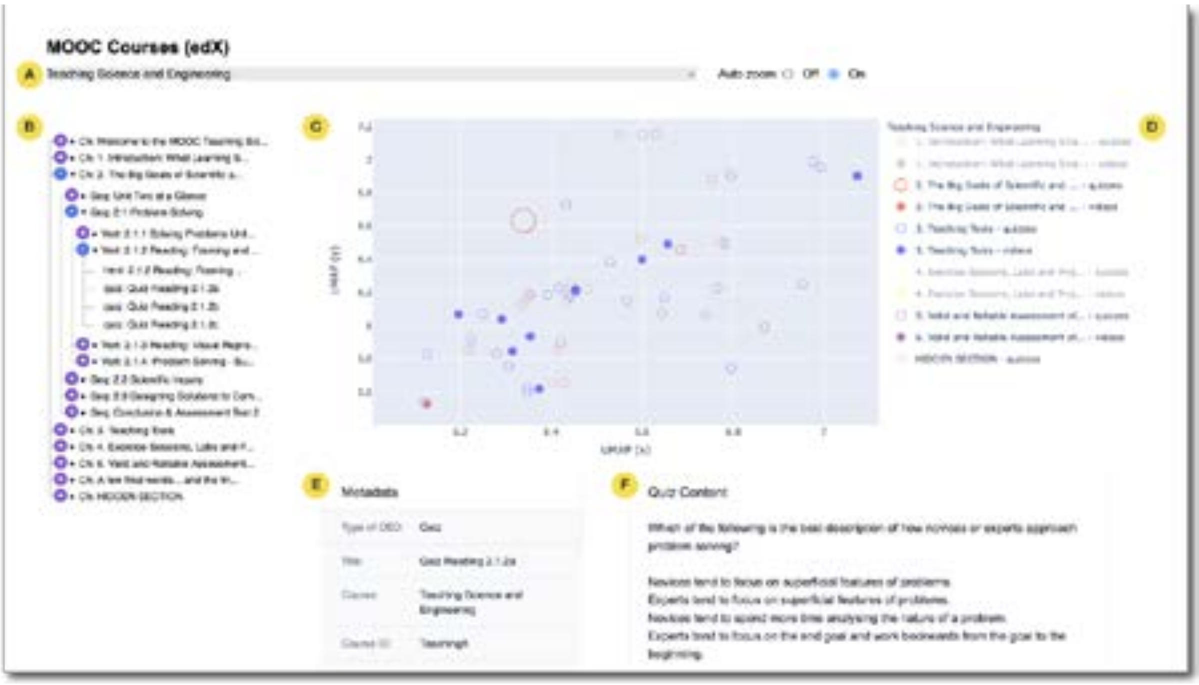

Fig. 3. Embeddings Explorer: Course Selector (A), Course Structure Panel (B), Interactive Scatter Plot (C), Interactive Legend (D), Metadata Panel (E) and Content Panel (F).

5.2 Lecture Finder Prototype for MOOCs

This prototype aims to allow users to find relevant indexed video lectures starting from a quiz. We used the RAG system described in section 2, splitting the process

[2] https://github.com/jllp-epfl/mooc-embeddings-visualizer

into two steps. In the first step (Fig. 1, Step 1), the system retrieves the closest semantically found lectures in order of similarity.

In the second step (Fig. 1, Step 2), the user can search for the specific fragment of these lectures containing the answer to the quiz. An LLM (GPT 3.5) receives the content of the given quiz and the transcript of the top-ranked video lectures and is asked to find the fragment of text that contains the knowledge to solve the quiz in the given transcripts. If the LLM finds the answer, the LLM is asked to quote the found answer and to playback the segment of the video lecture that contains it.

By asking the LLM to quote the lecture instead of rephrasing or summarising the answer, we take a safer approach, preventing the model from hallucinating.

5.3 Embeddings-based Course Retriever

To semantically compare courses, we developed a web-based application[3] in which we generated embeddings from course descriptions (Fig. 4, right side). When the user selects a MOOC course from a list, the top 20 semantically most similar non-MOOC courses available on our online platforms, based on the embeddings of their description, are shown in an interactive bar plot. The user can then select one of these top most similar courses, which will display additional information and both course descriptions side by side.

Fig. 4. Lecture Finder on the left side and Course Retriever on the right side.

6 SUMMARY AND CONCLUSIONS

In this study, we generated a dataset from MOOC courses' content to compare the retrieval capabilities of embedding models for text similarity. To evaluate the impact of several aspects of our educational setting, such as its multilingualism and the abundance of STEM content that contains mathematical notation, we created variants of our dataset to evaluate the influence of these factors in the retrieval.

Regarding the multilingual capabilities of text embedding models, we learned that, although in 7 out of 8 variants of our dataset, the best-performing model was one recommended for the language (English or French), a high-performing model conceived for French content, "Solon-embeddings-large-0.1", can outperform models recommended for English content when searching lectures in English. From the evaluated models described as multilingual, "Multilingual-e5-large" was the top

[3] https://github.com/jllp-epfl/mooc-embeddings-sim-other-courses

performer, being this one and “Solon-embeddings-large-0.1” our top choices for our use cases.

The results of our analysis on the capabilities of text embeddings to retrieve LaTeX representation of mathematical notation were inconclusive. This underscores the need for further research to identify other factors that may influence the retrieval performance of such models when searching for relevant lectures from quizzes from STEM courses.

Lastly, we applied the knowledge we gained to develop web-based applications and work-in-progress prototypes for finding lectures and courses based on the similarity of their embeddings.

REFERENCES

Abdulrahman Alawwad, Hessa, Areej Alhothali, Usman Naseem, Ali Alkhathlan, and Amani Jamal. ‘Enhancing Textbook Question Answering Task with Large Language Models and Retrieval Augmented Generation’. *arXiv E-Prints*, February 2024, arXiv:2402.05128. https://doi.org/10.48550/arXiv.2402.05128.

Gangwar, Neeraj, and Nickvash Kani. "Semantic Representations of Mathematical Expressions in a Continuous Vector Space." arXiv preprint arXiv:2211.08142 (2022).

Gao, Yunfan, Yun Xiong, Xinyu Gao, Kangxiang Jia, Jinliu Pan, Yuxi Bi, Yi Dai, Jiawei Sun, and Haofen Wang. "Retrieval-augmented generation for large language models: A survey." arXiv preprint arXiv:2312.10997 (2023).

Guinet, Gauthier, Behrooz Omidvar-Tehrani, Anoop Deoras, and Laurent Callot. "Automated Evaluation of Retrieval-Augmented Language Models with Task-Specific Exam Generation." arXiv preprint arXiv:2405.13622 (2024).

Han, Zifei Feifei, Jionghao Lin, Ashish Gurung, Danielle R. Thomas, Eason Chen, Conrad Borchers, Shivang Gupta, and Kenneth R. Koedinger. ‘Improving Assessment of Tutoring Practices Using Retrieval-Augmented Generation’. arXiv [Cs.CY], 2024. arXiv. http://arxiv.org/abs/2402.14594.

Harris, Zellig S. 1954. “Distributional Structure.” WORD 10 (2–3): 146–62. doi:10.1080/00437956.1954.11659520.

Ji, Ziwei, Nayeon Lee, Rita Frieske, Tiezheng Yu, Dan Su, Yan Xu, Etsuko Ishii, Ye Jin Bang, Andrea Madotto, and Pascale Fung. "Survey of hallucination in natural language generation." ACM Computing Surveys 55, no. 12 (2023): 1-38.

Jurafsky, Daniel and Martin, James (2024). Speech and language processing: an introduction to natural language processing, computational linguistics, and speech recognition. 3rd Edition draft. https://web.stanford.edu/~jurafsky/slp3/

Karpukhin, Vladimir, Barlas Oğuz, Sewon Min, Patrick Lewis, Ledell Wu, Sergey Edunov, Danqi Chen, and Wen-tau Yih. "Dense passage retrieval for open-domain question answering." arXiv preprint arXiv:2004.04906 (2020).

Levonian, Zachary, Chenglu Li, Wangda Zhu, Anoushka Gade, Owen Henkel, Millie-Ellen Postle, and Wanli Xing. ‘Retrieval-Augmented Generation to Improve Math Question-Answering: Trade-Offs Between Groundedness and Human Preference’.

arXiv E-Prints, October 2023, arXiv:2310.03184.
https://doi.org/10.48550/arXiv.2310.03184.

Lewis, Patrick, Ethan Perez, Aleksandra Piktus, Fabio Petroni, Vladimir Karpukhin, Naman Goyal, Heinrich Küttler, et al. 'Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks'. In Advances in Neural Information Processing Systems, edited by H. Larochelle, M. Ranzato, R. Hadsell, M. F. Balcan, and H. Lin, 33:9459–74. Curran Associates, Inc., 2020.
https://proceedings.neurips.cc/paper_files/paper/2020/file/6b493230205f780e1bc26945df7481e5-Paper.pdf.

Liu, Rongxin, Carter Zenke, Charlie Liu, Andrew Holmes, Patrick Thornton, and David J. Malan. 'Teaching CS50 with AI: Leveraging Generative Artificial Intelligence in Computer Science Education'. In Proceedings of the 55th ACM Technical Symposium on Computer Science Education V. 2, 1927. SIGCSE 2024. New York, NY, USA: Association for Computing Machinery, 2024.
https://doi.org/10.1145/3626253.3635427.

Martin, Louis, Benjamin Muller, Pedro Javier Ortiz Suárez, Yoann Dupont, Laurent Romary, Éric Villemonte de La Clergerie, Djamé Seddah, and Benoît Sagot. "CamemBERT: a tasty French language model." arXiv preprint arXiv:1911.03894 (2019).

McInnes, Leland, John Healy, Nathaniel Saul, and Lukas Großberger. 'UMAP: Uniform Manifold Approximation and Projection'. Journal of Open Source Software 3, no. 29 (2018): 861. https://doi.org/10.21105/joss.00861.

Mitchell, Margaret, Simone Wu, Andrew Zaldivar, Parker Barnes, Lucy Vasserman, Ben Hutchinson, Elena Spitzer, Inioluwa Deborah Raji, and Timnit Gebru. 'Model Cards for Model Reporting'. In Proceedings of the Conference on Fairness, Accountability, and Transparency. FAT* '19. ACM, 2019.
https://doi.org/10.1145/3287560.3287596.

Wang, Liang, Nan Yang, Xiaolong Huang, Linjun Yang, Rangan Majumder, and Furu Wei. "Multilingual e5 text embeddings: A technical report." arXiv preprint arXiv:2402.05672 (2024).

REAL-LIFE CASES IN CHALLENGE-BASED LEARNING

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ABSTRACT

Challenge-based learning is a teaching approach where the learning takes place through the identification, analysis and design of a solution to a sociotechnical challenge (problem). In this paper we present how we use challenge-based learning in a 2nd year course with focus on entrepreneurship. We especially focus on the cases and on how the students value working with real-life cases and what information is important. Based on a survey, we found that the students enjoyed working with real-life cases, which they found both motivating and as a good frame for the course. They did however stress the importance of having a good contact with the case-owner. The students also mentioned that the case should be relevant and realistic in addition to being well-framed and open. Furthermore, the students also highlighted the importance of having access to case-owners, data and to other stakeholders. Based on these reflections – and our own observations during this course over the past four years, we offer a list of recommendations for choosing and framing cases - and for aligning expectations with case-owners with regards to results and availability; especially when it comes to the use of cases as a tool for learning in more introductory courses, such as ours.

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1 INTRODUCTION

1.1 Background: Challenge-based learning

Engineering students are increasingly expected to be able to handle complex global 21st century challenges and to develop innovative technological and sustainable solutions (Hadgraft and& Kolmos, 2020). In order to ensure these competences, more and more engineering programs focus on active learning methods including group work, by offering courses based on challenge-based learning, problem-based learning etc.

Challenge-based learning (CBL) focuses on student-centered learning and has become increasingly popular in engineering programs and courses. CBL offers a frame for inter-disciplinary group work where teams of students address real-life, open-ended challenges. CBL aims to stimulate students to take the lead in their own learning, by acquiring and applying relevant knowledge to cases and challenges in order to both suggest solutions and develop interdisciplinary skills (Helker et al., 2024). In CBL, the teacher acts as a facilitator (Doulougeri et al., 2024).

CBL normally starts with an open-ended, real-life challenge, ideally addressed by interdisciplinary teams, as the students should integrate knowledge and skills from multiple areas. The students propose solutions to the challenges after a process of problem identification, investigation, ideation and implementation, applying entrepreneurial tools and design thinking (Doulougeri et al., 2024)

Cases used for CBL are normally societally relevant and connected to sustainable development goals. The cases are often presented by external partners and the student teams collaborate with both the case-owners, and internal and external stakeholders to develop a solution (Doulougeri et al., 2024). The use of real-life challenges allows students to link new and prior knowledge, while applying it to new challenges (Hadcraft and Kolmos, 2020); and by also addressing sociotechnical issues, the cases address pressing current challenges such as climate change; thus requiring that the students apply a combination of technological innovation, policy development and societal engagement (Malmqvist et al., 2015).

Challenges and cases in CBL are often characterized by being open-ended and real-world, with external industry partners and societal stakeholders (Doulougeri et al., 2024). The cases can be created by a group of teachers; it has however been reported to be difficult to create the cases both with and without industry partners (Doulougeri et al., 2024) and it is also time consuming (Bombaerts et al. (2021). There are many examples of literature in which external (extra-academic actors) are used in CBL projects, but only little information about what their input was, their perceptions of the CBL approach, and whether their participation was evaluated (Gallagher and Savage, 2020).

1.2 Case study description

In this study, we present how we work with challenge-based learning (CBL) in a 2nd year introductory entrepreneurship course. The goal of the course is that students develop an entrepreneurial mindset while at the same time developing an innovative solution to a case challenge. The students come from different BEng programs and bring a range of skills and competences to the course. The students are grouped in mixed, interdisciplinary groups.

The course consists of common sessions where students are introduced to various methods (e.g. Business Model Canvas, Effectuation, Value Proposition etc), and sessions where students pitch for their peers and receive feedback (from both peers and teachers). In addition, the students work independently on their own group projects and plan how to collect data and meet with stakeholders and case-owner. The students (in groups) can choose which challenge to work with. In the beginning of the course the cases are presented, and at the end of the course there is a poster session where the students pitch their solutions to the other groups, teachers and case-owners and receive feedback before handing in their final reports. The cases are connected to the local environment with a focus on real-life, open-ended challenges from local companies, start-ups or organisations. The students are asked to develop a solution with societal values in addition to sustainability focus. The case-owners are contacted some months before the course starts and we have a meeting with them to discuss the case and alignment expectations with regards to how the students can contact them, data available for the students etc.

An example of a case description

Case description – Food scraps for sled dog food

A large part of Sisimiut's waste is food. This resource is mostly thrown away and burned, but can it possibly be used differently? Sisimiut has about 2000 sled dogs, and as it is now, all their food is imported from outside.

Investigate, among other things, the Fish Factory, the Board, the Supermarkets, institutions and possibly catchers' residual waste.
Case questions:

o Can the discarded food resource be used as dog food?

o What is thrown away in the various production companies, institutions and eateries?

o What is the total food resource from waste? Give an estimated value in terms of protein, carbohydrate and fat.

o How should the leftovers be processed in order for it to be used as dog food?

o Can production possibly be run circularly?

Throughout the course the students have the opportunity to meet with the case-owner and other stakeholders to ask questions relating to the case.

The learning activities consist of both activating learning elements such as design thinking, ideation - and self-regulated learning in form of group work, self-study and reflection on the student’s own learning process. Furthermore, the students are encouraged to venture outside campus to meet the users, customers and stakeholders with relevance for the project.

In the first week of the course various definitions of entrepreneurship and innovation are introduced and the students are introduced to design thinking and effectuation. Theory is tested in practice by exercises. An individual portfolio is written based on the use of the methods and tools (individual report).
The groups develop a business opportunity and write a business plan and in the

process use entrepreneurial methods. The students should contact potential users/customers for ideating, having their feedback and use the feedback for further development of their concept/solution.
The groups present their result at a poster presentation during the the last week of the course. Subsequently, each group prepares a final report (group report) and submit it on the last day of the course – while each student also individually update and submit a revised portfolio of methods and tools, also reflection on the feedback they have received during the course.
During the course, the students work with peer feedback, thereby training them to give and receive feedback. More information about the course *'Entrepreneurship in Greenland'* and the learning objectives can be found in the course description at https://kurser.dtu.dk/course/62054

As is normally the case in CBL, the teachers increasingly act as facilitators in order to provide scaffolding and support the students while they work on the challenges. The teachers are available every day during the course. The first week of the course is more teacher directed with joint teaching sessions, while the last two weeks primarily consist of group work; with both planned group feedback sessions on specific topics (e.g. business model canvas for the case solution) - and both individual and group sparring sessions with the teachers when needed.

The course is a three-week course taking place at DTU's campus in Sisimiut, Greenland. The students primarily come from the two Bachelor of Engineering programs in Fisheries Technology and Arctic Civil Engineering - and for these students the course is mandatory and placed between their 2^{nd} and 3^{rd} semester. Furthermore, the course is open for other students to take as an elective course, and in 2023 five students from the Bachelor of Engineering program in Global Business Engineering participated (travelling to Greenland for the course). A total of 16 students were enrolled in the course in August 2023. And four groups were formed to include students from the different disciplines.

The course is an intensive 5 ECTS course where the students work every day for three weeks. The outcome after the course is a concept for how to solve the challenge – while using the methods learned during the course. It is not expected that the students in the relatively short period of time the course runs, produce prototypes or set their solution into actual production.

The course has been running since 2020 and each year we have used (new) real-life open-ended cases provided by local companies and start-ups. This time we asked the students about the cases, and what is important for them when working with cases in their courses.

2 METHODOLOGY

2.1 Background

The data was collected during the course held in August 2023.

The cases were all from Sisimiut/Greenland and included cases from start-up's and from more established companies. All cases focused on actual challenges observed by the case owner. The cases were chosen to be relevant for engineers and to have a technical aspect and a socio/sustainable focus.

In 2023 the student groups could choose between three different cases: One on using rest products for food for Greenlandic sled dogs; one on a design of a local knowledge walking-trail in Sisimiut for tourists; and one on the use of local rock and stone in production/construction. Two groups chose the sled dog-case, and one group each chose the remaining two cases.

2.2 Survey

A survey was conducted during the course. The survey consisted of 5 questions related to the use of real-life cases. There were 16 students enrolled in the course and of those 11 students handed in the survey.

Q1: Do you think it is relevant to work with cases in teaching? Please explain why/why not?

Q2: What do you think is important when working with a case in class?

Q3: What is important in relation to the case-maker/company?

Q4: What should a good case description contain (feel free to write keywords) of information?

Q5: Good advice for using cases in teaching.

The survey was handed out to the students in class, and they had time to fill it out and hand it in during class.

3 Results

Overall, the students enjoyed working with real-life cases, which they found motivating and as a good frame for the course. They did however stress the importance of having a good contact with the case-owner. The students also mentioned that the case should be relevant and realistic. Furthermore, the students highlighted the importance of having access to data and to stakeholders.

The feedback from the students fell in three categories:

- The cases provided a good and motivational frame for learning
- The importance of contact with the case-owner
- The importance of a well selected, well-framed, relevant and open case

The case as motivational frame for learning

Most respondents found the case to be a very relevant, motivational frame for the course and theory – and stated that it supported both learning and transfer of new knowledge. They stated that the case made it easier to relate theory to the real world, and that the real-life challenges made the theory much more relatable.

Statements (translated from Danish):

- “I think it is very relevant working with real life cases gives a better understanding of the goals and methods we read about. Also it makes it easier to remember the methods when I can connect it to an example”
- “It helps to connect the theory we learn in the classroom with the world outside”
- “it gives a deeper understanding”
- “it is easier to think of when it is a real-life problem”
- “It provides a good frame”

The importance of contact with the case-owner

The respondents generally stated that it is important that the case-owners have time to talk with the students about the case; that they are available – and willing to be “disturbed” by the students. Also important that they (and their case) have a relevant technical and educational background.

Statements (translated from Danish):

- ”They must be contactable and not too ‘big’”
- “[Important] that they have time for some questions / time to meet”
- “important that the case-owner knows or has an education within the case-industry”
- “Availability [is important]”
- “It is important that they are willing to cooperate and be disturbed by the students”

The importance of a well-selected, well-framed, relevant and open case:

The respondents emphasized throughout the questions the importance of a well-selected case, and they stated that the cases must be both relevant, open-ended – and well-framed. And at the right level and relatable for the students with regards to both their own background - and the topic of the specific course.

Statements (translated from Danish):

- ”The case must seem approachable”
- “it is important that the cases you can choose are realistic”
- “Also [important] that the case is relevant for where you are”
- “important that the case is well investigated by those who pose it”
- “must contain a topic that can be viewed from different perspectives”
- “[the case must be] inspiring (idea generating) … open question”
- “[the challenge must be] open but not too open and a frame that is not too narrow”
- “[the case must be] relatable”

Overall observations and reflections

We have been working with (different) real-life cases in this course every year since its launch in 2020. In 2023, we found that the set-up was working particularly well – and that it supported the group work process and the scaffolding and application of both new and existing tools and knowledge in the mixed student groups. One important difference this year was, that the case owners were much more available throughout the course, and it seemed to be easier for the students to form a working relationship with their case owners. This was further emphasized by the fact that all case owners participated in the final poster presentation session; also asking further questions to the groups regarding their solutions and thoughts, which has not been the case to that extend in earlier courses.

All in all, this has confirmed what both we – and the CBL-model stresses: that it is important to work with real-life – and open-ended challenges; and that it enforces both the motivation and co-creation in the teams – especially when they are able to have a continuous dialogue with the case owners. This also further supported the development of a team-identity in the groups, emphasising the use of the group's interdisciplinary skills and knowledge.

When working with open-ended real-life cases in challenge-based learning we recommend the following reflections when designing the course and choosing cases – especially in an introductory course like ours:

1) The use of real-life – and open ended – case-challenges is central
2) The cases must be framed to fit the learning objectives for the specific course, i.e. in this course, the cases must function as a supporting learning tool for the entrepreneurial content of the course
   - and not primarily be a 'wish-list' from the case-owner.
3) It is important that the case-owners are available during the course and willing to meet with the students and discuss the case and possible solutions
   - this stipulates that importance of the case-owner keeping an open mind with regards to possible solutions (rather than having a fixed solution in mind).
4) Based on the case-owners we have worked with over the years, we find that it may be more important that the (albeit still a real-life) case is framed to fit the course – rather than an actual company's specific demands and wishes. This also stipulates the importance of the case-owner understanding the learning objectives and/or setting of the specific course in order to engage in dialogue with the students – and having an open mind with regards to possible solutions. Especially in an introductory course like the one described.
5) In more advanced courses it may be more relevant to have more non-prepared case-owners (with regards to the specific course), as the dialogue with them will be a larger part of finding innovative solutions for the benefit of both the specific company – and globally.

It is overall our impression that the success of this year's cases as frames for the course to a large extend was based on the case-owners' understanding of the purpose and frame of the course (and thus their cases' role as tools for student learning) – and their willingness to enter into an open dialogue with the students, rather than having a preset mind with regards to a concrete and specific solution.

This paper thus introduces a novel and innovative approach to the development of challenges and cases for CBL where the case-owner not only develop the case but also is closely involved in the students' learning process throughout the course.

4 SUMMARY AND ACKNOWLEDGEMENTS

In this paper we present how we work with challenge-based learning in a course with the purpose of introducing entrepreneurship to the students. This time we asked the students what is important for them when working with cases in their courses. And based on their responses – and our own observations, we offer suggestions regarding the kind of cases and the frame around them in a challenge-based learning setting.

REFERENCES

Bombaerts, G., Doulougeri, K., Tsui, S., Laes, E., Sphan, A., and Martin, D.A. (2021) Enginering students as co-creators in an ethics of technology course. *Science and Engineering Ethics* (27(4), 26-48

Gallagher, S. E. and Savage, T. (2020). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education* 28(6), 1135-1157

Hadgraft, R. G. and Kolmos, A., (2020) Emerging learning environments in engineering education, *Australasian Journal of Engineering Education*, 25:1, 3-16 DOi

Helker, K., Bruns, M., Reymann, I. MMJ., and Vermunt J.D. (2024) A framework for capturing student learning in challenge-based learning. *Active Learning in Higher Education* 1-17

Doulougeri, K., Vermunt, J. D., Bombaerts, G. and Bots.,M (2024). Challenged-based learning implementation in engineering education: A Systematic literature review. *Journal of Engineering Education* XXX, Advance online publication

Malmqvist, J., Rådberg, K. K., and Lundqvist, U., (2015). Comparative analysis of challenge-based learning experiences. Proceedings of the 11th International CDIO conference, Chengdu University of Information Technology, Chengdu, Sichuan., P. R., China, June 8-11, 2015

PILOTING A SOCIOTECHNICAL MODULE ABOUT ELECTRIC VEHICLE BATTERIES IN A SMALL CIRCUITS COURSE

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ABSTRACT

Motivation to include sociotechnical content in engineering courses comes from students, the workplace, and accreditation bodies. However, incorporating explorations of engineering's social impacts is challenging for most engineering professors who have been educated with a deep technical focus. In this work, we offer one option for addressing social implications in a required course for many engineering students (i.e., Introduction to Circuits). We developed a one-hour class module focused on electric vehicle (EV) batteries and circular economies that can be integrated into the basic Circuits course. The module includes pre-class, in-class, and post-class materials contained in a comprehensive teaching guide. We piloted the module with a few students and then deployed it in a small undergraduate-focused institution. In this paper, we outline the module development process, which leverages the principles of backward design, and present examples of the module materials. Students did well on the related homework problems and were enthusiastic about the discussions, calculations, and focus on the circular economy. Interviews revealed that students valued the connection of technical and social aspects and enhanced their interest in electrical engineering. We hope that this module will help engineering instructors interested in teaching about social implications in their own Circuits courses.

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1 INTRODUCTION

Motivation to include sociotechnical content in engineering courses comes from students, the workplace, and accreditation bodies. Many undergraduate students enter engineering wanting to help people through their profession (Bairaktarova and Pilotte, 2020; National Academy of Engineering, 2008). They want to see how their engineering knowledge can make a difference in people's lives. Real problems provide this opportunity - they are multidimensional and interdisciplinary, and they encompass complex sociotechnical issues (Baillie, Pawley, and Riley, 2012; Leydens and Lucena, 2017; Riley, 2020).

To prepare graduates for the workforce, instructors must help students learn about technical and social dimensions of engineering. Engineering accreditation criteria (e.g., ABET, n.d.; the European Network for Accreditation of Engineering Education, n.d.) emphasize the importance of such sociotechnical knowledge by expecting engineering undergraduate programs to address ethical, global, cultural, social, environmental, and economic considerations in student outcomes.

However, many engineering instructors, educated with in-depth technical knowledge, are not sure how to incorporate explorations of technology's social impacts. Instructors may also feel that they do not have time to develop instructional material that connects the social and the technical. As a result, many students learn core engineering concepts with a focus on calculations and modelling but no critical evaluation of their major's impact on sociotechnical areas such as public welfare, ethics, climate change, and policy (Bielefeldt, 2018; Børsen et al., 2021; Jesiek et al., 2019; Williams and Trevelyan, 2013).

In our current research project, we offer one approach for addressing social implications in a required foundational course for engineering students. We aim to help engineering instructors to provide sociotechnical content for their students by making it as easy as possible. We are developing short, one-hour modules for use in the Introduction to Electric Circuits course that connect social and technical considerations. The Circuits course is typically the first course for students studying electrical engineering (EE) and is a common course for students in other disciplines of engineering. Thus, this course reaches many students. It is a course that students often find very abstract and struggle to find the relevance of (Bell and Horowitz, 2018). Our modules are designed to be used in this foundational course where we hope they will help students see the relevance of the technical content and instructors be empowered to conduct discussions of the sociotechnical nature of the course content (Lord, Przestrzelski, and Reddy, 2019; Finelli and Lord, 2023; Lord and Finelli 2023).

In this paper, we report on the development and implementation of a one class period (about one hour) module focused on electric vehicle (EV) batteries and circular economies that includes pre-class, in-class, and post-class materials contained in a comprehensive teaching guide. In May 2023, we piloted the module with a small group of students and then deployed this module in a small undergraduate-focused institution with twenty students. After the session, we conducted interviews with two student participants. In this paper, we present examples of the module materials and student feedback. We hope that this module will help engineering instructors interested in integrating social implications in their own Circuits courses.

2 DEVELOPMENT OF MODULE

The goal of this module, “Electric Vehicle Batteries and the Circular Economy” is to introduce students to issues related to recycling the rapidly growing number of electric vehicles (EVs) reaching end-of-life. This topic serves as a case study for applying principles of a circular economy. For the instructor, we supply the learning objectives; assignments for before, during, and after class; the in-class slides; and an accompanying instructor’s guide to the slides. Instructors may choose any combination of problems and/or slides and can choose when in the semester to insert the content.

The module was developed by a graduate student in EE along with two EE professors with decades of experience teaching the Introduction to Circuits course (preliminarily described previously Judge, Lord, and Finelli, 2022). We used the principles of backward design (Wiggins and McTighe, 2005) and constructive alignment (Biggs, 1996) to connect learning objectives with activities and assessments. We also followed guidelines developed by Gelles and Lord (2021) for integrating sociotechnical content into engineering courses.

1. Identify a salient course topic that has broader social and environmental implications.
2. Identify, add, or update existing course learning objectives and/or ABET student outcome that this sociotechnical course topic aligns with.
3. Create learning objectives for specific sociotechnical modules.
4. Create modules by designing activities for homework before and/or after class session(s) as well as class session(s) that integrate technical content and calculations students are familiar with and social and environmental context.
5. Include low stakes assessment for module (e.g., homework) and consider including sociotechnical questions on exams.
6. Conduct formative assessment and/or engineering education research on sociotechnical modules to get student input and improve module offerings in the future.
7. Refine modules and identify possible sociotechnical collaborators for the next course offering.

To accomplish Step 1, we began by relating the concept of voltage dividers to repurposing of electric vehicle (EV) batteries. The manufacturing and use of EVs has increased dramatically recently (Breiter et al., 2022; IEA, 2022). Many students are familiar with EVs; thus this topic is relevant to current undergraduate students’ lives and connects to EE. Once EV batteries have degraded to about 70% of their initial charge storage capability, they are no longer useful for EVs since they could leave a driver stranded. Recycling has many challenges (Kul, 2022; Morse, 2021). However, they may be very useful for other applications. (Ali, Khan and Pecht, 2021; Haram et al, 2021; Song et al., 2022). Thus, the repurposing of EV batteries is an excellent topic for introducing students to the circular economy. The circular economy is “a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting" (Ellen MacArthur Foundation, n.d.). In addition, because repurposing EV batteries likely involves changing a DC voltage, the topic can be connected to voltage dividers, a concept addressed in most circuits courses that can be used for both analysis and design. Voltage dividers are typically covered early in the Circuits course, and the EV module could be done any time after voltage dividers have been introduced. We acknowledge that voltage dividers are not the best way to provide a desired output from an EV battery and mention this to the students. However, we felt that it was important for them to see an application of something in the class that could be connected to a larger topic.

For Step 2, we identified a series of course learning objectives related to the EV module. The learning objectives include:

- Be able to write, derive, and apply the voltage-divider relationship for circuits containing two or more resistors.
- State when it is appropriate to use the voltage divider equation.
- Explain what a voltage divider is and why it is useful.
- Analyze batteries as DC electrical devices

Next, for Step 3, we identified specific learning objectives for the sociotechnical module. These module learning objectives include:

- Design a voltage divider for a DC source to illustrate repurposing EV battery packs
- Estimate energy available in end-of-life EV batteries and explain how they could be used for other purposes
- Describe societal risks introduced by recycling EV batteries that could be alleviated by applying circular economy principles

Steps 4 and 5 involved developing materials which will be summarized in the next section. This paper is part of Step 6 and we are in the process of Step 7 as we refine the module.

3 SAMPLE MATERIALS

3.1 Pre-class Problems

Before the class session with the integrated module, instructors could ask students to complete some pre-class activities. One possible pre-class activity is that students could listen to one or more podcasts that introduce concepts related to EV Batteries and the Circular Economy (e.g., Loveless and Sanderson, 2022; Whalen, 2020) and answer multiple choice questions. Another possible activity is a numerical calculation (Fig. 1, note that estimates of numbers of EVs may need to be updated as this is a rapidly changing field) which sets the stage for the need for EV battery repurposing. Instructors also have the option of not assigning pre-class activities and doing the initial calculations as an in-class activity.

End-of-life battery capacity and the circular economy: In the year 2021, there were about 16.5 million electric cars on the road, and the numbers continue to increase. Annual sales of electric cars are predicted to reach approximately 30 million in the year 2030. Assume that each EV battery pack has an initial 500-volt charge at time of sale and that approximately 70% of EV battery packs from 2021 will reach their end of life by the year 2030 (still having 75% of their initial capacity). Then, answer the following questions:

a. When the EVs from 2021 reach their end of life, how many total volts will remain on the battery packs?
b. What percentage of future battery demand (in Volts) could be supplied using repurposed batteries from 2021?
c. What does this imply about the feasibility of using repurposed EV batteries?

Note: The initial charge on EV batteries currently ranges from 300 – 900V, which connects to either a 400 or 800 V system. There is an industry movement to standardize the 800V system level design for faster charging.

Fig 1. Sample pre-class assignment

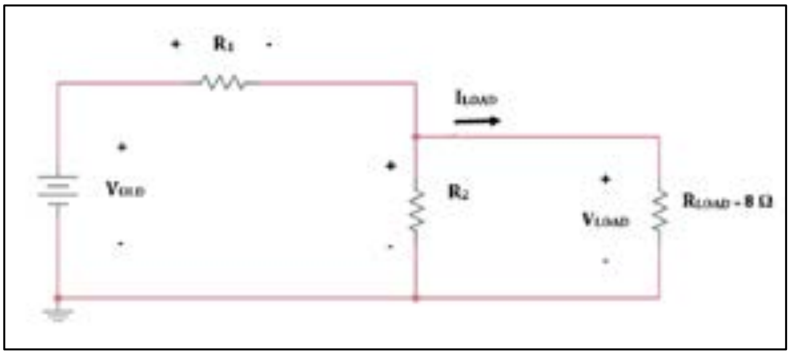
3.2 In-class Presentation

To support instructors using the EV module, we developed a slide presentation and accompanying script with suggested timings. The presentation includes descriptions of EVs and EV batteries, an overview of the circular economy, prompts for student discussions, and example voltage divider problems in the context of EV battery repurposing.

The instructor presentation begins by describing that, when they reach their end of life, the growing number of EV batteries are no longer suitable for use in EVs. The numerical example (done either as a pre-class activity or inserted in class at this point) illustrates that recycling can only meet about 30% of the demand for future EV batteries and that this complex problem requires engineers. The instructor then outlines assumptions that were part of the calculations and introduces benefits and challenges of recycling EV batteries, leading to a discussion of the circular economy and its implications for engineering design. Next, students are encouraged to think of applications of the circular economy for EE and then to focus on EV batteries. The instructor illustrates that an EV battery with an initial range of 150 miles has a reduced range of only 105 miles, potentially insufficient for the owner, when its capacity if diminished to 70%. Then, as a fun way to see this idea in action students check the health of their phone batteries.

Next, the instructor describes what the circular economy might look like throughout the life cycle of the battery. The instructor highlights some industry areas where repurposed EV batteries could be used, including microgrids, and then presents students with the challenge of powering a microgrid that requires a specific voltage (e.g., 350 Volts) with an EV battery having 493 Volts. Students are guided to use the voltage divider, and they design a circuit to provide the appropriate scaling. The instructor confirms their answers and discuss how the voltage divider is not the ideal circuit for this giving them a glimpse of more complex circuits. The instructor then transitions into preparing for the homework and summarizing main takeaways from the module.

1. (a) Provide an example of a challenge or solution for each of the following sociotechnical factors in the manufacturing and repurposing of EV batteries: Technical, Environmental, Health and safety, Economic. (b) Please provide a few sentence description of **one** of these.
2. In your own words, describe the purpose and benefits of a circular economy.
3. A repurposed battery (represented by V_{OLD} in the schematic diagram below) is used to power a mobile home. The load requires 240 V and 30 A to charge, and the load resistance (represented as R_{LOAD}) is included to draw current from the battery – this is a common rating in microgrid applications. In this problem, R_{LOAD} is 8 Ω and R_2 is 100kΩ.
   a. Assuming that the repurposed battery is a 600 V pack at 76% capacity, enter the following values in the table below.
      i. The effective voltage of the entire second-life battery pack, V_{OLD}. (You may assume that all the current can be supplied by the battery
      ii. The value of R1 required to set the output voltage and current to 240 V & 30 A.
      iii. The total power supplied by the repurposed EV battery to the load.
   b. Repeat the calculations for (i) – (iii) if the battery degrades over 2 years to 65%.
   c. Describe what concerns you might have about your results.



Battery Capacity	V_{OLD}(V)_	R_1 (Ω)	Power Supplied to Load (W)
76%			
65%			

Fig. 2 Example problems for after the module

3.3 Post-class Problems

We provide several options for post-class activities (Fig. 2, note that these problems could be used for homework and/or exams). We also provide a list of related references on EV manufacturing and the circular economy.

4 STUDENT RESPONSES

In May 2023, the graduate student who developed the EV module presented it in an "integrated approach to EE" course taught by a member of the research team. The course is for second year students and is a broad introduction to EE, including many circuits topics. The day before the module was presented in class, we piloted it with a small group of volunteer students who had taken the course the previous year. Overall, the volunteers found the module interesting and informative, and their feedback was incorporated into the module before it was presented to a class of 20 students on the following day.

4.1 Pre-class Problems

For the Spring 2023 offering, we did not do the pre-class problems. Rather, we incorporated the activity (Fig. 1) into the beginning of the class period. Students successfully completed the calculations for the activity during class.

As an extra credit assignment, students in the class were asked to listen to the two podcasts and explain which one they thought would be more beneficial as a future pre-class assignment. Of the 20 students, ten did not complete the extra credit assignment, six students preferred the longer podcast, which was about 40 minutes, (Loveless and Sanderson, 2022) for its comprehensive technical details, three preferred the shorter podcast, which was about 18 min, (Whalen, 2020) for its clear organization and relatable host, and one did not make a recommendation. Instructors can decide which, if either, is more appropriate for their class.

4.2 In-class Feedback

The student volunteers who participated in the first offering in Spring 2023 were very enthusiastic about the module and the topic. In fact, one of the students was so inspired that she proposed the topic of repurposing EV batteries for her engineering senior design course for Fall 2023-Spring 2024 and is currently working on this with an interdisciplinary team and considering starting her own business.

Students who participated in the class module recorded their impressions about it at the end of the session by listing one thing they liked about the module and one suggestion for improvement. Students liked the discussions, the calculations, consideration of the circular economy as a current issue, and thought the presenter did a good job. For example,

> *"Enjoyed calculations and real applications so we could see it wasn't as theoretical."*

> *"The discussions and activities went really well."*

Students also provided several suggestions for improving the module including considering the pacing as "s*ome points went too fast, but others took too long.*" Several students suggested topics to add such as more detail on manufacturing process for batteries, overview of how EV batteries work, where parts go, different types of batteries, and changes to infrastructure needed.

4.3 Homework Problems

Students completed the three assigned homework problems in cooperative learning groups of four (Lord, 2001) as part of the final assignment of the semester, and overall they did well on the problems. Of the five groups, three got full credit for

Problem 1, the fourth group earned 1.75/2 (88%) for not substantiating statements about costs, and the fifth group earned 2.25/2 for an outstanding job. For Problem 2, four groups earned full credit and one earned 0.75/1 for a grammatical error and not providing a citation for “biodiversity loss” as an integral part of the circular economy. For Problem 3, three groups received full credit, one earned 2.5/3 (83%) and one got 2.25/3 (75%). Common student errors included insufficiently explaining why numbers were chosen, using wrong numbers, and calculating power supplied by the battery rather than to the load. Students were encouraged to use Multisim simulation to check their work.

4.4 Interviews

Students responded enthusiastically to the implementation of EV module. Two students from the class, both of whom were female Integrated Engineering majors, participated in semi-structured interviews after the module. One was pursuing a concentration in biomedical engineering and the other in sustainability. Both students described the module as interesting, relevant, and helpful.

> *“I think if more people knew about [topics like this EV module] and it was brought to the attention of more people, especially like our generation of engineers, it would be really helpful towards the future.”*

> *“… [the EV module] definitely made me consider going into something that does more with like sustainability and stuff like that.”*

One student expressed an honest opinion about not being excited about EE at the beginning of the semester, stating that this module helped improve that outlook.

> *“... I came in hating electrical engineering, like it was just not for me. So I think like actually doing the voltage divider and using that for like sustainability purposes and the circular economy was really cool to like actually be like, okay, the stuff we're learning is like being used for something …. I liked that part of it.”*

One student emphasized the importance of this topic to them personally.

> *“… we are a part of the issue if we don't decide to fix it.”*

5.SUMMARY AND FUTURE WORK

We successfully designed and implemented a sociotechnical module about EV batteries and the circular economy in a small undergraduate engineering course. The module ties the technical topic of voltage dividers, typically included in an Introduction to Circuits course, to the circular economy using the idea of repurposing EV batteries. Students responded enthusiastically and liked seeing the connection between the social and technical concepts.

Next, we aim to scale up our implementation by integrating the module into a significantly taught by a member of the research team a different institution. We will also conduct surveys, interviews, and focus groups to gauge student feedback on the module and evaluate students’ homework solutions to assess their technical proficiency. Then we intend to collaborate with engineering educators to introduce this module into circuits courses at universities beyond our research team’s institutions.

We are currently partnering with eight graduate students from across the USA to develop more sociotechnical modules for the Introduction to Circuits class. Once these are successfully implemented in our own small and large courses, we will share them with other educators, thus impacting students at many universities.

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REFERENCES

ABET, "2023-2024 Criteria for Accrediting Engineering Programs." [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/ Accessed: 10 June 2024

Ali, H., H. A., Khan, and M. G. Pecht. "Circular economy of Li Batteries: Technologies and trends." *Journal of Energy Storage*, 40, (2021): 102690. https://doi.org/10.1016/j.est.2021.102690

Baillie, C., A. L. Pawley, and D. Riley, Eds., *Engineering and Social Justice*. Purdue University Press, 2012.

Bairaktarova, D, N., and M, K. Pilotte. "Person or thing oriented: A comparative study of individual differences of first-year engineering students and practitioners." *Journal of Engineering Education*, 109, 2 (2020): 230-242. https://doi.org/10.1002/jee.20309

Bielefeldt, A. R. "Professional Social Responsibility in Engineering." in *Social Responsibility*, I. Muenstermann, Ed.*, InTechOpen*, (2018): pp. 1–21. doi: 10.5772/intechopen.71709

Biggs, J. "Enhancing Teaching Through Constructive Alignment." *High. Educ.*, 32, 3, (Oct. 1996): 347-364.

Bell, S., and M. Horowitz. "Rethinking Non-major Circuits Pedagogy for Improved Motivation." Paper Presented at *2018 ASEE Annual Conference & Exposition*, Salt Lake City, Utah, June 2018. doi: 10.18260/1-2--30936

Børsen, T. et al. "Initiatives, Experiences and Best Practices for Teaching Social and Ecological Responsibility in Ethics Education for Science and Engineering Students." *Eur. J. Eng. Educ.*, 46, 2, (2021): 186–209.

Breiter, A., E. Horetsky, M. Linder, and R. Rettig. *Power spike: How battery makers can respond to surging demand from EVs*. McKinsey & Company, 2022. [Online]. Available: https://www.mckinsey.com/capabilities/operations/our-insights/power-spike-how-battery-makers-can-respond-to-surging-demand-from-evs#/ Accessed 10 June 2024

Ellen MacArthur Foundation. (n.d.). "What is a circular economy? Circular Economy Introduction." [Online]. Available:

.https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview Accessed 10 June 2024

European Network for Accreditation of Engineering Education. “Standards and Guidelines for Accreditation of Engineering Programmes.” [Online]. Available: https://www.enaee.eu/eur-ace-system/standards-and-guidelines/#standards-and-guidelines-for-accreditation-of-engineering-programmes Accessed: 10-Jun-2024

Finelli, C. J., and S. M. Lord, “Integrating Sociotechnical Issues in the Introduction to Circuits Course,” Paper presented at the *2023 European Society for Engineering Education (SEFI) Conference*, Dublin, Ireland, September 2023. https://doi.org/10.21427/2C7Z-7398

Gelles, L. A. and S. M. Lord. “Pedagogical Considerations and Challenges for Sociotechnical Integration within a Materials Science Class.” *International Journal of Engineering Education*, 37, 5, (2021): 1244 - 1260.

Haram, M. H., S. M., J. W. Lee, G. Ramasamy, E. E. Ngu, S. P. Thiagarajah, and Y. H. Lee. “Feasibility of utilising second life EV batteries: Applications, lifespan, economics, environmental impact, assessment, and challenges.” *Alexandria Engineering Journal*, 60, 5, (2021): 4517–4536. https://doi.org/10.1016/j.aej.2021.03.021

IEA, Global EV Outlook 2022, IEA, Paris, 2022. [Online] Available at https://www.iea.org/reports/global-ev-outlook-2022 Accessed 10 June 2024.

Jesiek, B. K., N. T. Buswell, A. Mazzurco, and T. Zephirin. “Toward a Typology of the Sociotechnical in Engineering Practice,” in *Research in Engineering Education Symposium*, (2019): 597–606.

Judge, M. G., S. M. Lord, and C. J. Finelli. “Development of a Sociotechnical Module Exploring Electric Vehicle Batteries for a Circuits Course,” Paper presented at the *2022 ASEE Annual Conference*, Minneapolis, Minnesota, June 2022. doi: 10.18260/1-2—40831

Kul, A. “Electric Vehicle Batteries Recycling: What are the Challenges and Solutions?” *Waste Advantage Magazine, 2022*. https://wasteadvantagemag.com/electric-vehicle-batteries-recycling-what-are-the-challenges-and-solutions/#:~:text=Because%20of%20the%20cost%20and,create%20an%20efficient%20recycling%20system. Accessed 10 June 2024

Leydens, J. A., and J. C. Lucena. *Engineering Justice: Transforming Engineering Education and Practice*. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2017.

Lord, S. M. “Student Response to Cooperative Learning Homework Teams: Midcourse and Final Evaluations,” Paper presented at *2001 Frontiers in Education Conference*, Reno, Nevada, October 2001. 10.1109/FIE.2001.963908

Lord, S. M., B. Przestrzelski, and E. A. Reddy. “Teaching Social Responsibility in a Circuits Course,” Paper presented at *2019 ASEE Annual Conference & Exposition*, Tampa, Florida, June 2019. doi: 10.18260/1-2--33354

Lord, S. M., and C. J. Finelli. “Work-in-progress: Sociotechnical modules for the

Introduction to Circuits Course," Paper presented at *2023 Frontiers in Education (FIE) Conference*, College Station, TX, October 2023. 10.1109/FIE58773.2023.10343488

Loveless, B., and H. Sanderson. "EV battery supply chain: Tensions on the ground," *Columbia Energy Exchange*. [Online]. Available: https://www.energypolicy.columbia.edu/ev-battery-supply-chain-tensions-ground (2022). Accessed 10 June 2024

National Academy of Engineering. *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, The National Academies Press, (2008). https://nap.nationalacademies.org/catalog/12187/changing-the-conversation-messages-for-improving-public-understanding-of-engineering

Morse, I. "A dead battery dilemma." *Science*, 372, 6544, (2021): 780–783. https://doi.org/10.1126/science.372.6544.780

Riley, D. *Engineering and Social Justice*. Morgan and Claypool Publishers, 2020. 978-1598296266

Song, Z., M. S. Nazir, X. Cui, I. A. Hiskens, and H. Hofmann. "Benefit assessment of second-life electric vehicle lithium-ion batteries in distributed power grid applications," (2022): 105939. https://doi.org/10.1016/j.est.2022.105939

Whalen, K. "Is there enough cobalt for electric cars and can circular economy help? In the loop games," (2020). [Online]. Available: https://intheloopgame.com/podcast/010/) Accessed 10 June 2024

Wiggins, G., and J. McTighe. *Understanding by Design*. Expanded 2. Alexandria, VA: Association for Supervision and Curriculum Development, 2005.

Williams, B., and J. Trevelyan. *Engineering Practice in a Global Context*. CRC Press, 2013.

PROPOSING A MENTORSHIP LIFE CYCLE FOR A DEVELOPING COUNTRY'S WOMEN ENGINEERING STUDENTS AND EARLY CAREER WOMEN ENGINEERS

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ABSTRACT

Women are underrepresented in STEM fields internationally and in South Africa, with engineering being the most male-dominated. Statistics show high attrition rates for women in engineering careers and education. Universities have implemented mentorship programmes to enhance learning experiences and increase the retention of female engineering students. Literature suggests mentorship positively contributes to undergraduate experiences, retention, performance, motivation, career outcomes, and health for mentees. This research explores the design and execution of mentorship programmes for female engineering students at national and international universities, considering the unique socio-economic environment in developing countries like South Africa. It also investigates the involvement of business and industry members in mentoring female engineering students and early career engineers. Using a descriptive and interpretative case study design with a mixed-

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method approach, this study identifies complexities surrounding mentorship for women in engineering. Quantitative and qualitative data inform the development of a robust mentorship framework by identifying key components for retaining female engineering students. The study aims to use the proposed framework to develop a mentorship programme for female engineering students and early career engineers. While focused on developing countries, the findings and proposed framework are anticipated to benefit STEM faculties and organisations worldwide in retaining females in STEM-related employment fields.

1 INTRODUCTION AND BACKGROUND

Addressing the underrepresentation of women in STEM fields, particularly in engineering, remains a critical challenge in South Africa and globally. Despite the high demand for qualified engineers, a significant gap persists in the enrollment and retention of female graduates in this sector. In response, the School of Engineering at a South African University, supported by the Manufacturing, Engineering and Related Services Sector (merSETA), established the Women Engineering Leadership Association (WELA) in 2011. WELA's comprehensive programme supports the entire life cycle of women engineers' education and early career, characterised by a structured mentorship and leadership development programme.

WELA's mentorship life cycle unfolds in phases designed to support Women Engineering Students (WES) during their academic journey through to their professional integration. In Phase 1, WES are invited to join WELA, where they are enrolled in a Leadership Development Programme (LDP). In Phase 2, they are assigned a peer mentor to guide their academic and early career development. In Phase 3, WES participants have the opportunity to become mentors themselves, passing on their knowledge and experience to the next generation of WES. Finally, in Phase 4, they transition into supportive roles, such as early career engineers, contributing back to the community and the engineering field at large.

Central to our study is the evaluation and potential expansion of WELA's mentorship initiatives, with a particular focus on leveraging e-mentoring (online mentoring) to overcome geographical barriers and enhance accessibility. This approach underscores the importance of e-mentoring within our proposed mentorship model, aiming to enrich the mentorship experience with global perspectives and digital connectivity.

This study presents an empirical investigation into the effectiveness of the existing WELA mentorship strategies and explores the potential of e-mentoring to augment the programme. By analysing quantitative data from new WELA members and qualitative insights from Early Career Women Engineers (ECWE), alongside a review of international mentorship programmes, we aim to propose a refined mentorship model. This model seeks to address the educational and professional development needs of WES and ECWE within the socio-economic context of a developing country, contributing to narrowing the gender gap in the engineering sector. Our goal is to provide a scalable, adaptable mentorship framework that incorporates both traditional and e-mentoring strategies, ensuring comprehensive support for female engineers at various stages of their career development.

South African Context and Women in Stem Challenges

The context of women in engineering and STEM fields in South Africa is deeply influenced by persistent societal and organisational challenges. As noted by Fajardo and Erasmus (2017), the traditional and stereotypical roles of male and female employees within organisations and society often place women aiming for senior roles in positions as "going against the grain". This sentiment is further compounded by familial contexts in South Africa, which play a significant role in perpetuating gender stereotypical roles, indicating a pressing need for a reimagined approach to conventional roles at home and in the workplace.

Moreover, the longitudinal study by Glass, Sassler, Levitte and Michelmore (2013) underscores a concerning trend that women in STEM-related occupations are more likely to exit their careers than their counterparts in other professions. This attrition rate is echoed by Hewlett and Luce's (2005) findings, who observed that despite the intellectual satisfaction and societal contribution reported by women in Science, Engineering, and Technology (SET) fields, they face considerable obstacles. These obstacles include extreme job pressures, limited career advancement opportunities and, often, a workplace culture that ranges from being unsupportive to outright hostile. Such environments severely hinder women's ability to thrive in the SET industry.

Adding to these challenges, Fouad, Chang, Wan and Singh (2017) highlighted the pervasive "old boys club" culture within organisations. This culture not only affects women's sense of belonging but also influences their job satisfaction levels owing to perceived inequalities in compensation and recognition. Women report having to work significantly harder than their male counterparts for equivalent acknowledgement and advancement, illustrating the systemic barriers that contribute to the high attrition rates of women engineers in South Africa.

The societal and organisational context in South Africa, characterised by entrenched gender norms and an often-unwelcoming industry atmosphere, which plays a crucial role in the career trajectories of women in engineering. This backdrop necessitates targeted interventions, such as the mentorship programmes, to support and retain women in SET fields. By addressing these systemic challenges, the barriers that women face can begin to be dismantled, paving the way for more inclusive and supportive professional environments.

2 CURRENT WELA MENTORSHIP PROGRAMME

The current WELA mentorship process consists of asking senior WELA members (these are students who are in their second year of the WELA LDP but are senior engineering students) to volunteer to be trained as mentors. Training consists of a one-day training programme. Mentees (other WELA members) are allocated to mentors (senior WELA members). They are encouraged to meet regularly, and, in their training, mentors are educated about certain topics, which they will need to discuss with mentees. Mentors are also encouraged to become involved in social and community activities. Since 2020, a former WELA member was contracted as the "lead mentor". The student had also been a mentee and a mentor, whilst being a former engineering student and graduate. Her tasks and duties included managing the mentors, obtaining feedback and guiding mentors in their duties.

The current mentorship programme allows mentors to teach or expose mentees to skills such as budgeting, flexibility, leadership, teamwork and assertiveness

(Lourens, Connelly and Plaatjes, 2019). This is in addition to supporting mentees in their academic activities. Feedback from mentors indicated that through the mentor-mentee relationship, WELA had created a learning community, supporting the notion that each WES is an "architect of her own learning" (Lourens et al, 2019).

Establishing learning communities is important in the current higher education context. This is especially so, as the academic community recovers from the impact of the 2016 #FeesMustFall campaign and, a few years later, the COVID-19 pandemic. As a result of these occurrences, it has become pertinent for the engineering curriculum to entrench a humanised pedagogy as well as digitalisation to meet these WELA goals. According to Salazar (2013:121), a humanising pedagogy is "crucial for both teacher and student success and critical for the academic and social resiliency of students". One effort that universities can make towards a humanised pedagogy is to encourage and actively pursue the establishment of learning communities and a collaborative pedagogy (Tinto, 2003). These are goals which WELA strives to achieve by providing mentorship.

3 Impact of Mentorship: Retention and Benefits

Wu, Thiem and Dasgupta (2022) refer to interventions to train people to cognitively reappraise their experiences, which often influence those who are underrepresented to mentally adapt to their environment. This includes strategies for re-affirmation, a growth mindset and emotional regulations. Wu et al (2022) further state that these strategies have been successful in reducing sex, race and class disparities in academic performance. However, Wu et al (2022) found that often the responsibility was placed on students to change their mindset rather than placing the responsibility on academic institutions to change the learning environment to meet the needs of diverse student populations. Furthermore, students' subjective experiences in academic spaces such as their feelings of belonging, confidence, anxiety and motivation are often not considered when developing interventions and support programmes. This confirms the importance of a mentorship programme to create a sense of belonging, improve feelings of self-efficacy and increase motivation.

In their study, Wu et al (2022) found that:

- Assigning female participants, a male mentor or no mentor significantly decreased their confidence in overall engineering skills and their motivation. However, another study (Nelson, 2023) found that male mentors in the workplace could have a significant impact in terms of coaching, support, allyship and being a champion. In addition, male mentors could build positive relationships with women in the organisation, and this could lead to male mentors improving interpersonal skills and broadening their outlook.
- Being assigned a female peer mentor was consistently associated with a reduced decline in confidence and motivation.
- Being assigned a female peer mentor was associated with an increased rate of participation in engineering internships during college, increased graduation rates and maintenance of higher aspirations to pursue post-graduate degrees.

- Offering female mentorship resulted in greater reported mentee emotional wellness.
- Having male mentorship or no mentee was associated with a decline in emotional well-being throughout college and one-year post college.

In addition, having a *stable confidence* in engineering ability best explained why female peer mentorship promoted success in engineering internships, completion of STEM degrees and pursuit of graduate training in engineering. Based on these abilities, it becomes evident that having both a male mentor, who can act as an ally and champion for change in the work environment, as well as a female industry mentor and a peer mentor can be beneficial to the mentee.

There is vast research and discussion on the benefits of mentoring, personally as well as professionally. There seems to be a clear cycle in the mentoring process and it has been found that 89% of those who are mentored go on further to mentor others, and 84% reported that the mentor and mentee relationship acted as dual inspiration for both parties (Winstanely, 2023). More statistics from the research conducted by Winstanely (2023) revealed that 87% of both mentors and mentees developed greater confidence and felt more empowered, while 84% felt that there was inspiration for both mentors and mentees in a mentoring relationship. However, no extensive research has been conducted on the benefits that a mentor has when mentoring a mentee. However, Lin, Cai and Yin (2021) indicated that learning-orientated members who acted as mentors found psychological meaningfulness in their work, which, in turn, enhanced their work engagement. In addition, retention rates were also higher for mentees and mentors as opposed to those who did not wish to participate in mentoring programmes (Winstanely, 2023). Behesti (2022) suggests that there is a positive link between mentoring programmes and diversity as well as inclusion within an organisation. Similarly, statistics provided by Cornell University School of Industrial and Labour Relations (2020) showed that there was a vast improvement in promotion and retention rates for minorities and women who participated in mentoring initiatives as opposed to those who did not.

In the rapidly evolving landscape of engineering education and professional development, the significance of mentorship, especially for female students and early career engineers in developing countries, is paramount. Faced with challenges such as geographical dispersion and limited access to experienced mentors, innovative mentorship approaches have become essential. E-mentoring, leveraging digital platforms to bridge physical distances, has emerged as a compelling solution to these challenges. The inclusion of e-mentoring in our study underscores our commitment to exploring comprehensive, adaptable mentorship strategies that resonate with the unique socio-economic environments of developing countries. E-mentoring, a critical component of our proposed mentorship programme, offers flexibility and broadens access to a diverse mentorship resource pool, effectively catering to the specific needs of female engineering students and early career engineers. This adaptability and accessibility align with our objective to create an impactful mentorship programme. Empirical evidence supports the efficacy of e-mentoring. For example, Single and Single (2005) highlight that it preserves the benefits of traditional face-to-face mentoring, including fostering honesty between mentors and mentees, thereby enhancing self-esteem, building confidence, and supporting risk-taking. Furthermore, e-mentoring’s global reach not only facilitates knowledge transfer and the exchange of field expertise (Rowland, 2011) but also broadens access to a more diverse pool of mentors (Hamilton and Scandura, 2002). E-mentoring, thus, presents a viable option for overcoming the logistical challenges inherent in mentorship in developing contexts.

Based on previous research, it becomes evident that mentorship is beneficial for the mentor, mentee and society as a whole. This can be especially advantageous in the South African context where deep-seated male and female traditional roles are still prevalent. In Section 5, a summary is provided based on key mentorship programme developments of well-known international universities that the researchers extracted based on the proposed concepts for the redesign of the WELA mentorship programme.

4 INTERNATIONAL PRACTICES

Table 1 provides a summary of selected higher education mentorship programmes and information regarded as important for the development of a mentorship programme for WELA members**.**

Table 1. Summary of international practices

INSTITUTION	DETAILS
Imperial College London UK Resource Centre for Women in Science, Engineering and Technology (2008) (www.ukrc4setwomen.org)	The programme at this university is run by the students and most activities are self-financed. There appears to be a large number of student clubs and societies and, hence, there is a good chance the issues of women will be noticed by students who form part of the student union. This type of student-run organisation is of great interest to the researchers as there is a drive to encourage more student ownership of the WELA mentoring programme.

University College Dublin (UCD) (2014) (UCD, 2014)	For this institution, students were provided with networking opportunities with experienced members of the industry to gain a better understanding of the expectations within a corporate environment. These networking opportunities could be extended into the mentoring process. UCD highlighted that networking opportunities of this nature could be beneficial to potential WES. As a result, the researchers noted that a meet and greet event should be included in the revised mentoring programme. Social media was also mentioned as a very effective marketing tool and UCD's future social media endeavours are similar to those of the proposed revised mentorship programme being investigated. These campaigns will include links to webpages, including biographies of potential role models and mentors. UCD's TV advertisements also made extensive use of women engineers, and, in the South African context, similar advertisements could be marketed across all social media platforms. As in South Africa, UCD noted that there is low visibility of role models for female learners. As a result, social media platforms could be a useful marketing tool to combat the low visibility of WES.
Brunel University London (nd) (brunel.ac.uk/wibec)	Brunel University London seems to have an extensive and successful mentoring programme. Their programme is structured, requiring mentors and mentees to commit to at least two mentoring events along with signing a mentoring contract. WELA currently asks members to complete a commitment form when joining WELA but can explore the possibility of a stand-alone mentorship commitment form. Students also complete the CliftonStrengths test

	(https://www.gallup.com/cliftonstrengths), which has proven to be a very useful tool to build self-awareness, and will be used in the revised WELA mentorship programme. There are ten stages to the mentorship programme at Brunel University, beginning with the completion of online profiles, which is an aspect that the revised WELA mentorship programme will consider. Students are then placed on a waiting list and matching is done considering career interests and studies. Students attend pre-programmed training, which is another consideration for the WELA mentorship programme to create self-ownership. A mentoring manager can be appointed to manage the programme. In the current WELA programme, a mentoring team leader was appointed, and this has been a valuable addition. As with UCD, Brunel hosts a mentor induction as well as a meet and greet, which is a component that the WELA mentoring programme will further explore.
University of Leicester UK Resource Centre for Women in Science, Engineering and Technology. (2008) (www.ukrc4setwomen.org)	This institution runs an online mentoring programme as its members and students are spread across the country. Online mentoring will allow the WELA programme to include a wider range of mentors as location will not be an issue. The University of Leicester's website includes women at various stages of their careers, which is another consideration for the revised WELA programme.

Although Stemazing's (2023) programme is traditionally geared toward learners and not higher education students, there were still concepts that the researchers felt were important to include in the redesign of the WELA mentorship programme. An important extract from this university is that they have highlighted the diversity and inclusion benefits of both young boys and young girls who have female role models. As a result, consideration into opening the WELA mentoring programme to male engineering students will be considered. It also appears to be an important aspect of any programme to provide extensive online training, in particular, for the new WELA mentorship programme. In addition, students often do not understand the reasons for mentoring and the long-term benefits associated with it, which should be made explicit.

Based on an overview of the selected mentorship programmes, it is important that the mentorship is run and managed by students, and it is clear that being a mentor and/or a mentee is a self-directed and self-managed activity. In addition, it is also important that students completely understand what mentorship is, the benefits as well as the long-term benefits thereof and that it is a developmental and networking opportunity. Training for both mentors and mentees appears to be a vital component of a successful mentoring programme. An important component would also be an assessment such as the CliftonStrengths test as used by Brunel University London (nd) not only to be used as a self-development instrument but also to serve as a tool to match mentors and mentees. From a technology point of view, mentorship can be offered online, and a mentorship platform can be designed where prospective mentors and mentees can meet and interact.

Social media is very important in marketing engineering as a desirable career, in addition to marketing the institution and the services it provides to students by offering a mentorship programme to WES. In addition, it would also be important that social media marketing is geared to primary and high school learners. Mentors can include both men and women in various stages of their careers working in industry, in addition to WELA peer mentors. This research has led to the development of a proposed framework, which is discussed in Section 6.

5 PROPOSED FRAMEWORK

The proposed framework in Figure 1 is explained below. Prior to the mentorship website's launch, a robust social media marketing campaign is planned to highlight the mentorship programme's benefits and the advantages of attending a university with a successful mentoring culture. The overarching aims of a successful mentorship programme, capturing the full life cycle of mentoring across all career stages of WES, are visually summarised in Figure 1 below.

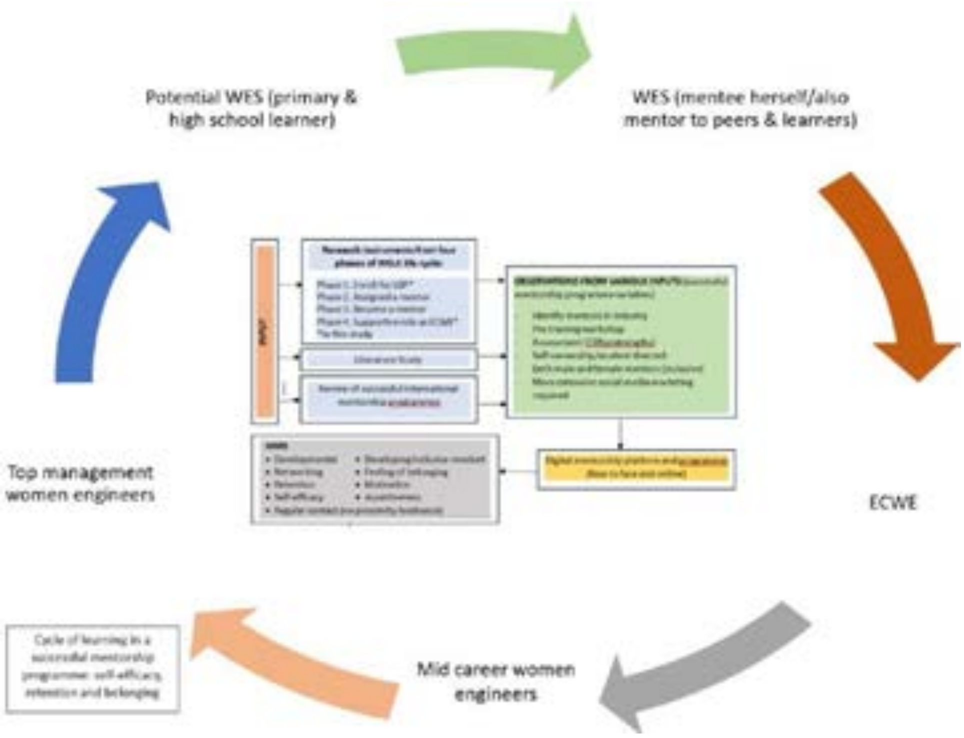

Fig. 1. Proposed framework

The proposed framework outlines the inputs reviewed for the redesign of the WELA mentoring programme, detailing the phases of the WELA LDP mentorship programme and the aims or goals necessary for successful execution. It also introduces a proposed cycle of learning that spans potential students, women engineering students, ECWE, mid-career women engineers, and top management. Central to the framework's effectiveness is ensuring a comprehensive understanding of the mentorship programme's benefits among WES and fostering their ownership of the process. An extensive training workshop is anticipated to bridge any gaps in understanding, thereby promoting self-ownership and active participation.

In developing the proposed mentorship framework, it is crucial to recognise that while certain practices have shown widespread success, the concept of *best practice* in mentorship must be viewed through a lens of adaptability and contextual sensitivity.

6 ACKNOWLEDGING

the diversity of socio-economic and cultural environments in which women engineers operate, our framework rather advocates for a *best fit* approach. This methodology emphasises the customisation of mentorship practices to meet the specific needs and conditions of different countries and communities, thus, ensuring greater effectiveness and inclusivity. The adoption of a paradox approach may also be beneficial, where acknowledging and leveraging the inherent complexities and contradictions within diverse contexts can lead to innovative solutions. Therefore, the framework is designed to be dynamic and flexible, allowing for the integration of successful elements of mentorship while adapting to local nuances, thereby more accurately reflecting the multifaceted nature of global engineering fields (see Figure 1).

Section 7 explains the methodology followed that aimed to confirm the findings of the literature review depicted in Figure 1.

7 METHODOLOGY

This research followed a descriptive and interpretative case study design to describe interventions and the real-life context in which they occurred (Maree, 2016). A mixed-method of quantitative and qualitative data was used to describe and understand WES's reasons for joining WELA, their fears and expectations, and their experiences of being a mentee and a mentor in addition to being an early career female engineer. The findings from the mixed-method study will inform the development of a mentorship framework for WES and ECWE. Table 2 summarises the instruments used in each phase of the WELA member life cycle, the number of respondents, the aim of the research instrument and the type of data collected. Finally, Table 2 illustrates the value of the data obtained as input for the revised mentorship programme.

Table 2. Data analysis

Phase	WELA LIFE CYCLE	INSTRUMENT	n	AIM OF INSTRUMENT	INPUT FOR MENTORSHIP PROGRAMME
1	First-year commitment form (new members)	Questionnaire	183	● Fears and challenges ● Expectations for joining WELA	● Address fears & challenges

2	Mentee feedback (year-end questionnaire)	Questionnaire	38	● Impact of mentorship	● Implement suggestions ● Address challenges & shortcomings
3	Mentor feedback (application form, training form, portfolio leader feedback form)	Questionnaire	9	● Suggested improvements ● Self-reflection	● Implement suggestions ● Address challenges & shortcomings
4	ECWE feedback (former WELA members, mentees and mentors)	Questionnaire and Interview	5	● Challenges in the work place	● Address challenges & shortcomings

This paper reports on the quantitative data from Phase 1 (new members) as well as the quantitative and qualitative findings from five ECWE (Phase 4) who are former WELA members, student mentees and mentors.

8 PHASE 1 AND PHASE 4 RESULTS AND DISCUSSION

Section 8.1 provides a summary of the findings of the first-year questionnaire where prospective WELA members were asked to list their perceived fears and concerns as women entering the field of engineering. It would be important in a mentorship programme to recognise and address these fears and concerns.

8.1 Phase 1: First-year commitment questionnaire

Over a six-year period (2016-2022), first-year WES and aspiring WELA members have consistently rated “being intimidated”, “made to feel inferior”, “undermined and discriminated against” as their greatest concerns upon entering a traditionally male-dominated field of study and work. These concerns are followed by “not being seen as an equal”, “not being taken seriously” and “not being heard”. One of the goals of the revised mentorship programme will be to provide WELA members with the self-knowledge and tools to create a sense of belonging and improve their feelings of self-efficacy. Having support from a mentor would greatly assist them in overcoming their perceived fears and concerns.

8.2 Phase 4: Experience of being an ECWE

Interviews and a short questionnaire were given to five WELA alumni who had graduated and were employed in various industries for at least five years. The respondents indicated that their experiences as female engineers in the workplace were challenging. One respondent indicated that, at times, she felt as if her suggestions were looked down upon “*just because I am regarded as young and* *female*", while two others stated that they felt as though they constantly had to prove themselves. One respondent indicated that even if she was "*looked down upon and undermined*", she was still expected to be "*assertive and respectful*". Although all the respondents reported experiencing challenges such as "*proving myself capable*" and being "*assertive, heard and respected*" as female engineers, they also mentioned how it had increased their self-reflection. One respondent stated she felt "*inspired [by] the fact that I am smart enough and I am capable to do work that my male colleague can do*". One respondent stated that the challenges "*pushes me to do better every day and I love being a female engineer and changing how it is seen by the world*".

Four of the respondents stated that they had never experienced sexual harassment, yet remarks had often been made about their appearance in the workplace. They further indicated that, at times, they were told they were "*over sensitive*" and felt as though their male colleagues did not fully understand gender equality and how to treat women as equals in the workplace. Four respondents also indicated that the workplace often felt like a "*boys club*" of which they would never be a part.

9 SUMMARY AND ACKNOWLEDGMENTS

The feedback from respondents underscores the significant challenges and experiences women face in traditionally male-dominated engineering environments. Despite these obstacles, the WELA programme played a pivotal role in preparing them for such environments, contributing not only to their professional readiness but also to their personal development and assertiveness in the workplace. Participants highlighted their undeterred motivation and determination to succeed as women engineers and serve as role models, underscoring the programme's importance at both the tertiary education level and within the workplace.

Acknowledging the limitations of our study, particularly the small sample size, we contend that the experiences of our participants reflect broader trends affecting many women in engineering. The need for further development of self-efficacy through additional workshops, like CliftonStrength assessments, and the creation of a supportive community through mentorship were identified as critical areas for programme enhancement. Such initiatives, coupled with training on addressing bias, micro-aggressions, and sexual harassment, are essential for fostering a more inclusive and equitable professional environment.

The proposed enhancements to the WELA mentorship programme, informed by both the initial feedback and subsequent phases of our study, aim to address these identified needs more effectively. Our proposed framework, emphasising both traditional and digital e-mentoring approaches, offers a scalable, adaptable solution to the unique challenges faced by female engineering students and early career professionals. This comprehensive framework is designed to be responsive to the evolving landscape of mentorship in engineering, particularly in the context of developing countries like South Africa.

Specifically, our study contributes novel insights into the mentorship field by empirically demonstrating how structured mentorship, integrated with leadership development initiatives, can profoundly impact the retention and success of women in engineering fields. The inclusion of e-mentoring significantly broadens access to mentorship opportunities, addressing key challenges such as geographical dispersion and the scarcity of female role models in engineering. These findings not only enrich the academic discourse on STEM mentorship but also offer actionable guidance for the design and implementation of more effective mentorship programmes that support women in overcoming the barriers to success in male-dominated industries.

Looking ahead, further research is warranted to examine the long-term impacts of such mentorship programmes on women's career trajectories in STEM fields. Exploring these longitudinal effects will be crucial in validating and potentially expanding the applicability and effectiveness of our proposed mentorship framework, ensuring it can adapt to and meet the needs of women engineers in various contexts and stages of their careers.

REFERENCES

Beheshti, N. (2022). *Improve Workplace Culture with a Strong Mentoring Program*, Forbes.[Online].Available from: https://www.forbes.com/sites/nazbeheshti/2019/01/23/improve-workplace-culture-with-a-strong-mentoring-program/?sh=7818117476b5 (Accessed 11 June 2023).

Brunel University London. (Year). *Mentor and Mentee Handbook*. [Online]. Available from: brunel.ac.uk/wibec (Accessed 1 April 2023).

Cornell University (2020) *Sense of Belonging | Cornell University Diversity and Inclusion*. Available at: https://diversity.cornell.edu/belonging/sense-belonging (Accessed: 28 June 2023).

Fajardo, C. and Erasmus, M. (2017). *Gender Disparity in South Africa*. [Online]. Available from: http://www.bain.com/publications/articles/gender-disparity-in-south-africa.aspx (Accessed 5 April 2022).

Fouad, N.A., Chang, W.H., Wan, M. and Singh, R. (2017). Women's Reasons for Leaving the Engineering Field. *Frontiers in Psychology*, 8:875. [Online]. Available from: https://doi.org/10.3389/fpsyg.2017.00875 (Accessed 5 April 2022).

Glass, J.L., Sassler, S., Levitte, Y.M. and Michelmore, K.M. (2013). What's so Special about STEM? A Comparison of Women's Retention in STEM and Professional Occupations. *Social Forces*, 92(2):723-756. [Online]. Available from: https://doi.org/10.1093/sf/sot092 (Accessed 2 April 2022).

Hamilton B.A. and Scandura T.A. (2003). E-mentoring: Implications for Organizational Learning and Development in a Wired World. *Organizational Dynamics*, 31:388-402.

Hewlett, S.A. and Luce, C.B. (2005). Off-ramps and On-ramps: Keeping Talented Women on the Road to Success. *Harv. Bus. Rev.*, 83:43-46.

Lin, L. and Cai, X. and Yin, J. (2021). Effects of Mentoring on Work Engagement: Work Meaningfulness as a Mediator. *International Journal of Training and Development*, 1-17. 10.1111/ijtd.

Lourens, A.S., Connelly, R.E. and Plaatjies, R.C. (2019). Establishing Learning Communities through Offering Mentoring Support to Female Engineering Students.

Proceedings of 30th South African Institute of Industrial Engineering (SAIIE) Conference. Port Elizabeth, South Africa, 30 Sept-2 October 2019.

Maree, K. (2016). *First Step in Research.* 2nd ed. South Africa, Pretoria: Van Schaik.

Nelson, I. (2023). Putting the Men in Mentoring: Practical Ways Men can be Better Allies. *TechLearningMagazine*. [Online]. Available from: https://www.techlearning.com/news/putting-the-men-in-mentoring-practical-ways- men-can-be-better-allies (Accessed 14 June 2023).Rowland, K.N. (2011). E-mentoring: An Innovative Twist to Traditional Mentoring. *Journal of Technology Management & Innovation, Vol 1, pp,228-237*. [Online]. Availablefrom:https://www.scielo.cl/scielo.php?pid=S0718-27242012000100015&script=sci_arttext&tlng=pt (Accessed 11 June 2023).

Salazar, M.D.C. (2013). A Humanizing Pedagogy Reinventing the Principles and Practice of Education as a Journey toward Liberation. *Review of Research in Education*, 37(1):121-148.

Single, P.B. and Single, R.M. (2005). E-mentoring for Social Equality: Review of Research to Inform Program Development. *Mentoring & Tutoring: Partnership in Learning*, 13(2):301-320.

Stemazing. (2023). *Impact Report 2021-2022*. [Online]. Available from: www.stemazingltd.com. (Accessed 11 June 2023).

Tinto, V. (2003). *Learning Better Together: The Impact of Learning Communities on Student Success.* Higher Education Monograph Series. Higher Education Program, School of Education, Syracuse University.

UK Resource Centre for Women in Science, Engineering and Technology. (2008) SET for Work Scheme handout. [Online]. Available from: www.ukrc4setwomen.org. (Accessed 11 June 2023).

University College Dublin (UCD). (2014). *Engineering Graduates Association Report: Towards Gender Balance in Engineerin*g.

Winstanely, G. (2023). Mentoring Statistics you Need to Know – 2023. *Mentorloop Mentoring Software*. [Online]. Available from: https://mentorloop.com/blog/mentoring-statistics/#:~:text=76%25%20of%20people%20think%20mentors,but%20only%2037

%25%20have%20one.&text=The%20vast%20majority%2C%2097%25%20of,go%20 on%20to%20mentor%20others. (Accessed 9 June 2023).

Wu, D.J., Thiem, K.C. and Dasgupta, N. (2022). Female Peer Mentors Early in College have Lasting Positive Impacts on Female Engineering Students that Persist Beyond Graduation. *Nature Communications*, 13(1):1-12. [Online]. Available from: https://doi.org/10.1038/s41467-022-34508-x (Accessed 11 June 2023).

The Cynefin Framework and Sustainability in Engineering Education

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ABSTRACT

This paper offers a policy analysis of UN document on how to address sustainability in engineering education. It argues that integrating sustainability into engineering education is not only a technical matter of course curricula and teaching methods but also a matter of fostering the awareness and attitudes.

The paper first describe how engineering education has sought to integrate sustainability in terms of curricular and programmatic building-blocks that acknowledge the complexity of most sustainability challenges and the contested nature of the concept of sustainability, which is illustrated through a policy analysis of UNESCO´s two reports on engineering education (UNESCO, 2010, 2021). Second, the chapter presents the Cynefin framework in relation to sustainable development in order to acknowledge complexity and to act accordingly. Finally, the paper exemplifies some practical didactical implications of this approach to sustainability in engineering education through a discussion of three general conceptions of sustainability and the horizons they open and invite change agents to investigate.

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1 INTRODUCTION

Sustainability is one of the most pressing challenges of the 21st century. It is pressing and challenging both because it has important, sometimes fatal consequences for many people and because it involves a broad and complex spectrum of interrelated economic, social and environmental issues, such as poverty alleviation, infrastructure enhancement, water availability, healthcare accessibility, and much more. The UNs Agenda 2023 (UN, 2015) has had a large impact on the global society in providing a vision of 17 sustainable development goals (SDG) that pinpoint the necessity to re-align the functioning of many institutions of society towards a sustainable development. Worldwide, private and public organizations are addressing the 17 SDGs, however the complex and interwoven nature of the SDGs and sustainability in general requires unforeseen creativity and collaboration.

Engineering education is instrumental for fostering the necessary skills for graduates to address sustainability challenges and be change agents for sustainable development. According to the UN´s Educational, Scientific and Cultural Organization (UNESCO, 2009, 2010, 2017, 2021), and the UN´s Principles of Responsible Management Education (UNPRME, 2009, 2016, 2018), higher education in general and engineering education in particular stands as a cornerstone supporting sustainable development and the 17 SDGs, however these organizations also argue that education needs change in order to enable the necessary "*transformation of how we think and act*" (UNESCO, 2017, p. 7). This is also stressed by higher education research that shows that higher education is instrumental but also that traditional course curricula and programs need to change be in order to foster the necessary knowledge, skills and attitudes (e.g. Amaeshi, Muthuri, & Ogbechie, 2019; Barth, 2015; Flynn, Tan, & Gudic´, 2018).

We have witnessed a growing effort to integrate sustainability into engineering education. In a recent bibliometric review of the literature on research how engineering education has approached sustainability since the 1990s, Narong & Hallinger (2024) identify an evolution in research trends through three periods or waves, from a first wave of research that focused mainly on curriculum development in terms of the professional competencies required by engineers to effectively address sustainability challenges, both `hard´ scientific and technical skills as well as `soft´ social skills related to creative thinking and interdisciplinary collaboration, through a second wave that focused on broader issues of program and teaching development, such as problem-based, project-based and team-based learning, to a recent wave, driven by increasing government rules and regulations, that focus on compliance to standards and certification procedures as well as how Industry 4.0 technologies can be instrumental in these processes.

Similar trends have been identified in previous reviews, for instance by Gutierrez-Bucheli et al. (2022) and Thürer et al. (2018), who identify an increasing effort to integrate sustainability into engineering education curricula, programs and teaching methods. These reviews, however, also identify difficulties and tensions. For instance, they note that many engineering educators and education programs struggle to change the senses and connotations of being and becoming and engineer. These reviews, thus, yield valuable insights into the trends and tensions involved in the integration of sustainability into engineering education in order to empower students as active and responsible change agents.

In this chapter, we argue that the integration of sustainability in engineering education is not only a matter of the technical building-blocks of engineering education curricula, programs and teaching methods, but also a matter of acknowledging complexity and this is not achieved through the application of a fixed yardstick, i.e. it is not a purely technical matter, but is a matter of awareness and attention to unforeseen elements and developments.

The remining part of the chapter is structured as follows: Firstly, we describe in more detail the difficulties involved in the integration of sustainability into engineering and illustrate this through a document analysis of UNESCO´s two reports on engineering education (UNESCO, 2010, 2021). Then, secondly, we argue that the Cynefin framework offers a conceptual foundation to sustainability and the complexities this encompasses. Thirdly and finally, we exemplify some practical didactical implications of this framework through a discussion of three general approaches to and ways of understanding sustainability and the challenges they raise for attempts to address sustainability issues in a responsible way.

2 NARRATIVE REVIEW: BUILDING BLOCKS IN ENGINEERING EDUCATION

As one of the oldest professions in the world, engineering has played a vital role in shaping the world as we know it. Engineering has helped to solve both daily problems and production needs with regards to food and water supplies, health care services as well as transportation and communication. Traditionally, engineering education has been characterized by a strong scientific and mathematical foundation for technical problem-solving. This can be illustrated with the first UNESCO report on engineering education from 2010, which defines engineering as:

"*Engineering is the field or discipline, practice, profession and art that relates to the development, acquisition and application of technical, scientific and mathematical knowledge about the understanding, design, development, invention, innovation and use of materials, machines, structures, systems and processes for specific purposes*." (UNESCO, 2010, p. 24)

As the quote states, engineering has usually been related to scientific and mathematical knowledge about materials, machines, systems and processes. Some of these solutions that engineering has contributed to, however, have turned out to create new problems, for instance regarding social and environmental sustainability. Thus, in as much as engineering have been instrumental in creating the technical underpinnings of modern society, it is also a symptom of the compartmentalization of knowledge into distinct building-blocks and the firm belief in technical problem-solving. Hence, engineering has not only caused various economic, social and environmental problems, but has contributed to the creation of economically, socially and environmentally unsustainable institutions and systems (Leifler & Dahlin, 2020).

As mentioned above, reviews of research on the integration of sustainability into engineering education shows that the early efforts often consisted of add-on sustainability courses with a very technical focus and the role of an add-on to existing programs, for instance as electives, while more recent attempts to integrate sustainability into engineering education has thus focused on more thorough integration of sustainability awareness and attitudes into programs and teaching methods (Gutierrez-Bucheli et al., 2022; Narong & Hallinger, 2024; Thürer et al., 2018). This can be illustrated with the second, more recent UNESCO report on engineering education from 2021, which is entitled *Engineering for Sustainable Development*, that stresses that:

"*Engineering is experiencing a moment of profound transformation and is facing immense challenges. As a discipline, it is expanding rapidly beyond the creation of artefact-based solutions to permeate economic, ecological and social systems. This evolution is taking place within a broader context in which the timeframe for new discoveries, new technologies, new materials and new products is becoming increasingly short. Meanwhile, the challenges facing engineering, including those encapsulated in the SDGs, are becoming ever more complex and often require multi-disciplinary, cross-country and inter-cultural solutions*." (UNESCO, 2021, p. 7)

As the quote states, engineering is facing still more complex challenges that require broad multi-disciplinary and inter-cultural competencies. The report thus suggests that engineering education must transcend traditional disciplinary boundaries and shift focus from optimizing current institutions and systems to facilitating system changes. In as much as engineering is to play a role in the transformation towards sustainable institutions and systems, it not only will have to find new technical solutions, but it will also need to adopt a broader view on how technical solutions affect economic, social and environmental systems in order to counter negative consequences such as inequality, oppression, environmental degradation and destructive climate change.

Thus the second UNESCO report goes on to argue that this requires a shift in engineering education away from a narrow technical focus towards a broader interdisciplinary and complex problem-solving approach that combines technical knowledge and solutions with societal and sustainable problem analyses (UNESCO, 2021:122). It introduces the so-called "cynefin framework" (Snowden & Boone, 2007) in order to stress that engineering education must address sustainability issues that are complex, if not chaotic. More specifically, the cynefin framework distinguishes between five different contexts one can be in regarding a problem: the context of simple problems, complicated problems, complex problems, chaotic problems and disordered problems.

"Cynefin" is a Welsh term referring to a condition of "multiple belongings", i.e. the condition of being rooted in several different places or cultures that influence how one thinks and acts, but of which one can only be partially aware, and a key point in the framework is that we usually find ourselves in the context of a disordered problem when we approach a problematic situation, and the first task, then, is to "order" or, in Schöns terms, "frame" the problematic situation at hand into either a simple problem, a complicated problem, a complex problem or a chaotic problems.

Simple problems are well-defined and characterized by clear cause and-effect relationships that are easily discernible by everyone. According to Snowden & Boone, simple problems are in the realm of "known knowns" (Snowden & Boone, 2007, p. 70), where the right answer is self-evident and undisputed. Som technical engineering problems are in this category, i.e. are simple problems that require straightforward management and monitoring in terms of command-and-control project management where directives are straightforward, decisions are easily delegated, and functions can be automated, while exhaustive communication is not usually required because disagreement about what needs to be done is rare.

Complicated problems, on the other hand, may contain multiple right answers, however although they are based upon cause-and-effect relationship, they require expertise to identify and handle. According to Snowden & Boone, complicated problems are in the realm of “known unknowns” (Snowden & Boone, 2007, p. 71), where appropriate action requires expertise within a particular field. Much engineering design is in this domain in terms of there being different acceptable solutions to a given problem. Although complicated problems require expertise, if suggestions by nonexperts are overlooked or dismissed, this may result in lost opportunities. Hence, complicated problems requires listening to experts while simultaneously welcoming novel thoughts and solutions from others, which in itself is complicated and involves a trade-off between finding the right answer and simply making a decision.

With complex problems right answers cannot be ferreted out. According to Snowden & Boone, complex problems are in the realm of “unknown unknowns” (Snowden & Boone, 2007, p. 74), where we can understand why things happen only in retrospect. Snowden & Boone stress that many business issues today appear complex because change – a shift in management, products, suppliers or customers – introduces unpredictability and flux. Instructive patterns, however, can emerge if one conducts experiments that are safe to fail. Thus, instead of attempting to impose a course of action, one must allow the path forward to reveal itself. Many sustainability problems require not only engagement with stakeholders to understand what which solutions could be acceptable but also require an experimental probe-response approach. If one does not recognize that a complex problem requires an experimental mode of management but try to over-control the situation, one will pre-empt the opportunity for informative patterns to emerge. Trying to impose order in a complex context is doomed to fail, but those who step back a bit and allow patterns to emerge will succeed in discerning opportunities for innovation and new business models.

With chaotic problems, searching for right answers is pointless. According to Snowden & Boone, complicated problems are in the realm of “unknowables” (Snowden & Boone, 2007, p. 74), where cause-and-effect relationship are impossible to determine. There are no manageable patterns, only turbulence. When facing a chaotic problem, one´s job is not to look for patterns but to stanch the bleeding. Top-down communication is imperative, since crisis demand decisive action with little or no time to ask for input. However, a danger for business developers who successfully handle a crisis is that they can develop an overinflated self-image and become legends in their own minds, and, hence, become less successful when they are not able to switch management styles to match other problems.

While we acknowledge the distinction between four kinds of problems, we do not recognize the argument made by Snowden & Boone (2007, p. 75) that chaotic problems always provide an opportunity for innovation, since people are open to novelty. This is not our experience, neither is it backed up by innovation research that suggest that innovation requires more involvement, dialogue and probing than the directive leadership that Snowden & Boone suggest. It is, however, beyond the scope of this chapter to address this issue further. Rather, we want to stress that UNESCO (2021, p. 123) makes an inspiring and instructive use of the cynefin framework to argue that most engineering disciplines are taught as simple problem solving, whereas this approach is inadequate regarding many challenges of sustainable development, since such challenges often involve not only simple or even complicated problems, but also complex and sometimes chaotic problems.

The report goes on to argue that problem-based learning (PBL), where students work in project-teams to identify problems and responsible approaches to them, is more appropriate. However, PBL is often limited to single subjects and single courses, and should, rather, be organized across subjects and disciplines, and, further, not only formulated within an academic context, i.e. ”course-based BPL”, but (also) together with stakeholders outside the academic context, which allows for even more complex and sometimes chaotic problems and learning processes (UNESCO, 2021, p. 124).

Table 1 sums up the characteristics of different kinds of problems and how they can be addressed in engineering education in terms of the key curricular elements and the learning methods that best support them.

Table 1. Different types of problems and their implications for education

Type of problem	Key characterictics	Curricular elements	Learning methods
Simple	Known solutions to known problems	Single discipline courses and subjects	Lectures and flipped classroom
Complicated	Unknown solutions to known problems	Multi-disciplinary collaboration	Academic PBL across disciplines
Complex	Unknown solutions to unknown problems	Inter-disciplinary projects	PBL involving stakeholders
Chaotic	Unknowable solutions to unknown problems	Crisis management	Training in immediate action

The UNESCO report (2021) thus makes a strong argument for a variation in problem and project types in order to allow students to work on different kinds of real-world engineering challenges and the different kinds of problems encompassed in real-world business development projects. Course-based PBL is useful in establishing an understanding of simple and complicated issues, but such academic-initiated projects may prove limited in terms of the complex and even chaotic problems involved in some business development projects.

On the other hand, collaboration with companies and other stakeholders allows students to understand the more complex and chaotic types of problems they may encounter in work settings, however such projects are often very hard to control as part of an academic curriculum as problems can lead in directions not anticipated at the outset. Hence, while Snowden & Boone suggest that students can learn to handle only simple and complicated problems and not complex and chaotic problems, which rely on “natural capabilities” (Snowden & Boone, 2007, p. 76), the UNESCO report suggest that the Cynefin framework is instrumental for organizing projects of various sizes and types of problems and learning outcomes. Projects can range from being course-related and academically initiated projects to those initiated by different societal actors, e.g. in the form of a student project in collaboration with a company, or a project identified and formulated by a group of students developing a business idea and business model themselves.

In the following section we will argue that this framework provides a didactic framework for addressing complexity regarding sustainable development in general and the 17 UN sustainable development goals in particular.

3 ENGINEERING AND SUSTAINABLE BUSINESS DEVELOPMENT

In this section we will exemplify some practical didactical implications of the Cynefin framework through a document analysis of reports and policies UNESCO and UNPRME. The document analysis identifies three general conceptions of sustainable development: a narrow, economic conception of sustainable development, a broader, balanced conceptions of sustainable development and a deeper, systemic conceptions of sustainable development. We use the metaphors of a "narrow", "broader" and "deeper" conception to illustrate the point made above that a conception like a horizon indicate what can be seen from a particular vantage point and, as such, it is at the same time enabling and limiting. It can be narrow, but at the same time also be opening up, and *Bildung* is exactly the ability to keep oneself open and, thus, being able to open up a limited horizon in the search for a better, more holistic understanding of sustainable business development.

A narrow understanding of sustainable business development

Traditionally, sustainable business development has predominantly been conceived of in economic terms and by reference to economic indicators such as revenue and profit. This understanding of sustainable business development thus represents "business as usual", i.e. a narrow understanding of business development that only stresses economic concerns. Both UNESCO reports (UNESCO, 2010, 2021) and UNPRME reports (UNPRME, 2016, 2018) stress that the narrow, economic understanding of sustainable business development has been dominant in engineering business education. For instance, one UNPRME report states that "*business school students are exposed to economics and finance courses based on a Homo economicus view of human nature*" (UNPRME, 2016, p. 9), e.g. by giving primacy to self-interest and shareholder value. As the quote indicate, the narrow, economic understanding of sustainable development is grounded in business and management traditions of taking the environment for granted. People and the natural environment are viewed as available resources which are separate and susceptible to control, and consequently they are not accounted for but are, rather, taken for granted and treated as externalities. Underpinning this understanding is an assumption of unlimited growth via increasing consumption of products and services.

The practical implication of this narrow, economic understanding of sustainable development is that economic concerns are understood as the main focus of business and business research. The didactical implication is that business education (and research) should relate to the economic content of traditional business dimensions finance, accounting, marketing, organization behavior, strategy, etc. Social and environmental issues are addressed as add-on concerns as if such issues are not relevant for running a successful business (Sharma & Hart, 2014).

Although the last decades have seen increasing recognition of environmental problems, the narrow, economic understanding of sustainable development is still widespread in engineering educations, and is a huge obstacle to real change in curricula and education programs. In the sustainability literature, this mindset is made explicit in hierarchical pyramid models (e.g. Carroll, 1991), which rank management concerns in order of relative importance, with economic concerns depicted as primary followed by legal, ethical and finally philanthropic concerns. Thus, the one-dimensional economic concern that if a business does not make a profit then it will not survive, and other concerns become a moot point (Masoud, 2017).

The profit-first mindset is implicit if not explicit in many models of management and creates strong norms for business behavior that can easily become self-fulfilling (Ghoshal, 2005), and efforts to integrate sustainability into engineering and management education risk being cosmetic green washing, predominantly due to the reluctance of textbooks, teaching staff and program directors to change their basic mindset (Baden & Higgs, 2015).

However, the Cynefin framework suggests that sustainability issues are more complex than this. For instance, even when the economic concern is taken as a starting point, one can justify a broader understanding of sustainable development in economic terms by investigating whether social and environmental responsibility can be profitable, for instance if they cut energy and material costs or offer good marketing opportunities (Brooks, 2010). With routine references to “efficiency” and “the bottom line” this might remain a feasible stance. However, the Cynefin framework would still consider this conception one-sided and limited and would seek towards other, more complex understandings of sustainable development.

A broad understanding of sustainable development

As mentioned, the second UNESCO report on engineering refers to the United Nations 2030 Agenda and the 17 SDGs and stress that enterprises today must integrate in a balanced manner the economic, social and environmental dimensions of sustainable development (UNESCO, 2021, p. 13). This broad understanding of sustainable development also dominates the UNPRME documents (UNPRME, 2016, 2018). For instance, they argue that the United Nations sustainable development goals are fundamental to the contemporary corporation need to balance environmental, social and economic considerations.

The broad understanding of sustainable development dates back to, at least, 1987 and the Brundtland Commission report, a report of the UNs World Commission on Environment and Development (WCED), which defined sustainable development as the ability to “*meet the needs of the present generation without compromising the ability of future generations to meet their own needs*” (WCED, 1987, p. 8). This report thus argued for a broad understanding of sustainable development that balance different needs, costs and benefits. Using scientific evidence to mobilize public awareness of the toxic side effects of industrial progress, the Brundtland Commission showed the risk of unproblematic commitment to economic growth and challenged business schools and business developers to incorporate a broad understanding of sustainable development into their curricula that balance economic, social and environmental concerns. Underpinning the broad, balanced understanding of sustainable development is the idea business developers face complementary concerns

The implication of the broad understanding of sustainable development is that business developers should understand both economic, social and environmental concerns and relate to the balances and trade-offs between them. Social and environmental concerns, then, should not just be an add-on, but should be built into existing functional areas and activities of management. For instance, these functional areas should address issues related to multiple bottom lines and thus integrate sustainable development goals into corporate strategies and operations (Chen, Wu, & Tsai, 2018).

Often, this mindset is illustrated in a Venn diagram that place sustainability at the intersection of environmental, social and economic concerns, which is also called the 3 P´s: profit, people and planet. Thus, business developers have several concerns and should seek a balance between concerns related to profit, people and the planet. The ideal overlap resides at the center of the diagram where economic, social and environmental concerns are simultaneously fulfilled, but other pure and partly overlapping segments create situations which also represents situations that one may face in the business world. A company may develop products or services for new markets or strategize to position itself as an environmental leader in an established market. The integration of environmental concerns into corporate strategies has become increasingly meaningful as customers in some markets want to see corporate environmental performance. As social and environmental problems have pervaded all areas of daily life, including business life, many corporations seek the business opportunities in them. Business developers, then, should not only relate to social and environmental content, but should counter the profit-first mindset.

The Cynefin framework would, however, invite us to seek even more complex relationships between economic, social and environmental systems.

A deep understanding of sustainable development

The broad understanding of sustainable development that promotes a balance between economic, social and environmental development dominates the recent UNESCO report (UNESCO, 2021) and UNPRME report (UNPRME, 2018), however these reports also entails elements that reflects a genuine systemic understanding of sustainable development that involves deep and thorough changes. Thus, it is emphasized that sustainable development entails both sustainable production and consumption with a view to decoupling economic growth from environmental degradation and enabling the transition to a circular economy, which involves building capacity to ensure environmental sustainability in the pursuit of the green growth.

For instance, the recent UNESCO report states "*megatrends, such as green and digital transitions, are also re-shaping the engineering landscape and educational requirements. The engineering education system needs to be reassessed and fully shift to technological problem-solving with an holistic approach that considers the impacts of engineering innovations and activities on the environment and on society more generally.*" (UNESCO, 2021, p. 154) Similarly, referring explicitly to the 17 sustainable development goals, UNPRME documents argue that sustainability involves new ways of organizing, such as shared value creation, social innovation, social entrepreneurship, diversity and gender equality issues, sustainable cities, circular and sharing economies, etc. (UNPRME, 2016, p. 4)

Underpinning the deep, systemic understanding of sustainable development is the assumption of the inherent value of ecosystems, which has deep historical and philosophical origins in ideas that emphasize the complex, interrelated, non-linear and therefore unpredictable nature of the world (Keulartz, 1998). The concept of “circular economy” has been developed by, among others, Stehal (2006, 2019), and is today promoted by several NGOs, such as the Ellen MacArthur Foundation, that have become influential in putting the circular economy concept on the agenda of policy-makers around the world. Criticizing the linear take-make-waste model of production and consumption, the concept of “circular economy” aims to redefine growth by decoupling economic activity from the consumption of finite resources, and designing waste out of the system. The transition to a circular economy, then, does not only amount to adjustments aimed at reducing the negative impacts of the linear economy but requires a systemic shift (EllenMacArthurFoundation, 2019).

The implication of this understanding of sustainable development is that business developers should understand corporations as part of a natural eco-system, i.e. a network that sees nature as the primary stakeholder, and establish closed-loop, cradle-to-cradle production systems in order not only to reduce the use of natural resources but renew them. Production and consumption should be conceived of as a circular borrow-use-return process, which if often energy and resource intensive (Stahel, 2019). As part of a systemic business environment and network, corporations should cooperate to minimize environmental degradation, for instance by building and sharing infrastructure to support recycling and renewable energy. By aiming for zero waste, corporations take responsibility for the complete life-cycle of its solutions. End-of-life products are recycled to produce new products in an industrial eco-system, recognizing that earth´s resources are finite (EllenMacArthurFoundation, 2019). A prosperous economy depends on social and ecological health and integrity and vice versa. Systemic thinking, then, involves seeing corporations as part of an interdependent ecological system where they may be facilitating the health of the whole population and of the long run. Systemic thinking draws attention to the networks in which the corporations partakes and without which they could not exist. According to a systemic view, corporations are embedded within valuable social and environmental systems that are internally linked to one another and thus inseparably intertwined.

The above analyses shows that UNESCO and UNPRME reports present different conceptions of sustainable development. We argue that it requires more than technical competence to recognize the distinct understandings and the different types of problems they encompass and to respond appropriately. The narrow, economic conceptions of sustainable development value economic concerns first and views social and environmental concerns as possible attachments, i.e. as add-ons, “bolted-on” to existing program curricula, for instance as electives that serves to satisfy a demand among students or policy makers. This understanding of sustainable development, then, only entails a very small commitment to reform business development in response to United Nations SDGs. The broader, balanced conceptions of sustainable development on the other hand entails a greater level of commitment to such change in business and management and research interests. This conception of sustainable development ascribes equal value to economic, social and environmental concerns and thus suggest that social and environmental content is integrated into the curricula, i.e. built-into the core courses on different functional areas and disciplines. The systemic conception of sustainable development entails an even stronger commitment to fundamental changes in response to United Nations SDGs. This conception of sustainable development views corporate systems as interdependent to social and environmental systems and thus suggest that business practices are re-imagined and re-designed with social and environmental content constituting core elements, i.e. with management courses being build-up around social and environmental concerns.

4 CONCLUDING SUMMARY

Sustainability is generally acknowledged as the most pressing challenge of the 21st century. We have argued that engineering education is instrumental for fostering the necessary skills for graduates to become change agents for sustainable development, however most efforts have focused on changing the building-blocks of engineering education in terms of the curricula, programs, and teaching methods, whereas we argue that integration of sustainability into engineering education require a focus on complexity.

We find the Cynefin framework particularly relevant to engineering education in order to address how many sustainability problems require not only technical competencies, but also an open awareness and attitude in terms of a continuous effort to understand more. Not in order to look away from what we currently focus on and tries to achieve, but in order to understand it better, within a larger whole. Such an awareness and attitude can be designed into engineering education through by allowing students to work on different kinds of engineering challenges in real-world development projects. Collaboration with companies and other stakeholders allows students to understand the complex and chaotic problems of real-world development projects.

Approaches to business development have been dominated by a narrow economic conception. The Cynefin framework invites us to seek to open up to other, more complex conceptions of economic, social and environmental systems and the relationships between them. Sustainable development is rarely simple, but rather often complex or even chaotic, involving competing and conflicting elements and perspectives. Sustainability never comes to an end. Understandings are produced and reproduced as traditions move. This need to be acknowledged in order to recognize the limits attached to any understanding of sustainable development that aspires to be sufficient.

Rather than focusing on one understanding of sustainable development, engaging with different understandings helps to understand sustainable development from different perspectives and to respond appropriately, i.e. to act responsibly. The strengths and weaknesses of specific conceptions of sustainable development need to be recognized in order to address their opportunities and limits. Sustainable development, then, is both indispensable and problematic, and business developers need to develop the ability to be open to new and better ways of understanding, while acknowledging that understanding is a continuous process. Hence, we cannot wait to act but must act responsibly as we go along, continuously trying to understand and act in better ways.

REFERENCES

Amaeshi, K., J. N. Muthuri, and C. Ogbechie. "Introduction." In *Incorporating Sustainability in Management Education. An Interdisciplinary Approach*, edited by K. Amaeshi, J. N. Muthuri and C. Ogbechie. Edingburgh: Palgrave Macmillan, 2019.

Baden, Denise, and M. Higgs. "Challenging the Perceived Wisdom of Management Theories and Practice." *Academy of Management Learning & Education* 14, no. 4 (2015): 539-55.

Barth, Matthis. *Implementing Sustainability in Higher Education: Learning in an Age of Transformation.* London: Routledge, 2015.

Brooks, S. "Csr and the Strategic of Economic Rationality." *The International Journal of Sociology and Social Policy* 11, no. 12 (2010): 604-17.

Busulwa, Richard, Matthew Tice, and Bruce Gurd. *Strategy Execution and Complexity: Thriving in the Era of Disruption.* London: Routledge, 2018.

Bækgaard, L., and C. T. Lystbæk. "Learning to Do Knowledge Work. A Framework for Teaching Research Design in Engineering Education." *International Journal of Engineering Education* 35, no. 1B (2019): 333-44.

Carroll, A. "The Pyramid of Corporate Social Responsibility. Towards the Moral Management of Organizational Stakeholders." *Business Horizons* (1991): 39-48.

Chen, M., Y. J. Wu, and K. Tsai. "Building an Industry-Orinted Business Sustainability Curriculum in Higher Education." *Sustainability* 10, no. 1-14 (2018).

EllenMacArthurFoundation. *Completing the Picture. How the Circular Economy Tackles Climate Change. .* The Ellen MacArthur Foundation (www.ellenmacarthurfoundation.org/publications The Ellen MacArthur Foundation, 2019).

Flynn, Patricia M., Tay Keong Tan, and Milenko Gudic´. "Introduction." In *Redefining Success. Integrating Sustainability into Management Education*, edited by Patricia M. Flynn, Tay Keong Tan and Milenko Gudic´. New York: Routledge, 2018.

Gadamer, H.G. *Truth and Method.* New York: Continuum, 1989.

Ghoshal, S. "Bad Management Theories Are Destroying Good Management Practices." *Academy of Management Learning & Education* 4, no. 1 (2005): 75–91.

Gutierrez-Bucheli, Laura, Gillian Kidman, and Alan Reid. "Sustainability in Engineering Education: A Review of Learning Outcomes." *Journal of cleaner production* Vol.330, no. 129734 (2022).

Habermas, Jürgen. *On the Logic of the Social Sciences.* Cambridge: The MIT Press, 1988.

Horlacher, R. *The Educated Subject and the German Concept of Bildung: A Comparative Cultural History.* London: Routledge, 2016.

Keulartz, J. *Struggle for Nature. A Critique of Radical Ecology.* London: Routledge, 1998.

Kolmos, A. "Future Engineering Skills, Knowledge and Identity." In *Engineering Science, Skills, and Bildung*, edited by J. Christensen, L.B. Henriksen and A. Kolmos, 165-86. Aalborg: Aalborg University Press, 2006.

Leifler, Ola, and Lon-Erik Dahlin. "Curriculum Integration of Sustainability in Engineering Education: A National Study of Programme Director Perspectives." *International Journal of Sustainability in Higer Education* 21, no. 5 (2020): 877-94.

Masoud, N. "How to Win the Battles of Ideas in Corporate Social Responsibility. The International Pyramid Model of Csr." *International Journal of Corporate Social Responsibility* 2, no. 4 (2017): 1-22.

Narong, David Kongpiwatana, and Philip Hallinger. "Traversing the Evolution of Research on Engineering Education for Sustainability: A Bibliometric Review (1991–2022)." *Sustainability* 16, no. 2 (2024).

Roberts, N.C. "Wicked Problems and Network Approaches to Resolution." *International Public Management Review* 1, no. 1 (2000): 1–19.

Schulz, R.M. *Rethinking Science Education: Philosophical Perspectives* Charlotte, NC: Information Age Publishing, 2014.

Schön, D. *Educating the Reflective Practitioner.* San Francisco: Jossey-Bas, 1987.

Schön, D *The Reflective Practitioner.* USA: Basil Books, 1983.

Sharma, S., and S. L. Hart. "Beyond “Saddle Bag” Sustainability for Business Education." *Organization & Environment* 27, no. 1 (2014): 10-15.

Sjöström, J., N. Frerichs, V.G. Zuin, and I. Eilks. "Use of the Concept of Bildung in the International Science Education Literature, Its Potential, and Implications for Teaching and Learning." *Studies in Science Education* 53, no. 2 (2017). https://doi.org/10.1080/03057267.2017.1384649.

Snowden, D.J., and M.E. Boone. "A Leader’s Framework for Decision Making." *Harvard Business Review* 2007, no. November (2007): 69-76.

Stacey, R. *Strategic Management and Organisational Dynamics. The Challenge of Complexity to Ways of Thinking About Organisations.* Harlow, UK: Pearson, 2011.

Stahel, W. *The Circular Economy: A User's Guide. .* London: Routledge 2019.

Stahel, W.*The Performance Economy.* London: Palgrave Macmillan, 2006.

Thürer, Matthias, Ivan Tomašević, Mark Stevenson, Ting Qu, and Don Huisingh. "A Systematic Review of the Literature on Integrating Sustainability into Engineering Curricula." *Journal of Cleaner Production* 181 (2018): 608-17.

UN. *Transforming Our World: The 2030 Agenda for Sustainable Development.* United Nations (New York: 2015).

UNESCO. *Bonn Declaration. From the Unesco World Conference on Education for Sustainable Development*. Bonn: UNESCO, 2009.

UNESCO. *Education for Sustainable Development Goals - Learning Objectives.* UNESCO (Paris: 2017).

UNESCO. *Engineering for Sustainable Development.* UNESCO (Paris: UNESCO, 2021).

UNESCO. *Engineering. Issues, Challenges and Opportunities for Development.* UNESCO Publishing (Paris: 2010).

UNPRME. *Good Practice Handbook for the Dissemination of the Sdgs in Educational Institutions*: UNPRME, 2018.

UNPRME *Towards Global Partnership. General Assembly Resolution Recognises Prme*: UNPRME, 2009.

UNPRME *Transformational Model for Prme Implementation*: UNPRME, 2016.

WCED. *Our Common Future*. New York: United Nations, 1987.

PROJECT-BASED APPROACH FOR ELECTRICAL ENGINEERING EDUCATION AT ETH ZURICH

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ABSTRACT

This practice paper introduces the project-based approach of the Center for Project-Based Learning within the Department of Information Technology and Electrical Engineering of ETH Zürich. This center's approach to education is built around a three-stage education model that includes projects early on in the students' educational journeys, gradually increasing their complexity in alignment with their growing level of experience. This approach ensures students develop both technical expertise and essential professional skills necessary for their engineering careers, scaffolding course work, small scale group projects and interdisciplinary flagship projects. The center is further enhanced by an evidence-based approach to

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continued improvement, using regular surveys, reflective journals, and research findings to refine course design and supervision. Students have reported high satisfaction levels with the courses, expressing that the projects aided their understanding of future aspirations and helped develop crucial soft skills, notably in collaboration, communication, and presentation. Projects focus on real-world applicability, ensuring students are well-prepared to tackle real-world challenges, with many focusing on contemporary problems in areas such as sustainability.

1 INTRODUCTION

The rapidly evolving technological landscape, accompanied by the rise of automation, has transformed the skills demanded by industries ("The Future of Jobs Report 2020 | World Economic Forum," 2020). In the field of engineering, professionals are now required to serve as effective intermediaries between human workers and automated systems. Recognizing these changing demands, prominent engineering accreditation bodies, such as ABET and the European Network for the Accreditation of Engineering Education (ENAEE), have incorporated professional skills into their criteria for accrediting engineering programs. Consequently, engineering programs have increasingly embraced inquiry-based learning approaches like Project-Based Learning (PBL) over the past five decades to enhance learning outcomes and foster the development of essential professional competencies (Bielefeldt, Paterson, and Swan 2009; Chen and Yang 2019; Jamison et al. 2022).

Numerous studies have shown that project-based learning equips students with a wide range of skills (Habbal et al. 2024). By engaging in projects, students develop problem-solving abilities as they tackle complex problems, break them down into manageable parts, evaluate multiple solutions, and make informed decisions (Finkelstein et al. 2011). Moreover, PBL cultivates positive attitudes toward learning (Holmes and Hwang 2016) and fosters collaboration, as teamwork often plays a vital role in project-based settings (Kaldi, Filippatou, and Govaris 2011). However, a notable gap remains between the competencies of graduates and the expectations of employers (Markes 2006; Nair, Patil, and Mertova 2009; Ramadi, Ramadi, and Nasr 2016). Frequently, students encounter projects only during their capstone projects, limiting their opportunities for competency development (Dutson et al. 1997). Delaying the practical application of professional skills until late in the curriculum can leave students ill-prepared for their future careers. Therefore, it is crucial to provide early exposure to projects, enabling students to face challenges repeatedly and better prepare them to address complex societal problems.

The Center for Project Based Learning at ETH Zürich was set up to provide project-based education to all the students of the Department of Information Technology and Electrical Engineering, regardless of their backgrounds and past academic achievements. The center aims to promote activities that involve projects early on in students' educational journeys, gradually increasing their complexity in alignment with their level of experience. Furthermore, interdisciplinary projects are emphasized, allowing students to collaborate and tackle real-world problems throughout their courses, theses, and interdisciplinary team projects. As a final culminating step in their project-based learning journey, they may participate in a so-called flagship project, where students from diverse backgrounds combine their unique skills and perspectives to tackle complex real-world problems in larger teams and in collaboration with external stakeholders. Our approach, which is built upon interdisciplinarity and collaborative problem-solving, promotes innovation by encouraging new forms of knowledge transfer, interaction, and independent learning. The center's approach is built on evidence-based practices from the ground up, with a focus on the development of essential skills. Additionally, the center conducts regular assessment of its courses and projects. The use of comprehensive evaluation methods, such as pre-and post-project surveys and weekly reflective journals, enables the center to effectively assess and monitor student progress. Through this feedback, the center continuously refines its course design and pedagogical approaches to enhance student engagement and optimize learning outcomes.

2 THE STRUCTURAL MODEL OF THE CENTER FOR PROJECT-BASED LEARNING

In this section, we will discuss how our curriculum is structured. Specifically, the center as adopted a three-stage education model that emphasizes a scaffolded progression of project-based learning and skill development, as shown in Figure 1.

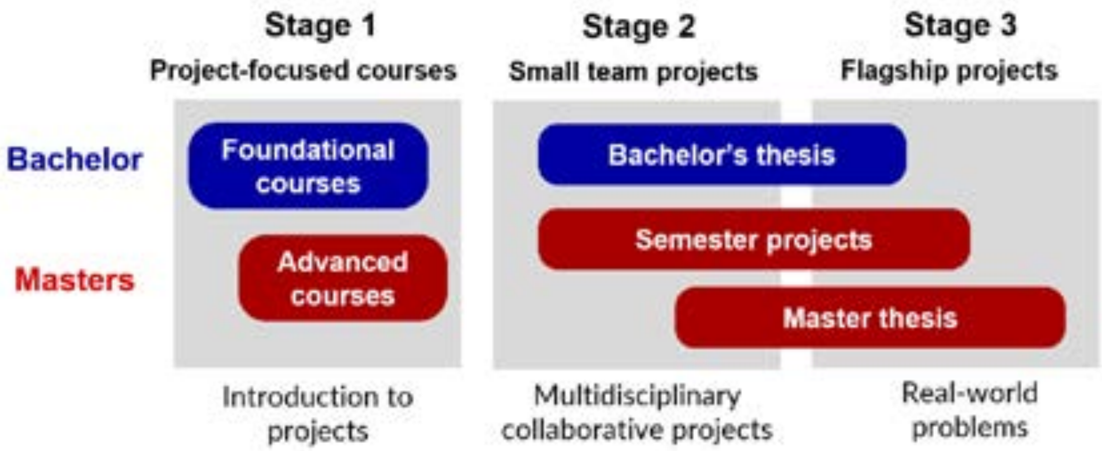

Fig. 1. Overview of the 3 stages and the feedback for constant monitoring

This model is built upon the realization that in the realm of engineering education, it is important to go beyond lectures and theoretical concepts, and instead create an environment that fosters practical application and hands-on experience. First, at both the Bachelor and Masters level, students participate in course work. These courses not only teach the theoretical foundations, but already incorporate significant project-focussed elements. Next, both groups of students have the opportunity to then participate in standalone projects, as part of their Bachelor's thesis, their Masters thesis or one or more semester projects (for Masters students).

As students move from project-focussed course work to projects, they progress through the three stages of our PBL model structure. This three-stage model captures the scaffolded nature of the student learning experience, where they progress from guided problem solving (stage 1) to small team projects (stage 2) to large complex multidisciplinary flagship projects (stage 3).

This three-stage model can also be understood in how it maps directly to three stages of problem solving. An important strength of project-based learning is that it has been recognized as a premier approach to teach students practical problem solving. This is extremely valuable, as the ability of be an effective problem solver is one the key skills that engineers need to possess [NACE 2023]. Our three-stage model can be viewed through the lens of progressively building students' problem-solving skills, which follow a similar progressing ("Problem-solve like an Expert", 2024). This is illustrated in Figure 2. Starting at the bottom, in their course work, students are doing projects and labs that relate directly to the technical core of these courses. Here, they need to apply debugging techniques, or more generally troubleshooting, where the challenge is to find why something that should be working is not. Progressing to small team projects, students are challenged with domain problem solving, which focuses on solution development: exploring how can a specific technical problem be solved. Finally, in the flagship projects, the problems become increasingly broad, where solutions need to become multidisciplinary and may combine expertise from a wide variety of fields. This requires students to develop their problem identification skills, focusing on exploring the problem space to find the point of high impact. Our structured progression of students through their PBL journey maps directly to the exposure to and practice with these increasingly advanced problem-solving skills.

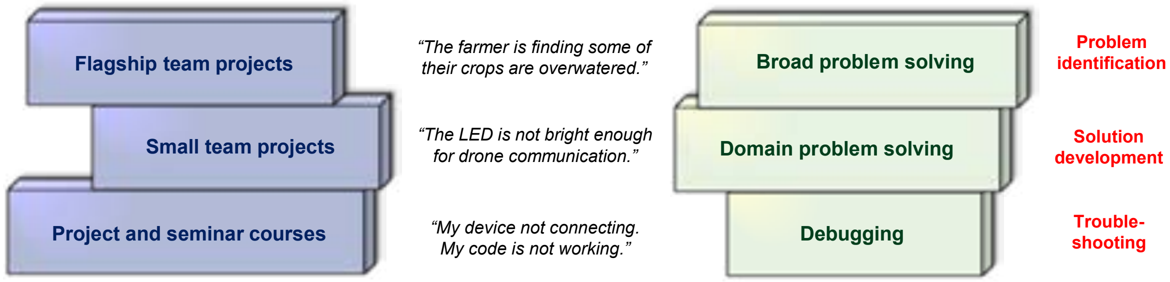

Fig. 2. Progressive development of problem solving skills

Note that, as suggested by Figure 1, there is crossover between the functional aspects of curriculum (course work versus thesis) and the structural aspects (stages in our model). A student's bachelor thesis, for example, can take the form of a small team project or be integrated into a flagship project. On the other hand, a flagship project may involve a heterogeneous team of students, with some being involved as part of their Bachelor thesis, others as part of a semester project and yet others as part their Masters thesis, with roles within the project commensurate with students' level of expertise. We also encourage interested students to write and publish papers on their projects. In the next section, we will elaborate on each of the three stages of our model in turn.

3 IMPLEMENTATION OF THE COMPREHENSIVE PROJECT-BASED LEARNING APPROACH

3.1 Stage 1: Building a strong theoretical foundation with practical applications

The initial stage of our model focuses on providing students with a solid theoretical foundation through project-focused courses. These courses convey fundamental knowledge in various engineering disciplines, ensuring students grasp the principles and concepts that form the basis of their future projects. The theoretical parts of each of these courses is supplemented with hands-on experiences, including laboratory work and small-scale projects. By combining theory and practice, students gain a deeper understanding of engineering principles and the ability to apply them to real-world scenarios.

At the bachelor level, the center offers over 15 project and seminar courses, where students engage in laboratory experiments and fieldwork, working with actual equipment, analysing data, and troubleshooting problems. This stage bridges the gap between theory and practice, enhancing students' problem-solving skills, specifically troubleshooting, and equipping them with a practical mindset. The projects are carefully designed to provide students with a solid foundation and prepare them for more complex challenges ahead. Each course prioritizes student engagement and follows a structured format, with exercises to deepen theoretical understanding and self-chosen projects for practical application.

At the masters level, more advanced courses also combine theoretical study with more extensive project work and project-based course assessments. As an example of such a course, in Machine Learning on Microcontrollers, students engage in a comprehensive 5-week project in small groups, culminating in a live demo showcasing of their intelligent sensor systems. By emphasizing practical application, students gain valuable hands-on experience, a strong foundation in realistic implementation and important industry-relevant competencies.

3.2 Stage 2: Cultivating collaboration with small team projects

As students progress in their education, they enter the second stage, which revolves around collaborative small team projects during their thesis (at the Bachelor or Masters level) and/or semester projects (at the Masters level). Working in small teams of 2 to 4 students, these projects provide an ideal opportunity for students to apply and expand upon the competencies gained in the various courses The projects are specifically designed to foster teamwork, communication, and project management skills. Working in teams, students tackle engineering challenges that require the integration of knowledge from various disciplines. This stage not only enhances their technical expertise but also cultivates their ability to collaborate effectively and think critically as a team.

An example of a recent small team project is the Smart Sailing project, initiated in September 2021. This project involves the collaboration of 7 bachelor theses and one semester thesis. The goal of the project is to build a fully autonomous and energy-sustaining boat capable of sailing independently and competing in international student competitions. Another example is the Test Environment for Solar Cells, which ran from the autumn of 2022 to the summer of 2023. This project involved 5 bachelor theses dedicated to developing a comprehensive test environment for solar cells. By utilizing approximately 3000 LEDs within the testbed, adjustable between 1 and 100,000 lux, the environment allows for evaluation under a wide range of lighting conditions, from indoor room lighting to outdoor sunlight, offering a unique vehicle to optimize energy harvesting circuits.

3.3 Stage 3: Confronting real-world complexity through flagship team projects

The third stage of our education model immerses students in advanced team projects, called flagship projects. By this stage, students have acquired a solid theoretical foundation, practical experience, and the ability to work collaboratively. The flagship projects are ambitious undertakings that simulate real-world engineering scenarios. Students can get involved with multi-year efforts, some revolving around engineering competitions, while others are conducted in collaboration with external stakeholders, such as industry or community partners, resulting in the development of real products. These projects immerse students in the complexities of budget constraints, time management, and interdisciplinary coordination, preparing them to tackle the challenges they will encounter in their future careers.

An example of a flagship project is our Autonomous Robot Dog for Assistant Living. The primary objective of this project is to develop an intelligent sensor subsystem that enables autonomous control of the robot to assist individuals with visual impairments. Since its inception in February 2022, this project has already involved two bachelor theses, a group project comprising three bachelor students, nine semester projects, and two Master theses.

4 An Evidence-Based Approach to Continuous Improvement

To support the center's evidence-based mission, it has a learning scientist affiliated with it. This learning scientist conducts regular surveys, consisting of pre-tests and post-tests, to assess improvements in various areas, including entrepreneurial education and motivational aspects. Additionally, students are assigned weekly reflective journals, providing a dynamic overview of their progress. Regular meetings between the learning scientist, lecturers, and supervisors ensure that course design and supervision are constantly refined based on insights derived from survey results. The monitoring results are compiled into bi-semester reports, which are shared with the instructors, accompanied by individual feedback. These reports incorporate the components of all three stages, i.e., bachelor courses, small team projects and flagship team projects.

Figures 3, 4 and 5 show extracts from an evaluation report of the project-focused courses (Stage 1), which is based on surveying 70 students at the semester's end. Figure 3 presents both technical and soft skills that students self-reported learning during the semester. The most prevalent technical skills reported were Python and microcontrollers programming, while the most prevalent soft skills included communication, teamwork, and presentation skills.

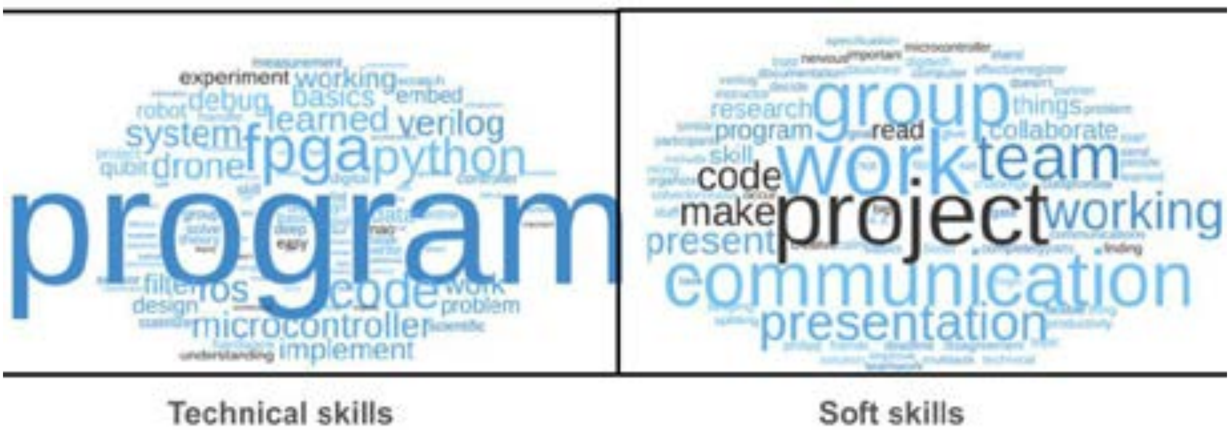

Fig. 3. Word cloud based on the answers of the students to the question "Which technical/soft skills did you learn during this course? Write N/A if you did not learn any."

Looking at student sentiments, Figure 4 illustrates that around 70% of students reported gaining deeper insight into their future aspirations after completing the project. In Figure 5, a comparison of student satisfaction across the six following courses is presented: Introduction to program Nao Robots for Robocup competition, Embedded Systems with Drones, iCEBreaker FPGA For IoT Sensing Systems, Autonomous Cars and Robots, Embedded Deep Learning with Huawei Atlas 200 AI Dev Kit, Microcontrollers for Sensors and Internet of Things, and FPGA in Quantum Computing with Superconducting Qubits.

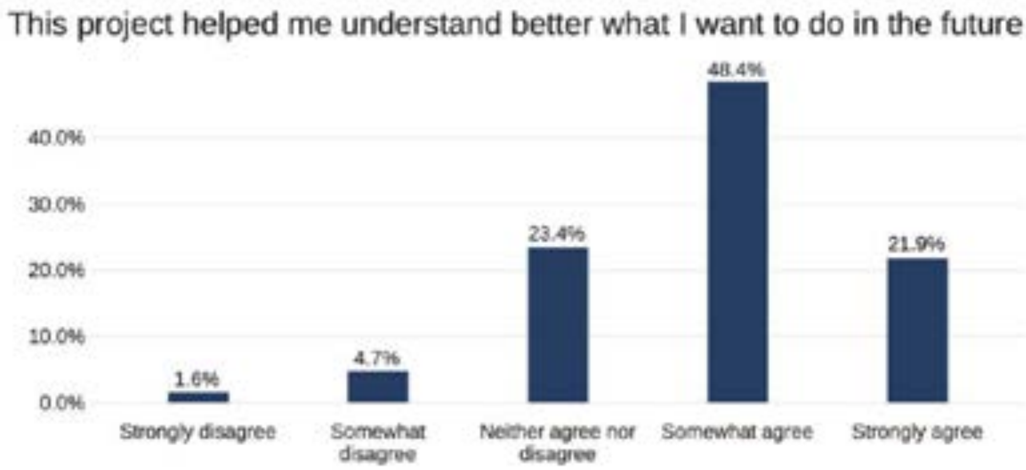

Fig. 4. Student sentiment data on future aspirations

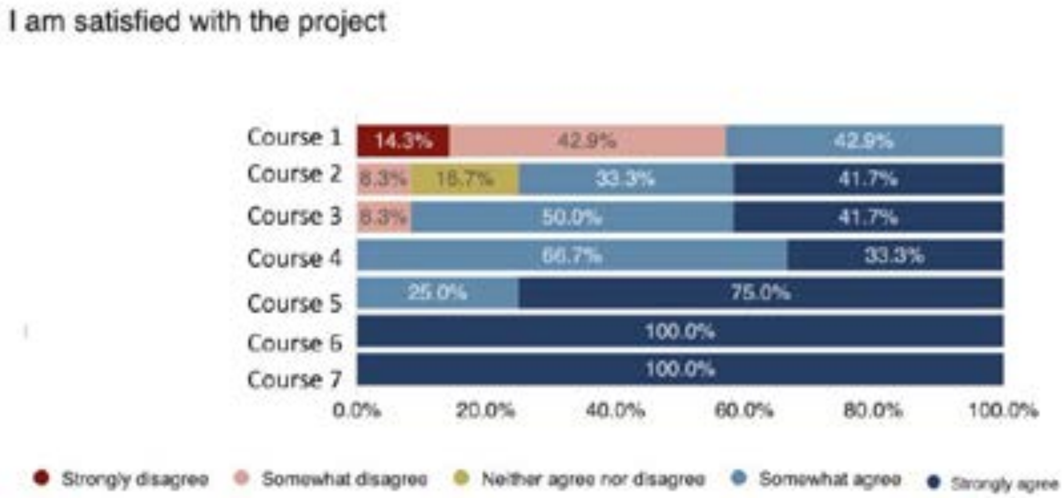

Fig. 5. Student satisfaction with project-focused courses

In addition to these formative assessments of our PBL program, a formal pedagogical study was also conducted in the center. It showed that the project-based learning activities that are integrated into the practical courses offer students more opportunities to develop professional skills compared to traditional exercise sessions(Abou-Khalil, Magno, and Kapur 2023)

3 CONCLUSION

In this paper, we have described the organizational model of PBL in the Center for Project Based Learning at ETH Zürich. It is built upon a strong commitment to student engagement, interdisciplinary collaboration, industry alignment, and sustainability in engineering education through project-based learning. Through a three-stage education model, encompassing bachelor courses, collaborative small-team projects, and flagship projects, we provide students with comprehensive learning experiences that combine theoretical knowledge with practical application. By explicitly fostering student engagement through various tools, methods, and measures, we ensure that students acquire not only technical expertise but also the ability to collaborate effectively and think critically in a team. Moreover, our flagship projects serve as a platform for interdisciplinary collaboration, allowing students to pool their diverse skills and perspectives to tackle complex, real-world challenges. These projects also provide students with valuable industry exposure, aligning their education with industry expectations and preparing them for successful careers. By participating in competitions focused on sustainability, energy efficiency, and other relevant areas, students can showcase their skills, gain recognition, and establish connections within the professional community.

REFERENCES

Abou-Khalil, Victoria, Michele Magno, and Manu Kapur. 2023. “Professional Competencies Experienced during Engineering Project-Based Learning: Occurrences, Diversity, and Variations.”

Bielefeldt, Angela, Kurt Paterson, and Chris Swan. 2009. “Measuring the Impacts of Project Based Service Learning.” In *2009 Annual Conference & Exposition*, 14–873.

Chen, Cheng-Huan, and Yong-Cih Yang. 2019. “Revisiting the Effects of Project-Based Learning on Students’ Academic Achievement: A Meta-Analysis Investigating Moderators.” *Educational Research Review* 26:71–81.

Dutson, Alan J., Robert H. Todd, Spencer P. Magleby, and Carl D. Sorensen. 1997. “A Review of Literature on Teaching Engineering Design through Project-Oriented Capstone Courses.” *Journal of Engineering Education* 86 (1): 17–28.

Finkelstein, Neal, Thomas Hanson, Chun-Wei Huang, Becca Hirschman, and Min Huang. 2011. “Effects of Problem Based Economics on High School Economics Instruction. Final Report. NCEE 2010-4022rev.” *National Center for Education Evaluation and Regional Assistance*.

Holmes, Vicki-Lynn, and Yooyeun Hwang. 2016. “Exploring the Effects of Project-Based Learning in Secondary Mathematics Education.” *The Journal of Educational Research* 109 (5): 449–63.

Jamison, Cassandra Sue Ellen, Jacob Fuher, Annie Wang, and Aileen Huang-Saad. 2022. “Experiential Learning Implementation in Undergraduate Engineering Education: A Systematic Search and Review.” *European Journal of Engineering Education*, 1–24.

Kaldi, Stavroula, Diamanto Filippatou, and Christos Govaris. 2011. “Project-Based Learning in Primary Schools: Effects on Pupils’ Learning and Attitudes.” *Education 3–13* 39 (1): 35–47.

Markes, Imren. 2006. “A Review of Literature on Employability Skill Needs in Engineering.” *European Journal of Engineering Education* 31 (6): 637–50.

Nair, Chenicheri Sid, Arun Patil, and Patricie Mertova. 2009. “Re-Engineering Graduate Skills–a Case Study.” *European Journal of Engineering Education* 34 (2): 131–39.

Ramadi, Eric, Serge Ramadi, and Karim Nasr. 2016. “Engineering Graduates’ Skill Sets in the MENA Region: A Gap Analysis of Industry Expectations and Satisfaction.” *European Journal of Engineering Education* 41 (1): 34–52.

“The Future of Jobs Report 2020 | World Economic Forum.” n.d. Accessed December 21, 2022. https://www.weforum.org/reports/the-future-of-jobs-report-2020/.

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POPULAR FILMS ENCOURAGE ENGINEERING STUDENTS TO REFLECT ON RESEARCH METHODS

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ABSTRACT

The purpose of this practice paper is to present the approach we have undertaken at WMG, University of Warwick, UK, to use popular films to support Research Methods (RM) teaching and learning. RM is a vital component of postgraduate engineering courses, as students build skills for evidence-based practice. Students' learning and grasp of RM threshold concepts can be improved by using active learning approaches. Popular films have been used to support teaching and learning in various disciplines. Evidence suggests that using them can enhance student engagement and learning. However, literature discussing the use of popular films to

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teach RM is scarce. We present a case study of our current practice organising a RM Film Club as a co-curricular activity for postgraduates. The Film Club has been co-created by an academic member of staff and three PhD students who are also Graduate Teaching Assistants in a RM module. We share our experience and the films we have curated to support reflection. We present an outline of ongoing research in which we are exploring how postgraduate students perceive the use of popular films in supporting the teaching of RM. To finalise, we reflect that our experience organising the RM Film Club has been positive as we perceive students enjoy the event and have learnt about RM in a fun environment. Further research on the impact of the intervention is needed. We encourage educators to consider similar approaches.

1 INTRODUCTION

The purpose of this practice paper is to present the approach we have undertaken at WMG, University of Warwick, UK, to use popular films to support Research Methods (RM) teaching and learning. We provide a literature review of common approaches of teaching research methods, the use of films in teaching and learning, and how films can be used as a part of engineering education's pedagogical toolbox. We then present initial reflections from our practice in using popular films in teaching RM to engineering and management postgraduate students, and preliminary results from an ongoing research project on how postgraduate engineering and management students perceive a co-curricular Research Methods Film Club in supporting their learning. This is an exploratory project focused on students' reflection on their learning RM, such as how research can be conducted, how to design experiments, and understanding of research paradigms. We invite engineering educators to explore further how films might be used in their settings and areas of expertise.

1.1 Teaching Research Methods to engineering students

Teaching research methods is an important part of many academic programmes. The aim of these courses is to provide skills that students can use during their studies and in their careers, when they need to gather, evaluate, and utilise data or research information. In engineering courses, where students are required to design, test, or enhance engineering solutions -such as optimizing manufacturing flows or improving material properties -RM is foundational (Escudero-Mancebo, 2023). RM in engineering courses supports students to learn to evaluate, conduct research and apply this knowledge to practical problem solving and product assessment (Baekgaard and Lystbaek, 2019). To successfully identify what and how to teach research methods to engineering students can be a challenging task because engineering research involves a wide range of disciplines, and it can adopt many methods. In a recent review of engineering design RMs, Escudero-Mancebo et al. (2023) found that no single method or approach could be applied. Instead, a wide range of data collection methods and approaches have been adopted. Notably, qualitative methods have been significantly preferred, possibly due to the recognition of engineering design as a complex process that affects humans and their environments (Escudero-Mancebo et al., 2023). The diversity of RMs in engineering research is also evident from recent calls for more transdisciplinarity and convergence with methods commonly employed in social science research, as engineering researchers see the value of involving human and organisational considerations within their practices (Szajnfarber and Gralla, 2017; Lenberg et al. 2023). Hence, postgraduate RM courses in engineering must provide students with the understanding of a variety of methods which they might use in their academic and professional research.

Threshold concepts can provide a framework to define foci for RM teaching. Defined as topics or themes that transform student's understanding of a subject, they hence play a crucial role in development of knowledge (Barradell 2013; Olaniyi, 2020). Threshold concepts in RM include the research process, setting a problem, question, and objectives, understanding constructs and operational definitions, and research approaches and designs (Manyiwa 2003). In addition, writing up research findings might also be considered a threshold concept (Harlow and Peter 2014; Humphrey and Simpson 2011; Johnson 2014). In our experience working with diverse postgraduate students enrolled in postgraduate education in engineering and management, the concepts students find most troublesome and transformational include diverse research paradigms, research ethics, and the integration of human participants in engineering research. To help students grasp threshold concepts requires a teaching approach that helps to understand, interpret, and apply content (Zepke, 2013:99). For example, Olaniyi (2020) used flipped lessons to increase active learning and comprehension of threshold concepts in thermodynamics lessons. Other pedagogical approaches should also be considered, such as using multimedia to support delivery.

1.2 The use of popular films in teaching and learning

The idea of using popular films in teaching and learning is not new. For example, in the UK the membership organisation Learning on Screen (n.d.) has been working to promote the use of film in higher education and research since 1948. This method has also been used in primary and secondary education, for instance teaching history in US ninth-grade classes (Stoddard, 2012). Films have also been recognised as one of the most effective ways to engage with students from different cultural backgrounds, helping to learn about different cultures and languages (Wang, 2009; Nur, 2016). Some research suggests that university teachers integrate popular films in their practice (Goldenberg, Lee and Obannon, 2010). However, in our experience it is a method that is not widely used in engineering education. Despite that, the use of popular films in teaching can function as an active learning method and provide an opportunity for students to reflect deeply on issues covered in class (Blasco, Moreto, and Pessini 2018).

Kankal et al. (2023) presented a systematic literature review on the use of films as a pedagogy tool in management education. They report that three themes emerged from their study: at the 'Teacher-level' research points to the need to prepare, select and connect themes from films to the subject, at the 'Teacher-student-engagement-level' films encourage active learning and deep learning, and at the 'Students learning experience-level' films encourage reflection, camaraderie and challenge perceptions of the subject. Yesildag and Bostan (2023) found that, for undergraduate health management students, watching a feature length film followed by discussion with a teacher had a significant impact on students' exam results, when compared to students who did not watch a movie or watched it without guidance. Additionally, they found that student satisfaction with this teaching method was high due to its more engaging nature in comparison with traditional lecturing. Rather than watching full feature films, some teachers use film excerpts: Blasco, Moreto, and Pessini

(2018) used film clips to teach ethics to medical students. They found that sharing life stories from films increased discussion and the recognition of emotional responses to case studies. In a similar approach, Moskovich and Sharf (2012) integrated films in their “Introduction to Sociology" and "Organizational Behavior" courses to enrich sociological and organizational learning, engaging students through cinematic examples to concretize abstract concepts, facilitate critical analysis, and encourage reflective discussions on theoretical applications. It is evident from this research that the decision to integrate films into teaching should consider the aims for which they are used and the format in which they will be shown.

Moreover, the choice of films is also an important consideration. Pandey and Ardichvili (2015) employed the film "Outsourced" for teaching intercultural concepts within higher education settings in India and the United States, effectively raising awareness of cultural differences, stimulating discussions on stereotypes and adaptation processes, and enriching students’ comprehension of cross-cultural communication and cultural intelligence. Toye et al. (2015) utilized the film 'Struggling to be Me' in clinical education to present insights into chronic pain, fostering students' deep understanding of patients' personal struggles, the limitations of the medical model, and emotional responses to despair. Considering the messages to be picked from each selected film requires the active involvement of the teaching team.

1.3 Research methods teaching and learning through popular films

Despite its widespread application across various fields, the use of films in teaching research methods seems uncommon, with relevant research being very limited. Tan and Ko (2004) explored the use of feature films in an undergraduate research methods course, addressing the challenge of teaching the fundamental role of empirical evidence in sociology. They concluded that using a film as part of an observation task allowed students to observe the same phenomenon and learn through reflection by comparing their findings. It must be noted that full length feature films were used as examples of social phenomenon and not as research methods examples. Only the article by Saldaña (2009) outlines the use of film in graduate-level qualitative research methods courses as an innovative instructional strategy. By employing cinematic excerpts, Saldaña aims to clarify complex concepts, stimulate classroom discussion, and enhance students' understanding of qualitative inquiry. For example, they use an excerpt from The Matrix (Wachowski and Wachowski, 1999) to discuss epistemology and ontology, and an excerpt from The Silence of the Lambs (Demme, 1991 in Saldaña, 2009) to explore phenomenology. Feeback from graduate students indicated that using film clips is “novel, motivating, enjoyable to watch and help clarify concepts” (Saldaña, 2009: 259).

Building on this foundation, our practice seeks to extend the application of the use of films within educational settings, specifically focusing on using films to deepen postgraduate students' understanding of research methodology, including aspects such as research paradigms, ethics in research design, and formulating research questions.

2 CASE STUDY: RESEARCH METHODS FILM CLUB

Since January 2024, we have offered a Research Methods Film Club as a co-curricular activity open to all current postgraduate students at WMG, most of whom are enrolled in full-time master's courses (around 1,500 vs around 250 PhD students). In this section, we describe the Film Club and present our initial reflections.

2.1 Co-creating a Research Methods Film Club

One of the authors wondered how popular films could be used to enhance the student experience around RM learning. They were aware of the excellent resource provided by Learning on Screen (n.d.), which makes copyright approved video and film recordings available for teachers. They proposed that a Film Club might provide a fun experience, while also giving space for reflection on research related threshold concepts. Three Graduate Teaching Assistants (GTAs) joined the project as student co-creators; as current PhD students, they brought their personal perspective and understanding of RM.

We agreed that each session would include a teacher led introduction to the week 's theme and how the firm relates to it, a film screening, and a plenary Q&A session. Including students as co-creators in this project provided insights on what contents might be useful for attendees. For example, GTAs suggested that reflection questions were posed before watching each movie. They also provided guidance on which concepts might need deeper explanations and which methods we could use to introduce them (e.g. choosing existing videos, teacher talk).

The teacher chose the first two films. Attending students have since been able to choose which film will be scheduled next, from a curated list of films that relate to research methods and are available to watch through Box of Broadcast (Makrinov, n.d.). Students have been invited to share ideas for further movies to be added if they can demonstrate how they relate to RM. Details of films and themes covered are presented in Table 1.

Table 1. Film club timetable

	Film	Theme
12 January 2024	The Matrix (Wachowski and Wachowski, 1999)	Research paradigms
7 February 2024	The Stanford Prison Experiment (Alvarez, 2015)	Ethics in design
8 March 2024	Inception* (Nolan, 2010)	The research process
19 April 2024	The Truman Show* (Weir, 1998)	Observation
10 May 2024	Gorillas in the Mist (Apten, 1988)	Action research
Other curated films	Kinsey (Condon, 2004)	Interviews and coding
	Experimenter (Almereyda, 2015)	Research design and deception
	Miss Evers' Boys (Sargent, 1997)	Participant engagement
	Radioactive (Satrapi, 2019)	Lab research

* Films chosen and voted for viewing by students

All postgraduate students at WMG are invited to attend the events; they can choose how many and which they take part in. Due to the size of the room, up to 99 students can book into each.

The Film Club was announced through various means, including mentions on the Student Experience weekly newsletter, module announcements for a research methods module offered to most master's students, listings on a university's event booking system, and digital posters displayed in screens across the department (see Fig. 1).

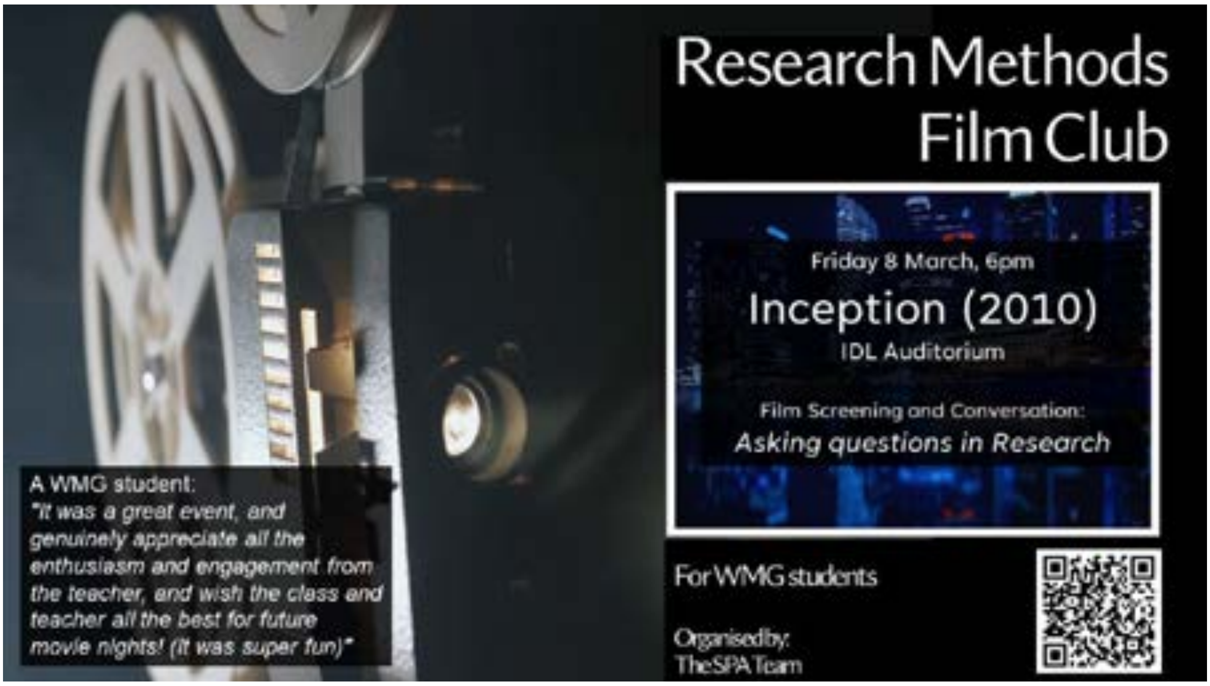

Fig 1. Digital screen poster example

3 ONGOING RESEARCH

We are currently conducting a study which will provide additional evidence through the evaluation of the student's perception of the pilot Research Methods Film Club. The study addresses the research question: How do postgraduate students perceive the use of popular films in supporting the teaching of research methods?

This exploratory study follows a participatory action research approach (Baumfield, Hall and Wall, 2013; Dickens and Watkins, 1999; Kemmis, McTaggart and Nixon, 2014). The research team includes two current PhD students at WMG, their involvement reflects the participation of users in the design of the Film Club as an intervention, in line with the University of Warwick's (n.d.) commitment to co-creation. Following action research approaches, the study will include cycles of reflection and (re)design of 5 guided RM Film Club sessions.

At the end of each session taking place after ethical approval was granted, participants are invited to complete a short online survey designed on Qualtrics, including questions about demographic characteristics and participants' reflections after the event. Participants are also being invited to take part in a semi-structured focus group taking place after each session. Additional focus groups will be offered after the final session so all students who want to participate in the study can do so.

It is important to note that the study focuses on student perceptions, as an initial exploratory analysis of the potential effectiveness of using a Film Club to support Research Methods teaching and learning. We expect results will provide an insight on the reaction of participant, but does not represent a full evaluation. Following Kirkpatrick's model (Kirkpatrick and Kirkpatrick, 2016), future research can be conducted to evaluate the impact on learning, behavioural change, and results.

Participants are selected through convenience sampling. All full-time master's students at WMG in 2034/24 and all PhD students at WMG in the same period are invited to participate in the Film Club (an estimated population of around 2,000 students). Up to 99 students can participate in one or more Film Club sessions, places are allocated on a first come first served basis.

Quantitative data will be analysed using SPSS. Descriptive statistical analyses will be conducted with demographic data, to ensure the sample is appropriately described. Closed questions in the survey will be reported through descriptive statistics. If response rates allow, inferential statistics will be used to compare responses between groups (e.g. students in different courses or from different countries).

Qualitative data will be analysed following using thematic analysis to allow deep understanding of the experiences of participants (Braun and Clarke, 2021). Qualitative data to be analysed includes open questions in the survey and data collected through focus groups and/or interviews. Text data will be coded and grouped into themes, using a reflexive collaborative coding approach that is informed by the positionality of the researchers.

4 REFLECTIONS ON OUR PRACTICE

So far, our experience of organising the RM Film Club has been positive and we would encourage educators to consider similar approaches. We participate because it is an innovative approach to teaching and engaging with students. Using films, students have discussed RM themes in settings that are unusual. Moreover, informal feedback from students and staff has related to how fun and learning have been brought together in this activity. We expect that participation in the film club will help students develop an understanding of the whole picture of what research looks like, and an in-depth grasp of some of the threshold concepts that will allow them to succeed in their research projects.

Many of our students watch films for entertainment, they enjoy watching them. By participating in the Film Club, they have had the opportunity to watch older films in a big screen. RM, in contrast, can be perceived as boring. A short add on reflection to a fun experience can support student engagement with the subject and that may positively influence their learning. We believe the balance between a brief period focusing on RM context and a long time spent watching a full-length feature film has been important to achieve this. RM seems like an add on, while when clips are used as part of teaching the films theory takes precedence over fun.

Adding reflective questions and an opportunity for discussion has provided a no pressure environment for students to participate. We have observed that they engage more with the conversation during Film Club than they do in small group teaching sessions. In both scenarios, attendance is optional. However, it is possible that students perceive that they have different motivations from taking part. There are also variations in the level of engagement as a response to the theme and movie. We believe Stanford Prison Experiment (Alvarez, 2015) has been our most successful screening so far. The film stuck a cord with our students, who seemed to display a strong emotional reaction. This led to a long 30-minute question and answer session in which we shared concerns about the importance of research ethics and reflections on power and powerlessness. In comparison, the question-and-answer sessions for The Matrix (Wachowski and Wachowski, 1999) and Inception (Nolan, 2010) where shorter, at just around 10 minutes each.

The role of organisers as curators is also important. For example, we did not watch Inception (Nolan, 2010) before presenting it to the group and chose the theme based on a student recommendation. We were all (students and staff) baffled by how we could relate the film to RM, until one of the GTA organisers suggested the film would provide an excellent opportunity to reflect on the research process rather than our planned discussion on research questions.

Others may wish to implement a similar approach in a different university or with different content matter. From our experience, we would recommend considering the intended outcomes of such an activity. Using full movies, as we have done, has the potential to support deep learning but also takes time which may be limited. Hence, a Film Club might work best as a co-curricular activity that aims to develop a community of practice and improve the student experience, as well as supporting learning in a particular subject. We would also recommend that educators co-create the activity with students, this adds value as it considers diverse perspectives. Curating and planning how each film relates to the subject matter provides a basis for conversations that allow students to construct their knowledge in an active way. It should be noted that using media such as popular films in teaching requires consideration of copyright and permissions; educators should make informed decisions, which an be supported through their local libraries.

Our current research project is exploratory and focuses on student perceptions. It is important to us that those who take part report that they enjoy the event and that they have learnt. Future research should focus on an impact evaluation, as we are aware that the perception of learning does not equate to learning. We would like to answer the research questions “Do students learn by participating in the RM film club?” and “Does participating in RM Film Club make a difference in students’ research performance?”.

REFERENCES

Almereyda, Michael. Experimenter. United States: Magnolia Pictures (2015).

Alvarez, Kile Patrick. *The Stanford Prison Experiment.* United States: IFC Films, 2015.

Baekgaard, Lars and Christian Tang Lystbaek. Learning to do knowledge work: a framework for teaching research design in engineering education. *International Journal of Engineering Education*, 35, 1B (2019):333–344.

Barradell, Sarah. “The identification of threshold concepts: a review of theoretical complexities and methodological challenges” Higher Education, 65, 2 (February 2013): 265–276. https://doi.org/10.1007/s10734-012-9542-3

Baumfield, Vivienne, Elaine Hall, and Kate Wall. Action research in education: Learning through practitioner enquiry (Second ed.). Online: SAGE (2017). https://doi.org/10.4135/9781526402240

Blasco, Pablo González, Graziela Moreto and Leo Pessini. “Using movie clips to promote reflective practice: a creative approach for teaching ethics”. *Asian Bioethics Review,* 10 (2018), 75–85. https://doi.org/10.1007/s41649-018-0046-z

Braun, Virginia and Victoria Clarke. *Thematic analysis: A practical guide to understanding and doing (1st. ed.).* London: SAGE (2021).

Condon, Bill. *Kinsey.* United States: Fox Searchlight Pictures (2004).

Dickens, Linda and Karen Watkins. “Action research: Rethinking Lewin”. Management Learning, 30, 2 (June 1999): 127-140. https://doi.org/10.1177/1350507699302002

Escudero-Mancebo, David, Nieves Fernández-Villalobos, Óscar Martín-Llorente, and Alejandra Martínez-Monés. 2023. “Research Methods in Engineering Design: A Synthesis of Recent Studies Using a Systematic Literature Review.” *Research in Engineering Design* 34 (2). Springer Science and Business Media Deutschland GmbH: 221–56. doi:10.1007/s00163-022-00406-y.

Goldenberg, Marni, Jason W. Lee and Teresa Obannon. “Enhancing recreation, parks and tourism courses: Using movies as teaching tools”. *The Journal of Hospitality Leisure Sport and Tourism,* 9**,** 2 (2010): 4-16.

Harlow, Ann and Mira Peter. “Mastering threshold concepts in tertiary eduction: “I know exactly what you are saying and I can understand it but I’ve got nowhere to hook it”.”. Waikato Journal of Education, 19, 2 (2014): 7-23. https://doi.org/10.15663/wje.v19i2.95

Humphrey, Robin and,Bob Simpson. “Writes of passage: writing up qualitative data as a threshold concept in doctoral research.” *Teaching in Higher Education,* 17, 6: 735–746. https://doi.org/10.1080/13562517.2012.678328

Johnson, E. Marcia. “Doctorates in the dark: threashold concepts and the improvement of doctoral supervision”. Waikato Journal of Education, 19, 2 (2014): 69-81.

Kankal, Bhushan, Santosh Kumar Patra and Rasananda Panda. “Pedagogy innovation and integration of films in management education: Review and research paradigms”. *The International Journal of Management Education,* 21**,** 2 (2023): 100804. https://doi.org/10.1016/j.ijme.2023.100804

Kemmis, Stephen, Robin McTaggart, R. and Rhonda Nixon, R. *The action research planner: Doing critical participatory action research.* Online: Springer (2014). https://doi.org/10.1007/978-981-4560-67-2

Kirkpatrick, James D. and Wendy Kayser Kirkpatrick. *Kirkpatrick's four levels of training evaluation.* Association for Talent Development.

Learning on Screen. *The Learning on Screen story. (n.d.)* Accessed on 5 April 2024 from https://learningonscreen.ac.uk/about-us/the-learning-on-screen-story/

Lenberg, P., Feldt, R., Gren, L., Wallgren Tengberg, L. G., Tidefors, I., and Graziotin, D. (2023). “Qualitative software engineering research: Reflections and guidelines.” *Journal of Software Evolution and Process*, https://doi.org/10.1002/smr.2607

Manyiwa Simon. “Threshold concepts in teaching and learning undergraduate marketing research”. Middlesex University Discussion Paper 40 (November 2006)., Available at http://eprints.mdx.ac.uk/10040/1/Manyiwa.pdf [Accessed on 07.04.2024]

Moskovich, Yaffa and Simha Sharf. “Using films as a tool for active learning in teaching sociology. *Journal of Effective Teaching*, *12*, 1 (2012), 53-63.

Nolan, C. *Inception*. United States, Warner Bros: 2010.

Nur, S (2016) Increase Students’ Cultural Awareness by using film in teaching cross cultural understanding. *TEFLIN International Conference, 371-373*. Available at https://core.ac.uk/reader/43025554 [Accessed on 07.06.2024]

Olaniyi, Nkaepe E.E. “Threshold concepts: designing a format for the flipped classroom as an active learning technique for crossing the threshold.” *Research and Practice in Technology Enhanced Learning,* 15: 2 (2020). https://doi.org/10.1186/s41039-020-0122-3

Pandey, Satish and Alexandre Ardichvili. “Using films in teaching intercultural concepts: An action research project at two universities in India and the United States”. *New Horizons in Adult Education and Human Resource Development*, *27*, 4 (27 October 2015): 36-50. https://doi.org/10.1002/nha3.20121

Saldaña, Johnny. “Popular film as an instructional strategy in qualitative research methods courses”. *Qualitative Inquiry*, 15, 1 (25 August 2008): 247-261. https://doi.org/10.1177/1077800408318323

Sargent, Joseph. *Miss Evers’ Boys.* United States: HBO NYC Productions (1997).

Satrapi, Marjani. *Radioactive.* United Kingdom: Working Title Films and Shoebox Films (2019).

Szajnfarber, Z., and Gralla, E. (2017). “Qualitative methods for engineering systems: Why we need them and how to use them.” *Systems Engineering*, 20 (6), 497-511. https://doi.org/10.1002/sys.21412

Stoddard, J. D. (2012) “Film as a ‘thoughtful’ medium for teaching history.” *Learning, Media and Technology,* 37, 3, pp.271-288.

Tan, JooEan and You-Chung Ko. “Using feature films to teach observation in undergraduate research methods”. *Teaching Sociology*, 32, 1 (January 2004): 109-118. http://dx.doi.org/10.1177/0092055X0403200110

Toye, Fran, Sue Jenkins, Kate Seers and Karen Barker. “Exploring the value of qualitative research films in clinical education”. *BMC Medical Education*, 15 (2015): 214. https://doi.org/10.1186/s12909-015-0491-2

University of Warwick. *Excellence with Purpose – University Strategy.* Retrieved on 8 April 2024 from https://warwick.ac.uk/about/strategy/

Weir, P. *The Truman Show.* United States, Paramount Pictures: 1998.

Yesildag, Ahmed Y. and Sedat Bostan. “Movie analysis as an active learning method: A study with health management student”. *The International Journal of Management Education*, 21, 1 (March 2023): 100759, https://doi.org/10.1016/j.ijme.2022.100759

Zepke, Nick. “Threshold concepts and student engagement: Revisiting pedagogical content knowledge”. *Active Learning in Higher Education,* 14, 2 (July 2013): 97-107. https://doi.org/10.1177/1469787413481127

Wachowski Lana and Lilly Wachowski. *The Matrix.* United States: Warner Bros, 1999

Wang, Y. (2009). Using films in the multimedia English class. English Language Learning,2(1), 179-184. https://10.5539/elt.v2n1p179

ROLE OF AI IN HIGHER EDUCATION: OPPOPTUNITIES AND CHALLENGES OF USING AI TECHNOLOGIES

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ABSTRACT

Artificial Intelligence (AI) is transforming our world by enhancing efficiency and supporting decision-making across various sectors. It enables machines to learn from experience, adjust to new inputs, and perform human-like tasks. In education, AI is revolutionizing learning, teaching, assessment, and administrative work. AI enables personalized learning experiences, assists educators in curriculum development, and offers real-time feedback. Additionally, AI streamlines assessment by automating grading and providing insights into student performance. For administrative tasks, AI improves efficiency in student admissions and resource management. This integration of AI in various educational aspects enhances the overall quality and effectiveness of the educational process. This research paper explores the multifaceted role of AI in higher education, examining its current applications, opportunities, and challenges. It delves into various AI methodologies such as Machine Learning, Neural Networks, and Natural Language Processing, applied in educational settings to enhance teaching, learning, and administrative processes. The paper addresses three critical questions: what the AI techniques are currently used in education, what are the potential benefits AI brings to the higher education sector, and what are the challenges of integrating AI in educational contexts. Based on the findings, we have delineated the gradual steps we are implementing to incorporate AI into the framework of our universities.

1 INTRODUCTION

The concept of Artificial Intelligence (AI) often sparks extensive debate regarding its precise definition and meaning. For instance, one definition frames AI as a specialized branch within computer science, focusing on creating computers capable of performing tasks that typically require human intelligence. These tasks include the ability to learn, reason, and self-correct, mirroring human cognitive processes. This perspective emphasizes AI's goal to replicate or simulate human-like thought and reasoning in a computational context (Kok et al., 2009). AI is a transformative force in various fields, including education (Gruetzemacher and Whittlestone, 2022). Its integration into education has opened new avenues for enhancing teaching and learning experiences (Ng et al., 2023). The application of AI in higher education is multifaceted. It includes personalized learning experiences through adaptive learning systems, automation of administrative tasks, and provision of intelligent tutoring systems. These applications aim to enhance student engagement, improve learning outcomes, and optimize educational processes. This paper presents a review of AI technologies in higher education, focusing on the current AI techniques used in educational tools, their positive impacts on various aspects like learning, teaching and administration, and the challenges associated with the use of AI in education.

The importance of this research lies in its potential to influence future educational strategies and policies. This understanding is vital for educators, administrators, policymakers, and students, as it guides the development of more effective, efficient, and equitable educational systems. This paper is organised as follows: Section 2 presents a review of AI technologies in higher education, focusing on the current AI techniques used in educational tools, their positive impacts on various aspects like learning, teaching and administration, and the challenges associated with the use of AI in education. Section 3 elaborates on the strategies for incorporating AI at Bahria University (Pakistan) and University of Warwick (UK). Finally, conclusions are presented in Section 4.

2 LITERATURE REVIEW

In this section, we present a review of AI technologies in higher education. We delve into the current AI techniques utilized in educational tools, explain their positive impacts on various aspects such as learning, teaching, and administration, and identify the challenges associated with their integration into education.

2.1 Current AI Techniques used in Educational Systems

AI techniques, such as machine learning, deep learning, and natural language processing, are being increasingly applied in the field of education to improve the teaching and learning process. Machine learning plays a crucial role in education by automating tasks like grading, generating questions, and providing personalized learning experiences (Alpaydin, 2020; Kučak et al., 2018; Asthana and Hazela, 2020; Nafea, 2018). Various machine learning algorithms, including Linear Regression, Logistic Regression, Neural Networks, Decision Trees, Naïve Bayes, Support Vector Machines, Fuzzy Logic, and a combination of these techniques, are commonly used in educational systems for enhancing the overall learning experience (Halde, 2016; Korkmaz and Correia, 2019; Shrestha and Pokharel, 2019; Farhat et al., 2020).

Linear Regression is frequently employed in forecasting student achievement, whereas Logistic Regression acts as a preemptive alert mechanism for underperforming students (Halde, 2016; Poh and Smythe, 2014; Sagala et al., 2022). A linear regression model was devised by Gadhavi and Patel (2017) to aid students in predicting their grade in a specific subject. Nonetheless, the limitation of linear regression is its inability to accurately capture nonlinear patterns among the variables (Rao and Nagaraj, 2014). Adaptive tutoring systems have successfully incorporated neural networks, such as artificial neural networks and reinforcement learning, resulting in impressive levels of accuracy (Fenza et al., 2017; Lukic and Acuna, 2012). Automated essay scoring and the categorization of students' study habits have been effectively carried out using Naïve Bayes classifiers (Mulyati and Setiani, 2018). Gutierrez and Atkinson (2011) devised an AI technique for adaptive feedback in foreign language Intelligent Tutoring Systems by combining support vector machines and Conditional Random Fields (CRF). By analyzing classroom interaction data, they were able to predict effective feedback strategies. Their approach demonstrated superiority over traditional methods, as it dynamically adjusted feedback based on the dialogue state, guiding students towards correct answers with minimal intervention.

Deep learning plays a crucial role in natural language processing (NLP). Recurrent Neural Networks (RNNs) are particularly adept at tasks such as language modeling and machine translation, while Convolutional Neural Networks (CNNs) excel in text classification and sentiment analysis. Long Short-Term Memory (LSTM) networks, a subtype of RNN, are valuable for sentiment analysis and text generation. A significant advancement in NLP is the emergence of transformer models like BERT (Bidirectional Encoder Representations from Transformers), which are highly effective in question answering and named entity recognition tasks. Transformers leverage self-attention mechanisms to grasp intricate word relationships, thereby enhancing performance and contextual understanding in NLP. This breakthrough has resulted in substantial enhancements across various NLP applications (Otter et al., 2021). Generative Pre-trained Transformer (GPT) is an advanced NLP model that utilizes transformer decoder blocks. It operates in a unidirectional manner, focusing on preceding words, unlike BERT which predicts masked words. GPT does not incorporate an encoder or cross-attention. Its primary function is to predict the next word in a sentence based on previous words, generating coherent and contextually relevant text extensions. For example, if the initial content revolves around psychology, the trained GPT model will continue generating words and sentences related to psychology, thereby completing the text. It is important to note that GPT functions as an unsupervised model (Topal et al., 2021). Following the launch of the GPT known as ChatGPT, in November 2022, there has been a surge of interest worldwide in generative artificial intelligence (AI) (Van den Berg and du Plessis, 2023). Numerous researchers have delved into the potential and challenges posed by AI and tools like ChatGPT in the field of education. Many explore the opportunities it offers and how it could potentially reshape educational environments and practices (e.g. (Javaid et al., 2023; Adeshola and Adepoju, 2023)). Simultaneously, they express concerns regarding the potential for AI-generated misinformation and biases, delving into the ethical implications that arise (e.g. (Kasneci et al., 2023; Saunders, 2023; Adeshola and Adepoju, 2023, Huallpa, 2023).

2.2 Current opportunities in AI enhanced Education

In this section, we present an overview of educational tools which are utilized by several authors to automate their learning, teaching, assessment, and feedback process. This section also covers how AI can help teachers to do course designing, planning and complete administrative tasks.

2.2.1 Learning and Teaching

Computer-based learning is being progressively merged with AI methods to create personalized educational systems, commonly referred to as Intelligent Tutoring Systems (ITSs). These systems leverage AI to recognize students' comprehension levels and tailor learning materials, accordingly, supporting them in reaching their full potential (Mousavinasab et al., 2021; Liriwati, 2023). Among AI tools, chatbots play a significant role in educational activities. Studies have shown that AI chatbots in programming courses can significantly enhance student learning by providing timely support and fostering independent work (Verleger and Pembridge, 2018). For example, Ismail and Ade-Ibijola (2019) developed an interactive AI chatbot using IBM Watson API, assisting beginners in programming, and addressing academic questions effectively. Additionally, AI chatbots like EnglishBot and "Ellie" have shown effectiveness in improving fluency and engagement in language learning classes (Ruan et al., 2021; Yang et al., 2022). Moreover, systems like Robo-Sensei, TAGARELA, and E-Tutor have been successfully integrated into language classrooms, offering personalized learning environments, and supplementing existing pedagogical materials through a combination of NLP and AI approaches (Slavuj et al., 2015).

2.2.2 Assessment and Feedback

Automated Essay Scoring (AES) systems offer efficient essay grading by reducing the need for human assessors, with recent advances in deep learning enhancing their capabilities (Uto et al., 2020; Hussein et al., 2019). Studies have developed AES using methods like regression and clustering, focusing on text features such as word count and syntax, with evaluations revealing satisfactory correlations with human grading (Ramalingam et al., 2018; Salim et al., 2019; Song and Zhao, 2013). Advanced AES models have been developed focusing on detailed essay traits like organization, coherence, and language proficiency (He et al., 2022; Hussein et al., 2020). Question Generation models have been developed for educational purposes using machine learning methods, including NLP and image captioning, to generate questions from text and images (Kokku et al., 2018; Srivastava et al., 2020). Large Language Models (LLMs) like ChatGPT have been explored for generating high-quality quiz questions, delving into different facets of the topic (Lee et al., 2023; IONESCU and ENESCU, 2023; Zhu et al., 2023). Automated Question Generation aims to ease the task of making evaluations and assessments for teachers, with various techniques producing a variety of question types, including multiple choice and true/false questions (Hsiao and Chung, 2022; Killawala et al., 2018). Overall, Question Generation models have been created for educational objectives, providing a range of question types tailored to different learning needs (Chung et al., 2023; Lu et al., 2021).

2.2.3 Course Designing, Planning, and Administrative Function

Educators are utilizing AI capabilities for curriculum development and lesson planning. In addition, generative language models like ChatGPT enhance educational equity and accessibility by providing free resources like lesson plans and supplementary materials through generative language models such as ChatGPT (Somasundaram et al., 2020; Revelle, 2023; van den Berg and du Plessis, 2023). Some studies have only briefly mentioned lesson planning and course design, leaving a noticeable gap in the literature on this topic. Adoption of AI-based technologies relieves teachers of routine administrative tasks, allowing them to focus more on personalized advising, coaching, and counseling (Kuleto et al., 2021). AI chatbots are handling inquiries from students and parents, with their interaction improving over time, and institutions like Siglo 21 University are leveraging them to provide support to its extensive student body (Kurni et al., 2023; Aivo, 2023). Additionally, AI models are optimizing university admissions processes, although concerns have been raised regarding potential biases in such systems (Vohra, 2011; Waters and Miikkulainen, 2014; Marcinkowski et al., 2020; Martinez Neda et al., 2021).

2.3 Challenges associated with applying AI in education

Current challenges in applying AI in education are multifaceted, spanning accuracy, biases, explainability, and ethical deployment.One of the concerns about the reliability of the process of making decisions through algorithms is the utilization of surrogate indicators, where quantified data serves as a substitute for complex phenomena (Marjanovic and Cecez- Kecmanovic, 2017). These systems, lacking true understanding, may assign high scores to flawed essays, presenting challenges in reliable assessment (Berrett, 2013). Biases in AES systems, inherited from human assessment data, pose another hurdle, potentially perpetuating and amplifying existing biases (Marcinkowski et al., 2020). Moreover, the lack of explainability in AI algorithms hinders trust and raises questions of fairness and accountability, especially in contrast to human assessors who provide clear feedback (Aloisi, 2023).

The introduction of ChatGPT further complicates matters, with educators worried about its potential to facilitate plagiarism and compromise academic integrity (Rudolph et al., 2023; Dibble, 2023). A review by (Sallam, 2023) of 60 studies on ChatGPT revealed various concerns and potential risks associated with its usage. These encompass ethical considerations, the risk of bias, plagiarism, copyright issues, transparency concerns, legal implications, lack of originality, potential for incorrect responses, limited knowledge, inaccurate citations, the generation of misinformation, and the provision of incorrect or nonsensical answers. Moreover, the constrained knowledge base, which is limited to information available up to the year 2021.

Ethical deployment of AI in education encompasses privacy, anonymity, surveillance, autonomy, non-discrimination, and data ownership concerns. The collection and analysis of extensive student data raise privacy issues, necessitating measures to protect personal information (Kamenskih, 2022). Additionally, anonymity comes as a concern because its challenging to balance personalized learning with privacy rights arises due to AI's ability to identify individuals (Sweeney, 2000). Surveillance in AI-driven education may restrict student autonomy and raise fairness concerns, highlighting the need for transparent data ownership and control measures to safeguard individuals' rights (Dabbagh et al., 2021);

The use of AI in education facilitates a more detailed and continuous observation of students by collecting data on their learning processes and capturing learners' patterns of reviewing the content or responding to questions to gain insights into their thinking processes. All this information is then fed into predictive analytics programs to ascertain student learning patterns, strengths, weaknesses, and generate personalized recommendations based on their needs (Regan and Jesse, 2019). However, students' engagement in the learning process may be restricted if they know that their online interactions and activities are monitored and tracked, as it may make them feel unsafe about freely expressing their thoughts (Remian, 2019; Akgun and Greenhow, 2021). Surveillance systems give rise to autonomy-related concerns (Akgun and Greenhow, 2021). Different previous studies have highlighted various concerns related to autonomy in AI-based systems, revealing instances where these systems may compromise or limit human autonomy. AI technologies are currently employed to dynamically tailor and personalize the options or choices presented to individuals using previously unseen methods (Yeung, 2019; Pariser, 2011) and the increase in effectiveness brought by AI is not enough to justify giving up decision-making authority to the machines. Autonomy constitutes another concern linked to AI, specifically focusing on the principle of treating individuals fairly and impartially, without discrimination based on attributes such as race, gender, or age, and even considering factors of which they may not be aware. As more and more judgements are left to artificial intelligence (AI) methods like machine learning, digital discrimination is turning into a major problem (Ferrer et al., 2021). Lastly, it has long been acknowledged that issues pertaining to data ownership and control over their interpretations are crucial to AI in education (Bull and Kay, 2016)

3. INTEGRATING AI TO SUPPORT STUDENT SUCCESS

To effectively integrate AI to support student success, a structured framework is essential. This framework should encompass several key elements. First, identify student needs by analysing the student population to understand their backgrounds, learning styles, and any specific challenges they may face. Next, develop AI-powered tools that address these identified needs. Following this, pilot and refine the tools by starting with a small-scale pilot programs to test the AI tools and gather feedback from students and instructors. Finally, adopt continuous improvement by continuously monitoring and evaluating the impact of the AI tools. This could involve analyzing student performance data, satisfaction surveys, and focus groups. Use this data to further improve the AI tools and ensure they are meeting student needs.

3.1 Bahria University

The thorough literature review enabled us to propose AI based student centered support system at Bahria University where we will blend AI harmoniously into the life of each learner to ensure continuity, accountability, and support on their educational path. One of our key initiatives involves the development of a prototype aimed at facilitating access to information across multiple books and summarizing it for students. This prototype leverages AI technology to enable students to answer questions sourced from various textbooks efficiently. Rather than relying on a single source, students can benefit from insights gathered from a diverse range of materials. The prototype operates through a series of integrated features: Multi-Source Data Retrieval retrieves pertinent information from diverse educational resources. Students can input queries into the interface, prompting AI-driven question-answering models to analyse and generate accurate responses sourced from various texts. Additionally, the prototype offers a summarization feature, condensing information from multiple sources into concise summaries for easier comprehension of key concepts. We are currently working on Its interface to facilitate seamless navigation including search functionalities, filters, and visualization tools. Furthermore, a feedback mechanism will be incorporated to allow students to contribute input on the relevance and accuracy of answers and summaries, aiding in the refinement of AI algorithms for continual improvement. The prototype is now ready. We will identify few courses in the Department of Computer Engineering to test it during the Fall 2024 semester.

Another initiative is to equip students right from their start at campus, helping them choose modules corresponding to their potential and preferences during the duration of their studies at the University.

It involves assisting students in selecting their modules based on their academic performance. By analysing their previous grades and performance data, AI algorithms can provide personalized recommendations on which subjects students may excel in and which ones may not be suitable. This tailored guidance aims to help students make informed decisions about their course selections, ultimately enhancing their academic journey and improving their overall learning experience. Currently, our dedicated student advisors guide students who have encountered academic setbacks (failing one or two subjects) towards suitable modules for the following semester. This personalized approach considers both a student's academic record and their interests, ensuring a manageable work load and minimizing the risk of future failures. This process currently occurs at the start of each semester for each student facing academic challenges. We aim to develop an AI-powered course recommendation system aimed at alleviating the workload of our advisors. We're in the phase of collecting this data that will be used to train the AI model. This AI system will automate a significant portion of the data analysis currently performed by the faculty, freeing up valuable time for advisors to focus on deeper student engagement and personalized support.

3.2 WMG, Warwick University

At WMG (one of the largest department at the University of Warwick) , our objective is to leverage AI to enhance our understanding of students' needs. Our goal is to employ AI methodologies to deliver personalized learning experiences to our students Our student body comprises undergraduate and postgraduate students from the UK and various other countries, alongside participants in our industry-led degree apprenticeships at Warwick, where apprentices engage in industry work alongside pursuing their degree programs. The diverse nature of our student population necessitates a nuanced approach to addressing their needs, which is influenced by factors such as the mode of provision they receive and whether they are actively engaged in industry work.

Our first initiative is to develop AI support system for our degree apprenticeship students as they struggle with work life balance because they are studying and working at same time. In degree apprenticeships, we conduct a comprehensive skills assessment prior to the start of the program for each apprentice, aiming to ascertain their existing skills, learning requirements, backgrounds, strengths, and prior knowledge. We will allows us to tailor the module content delivery according to the individual preferences and needs; for instance, adapting content for visual learners or those who prefer textual materials. Additionally, we recognize the importance of accommodating students with physical or mental disabilities, and thus, we are working on leveraging AI to customize content and delivery methods accordingly. The implementation of AI based support tool for DAs is in progress and prototype will be ready in next three months.

Looking ahead, we plan to implement diagnostic testing for both undergraduate (UG) and postgraduate (PG) students to gain insights into their unique learning requirements. By doing so, we aim to offer flexible learning opportunities that cater to individual strengths and areas for improvement. This proactive approach aligns with our commitment to providing inclusive and effective educational experiences for all students, regardless of their learning styles or challenges they may face.

With numerous AI tools like Dall-E, Microsoft Co-pilot, ChatGPT, and Stable Diffusion accessible online, our goal is to enhance the skills of our teaching and administrative staff in using these technologies. By doing so, we aim to automate routine administrative tasks, increasing efficiency and reducing workload. Furthermore, we plan to leverage AI capabilities to predict enrolment trends accurately, allowing us to optimize resource allocation effectively. This initiative will not only streamline our operations but also ensure we are better prepared to meet future demands and improve overall institutional performance.

4. CONCLUSIONS

This paper presents extensive research into AI's application in education, envisioning a future where education is deeply intertwined with AI technologies. The remarkable potential of AI in personalizing educational experiences is underscored. It is envisioned that future educational systems will progressively incorporate AI to customize learning materials and assessments based on individual student profiles. This approach includes providing tailored feedback, focusing on each student's unique strengths and areas for improvement. Predictive analytics will play a pivotal role in forecasting student outcomes, thereby enabling educators to offer proactive support and interventions where necessary. The utility of AI extends to being a supportive tool for educators. AI can significantly reduce the administrative workload and refine instructional methodologies. It is recommended that educators need to upskill themselves with AI tools to assist in curriculum development, lesson planning, and in offering personalized student feedback. However, to fully harness the potential of AI in education, substantial investments are necessary in both technological infrastructure and professional development.

Educators and administrators need comprehensive training to effectively integrate AI tools into their teaching methodologies. Classrooms should be equipped with advanced computer systems that can support AI-based learning modules. Additionally, there is a pressing need to develop secure online learning platforms that utilize AI for more intelligent learning, assessment, and feedback processes. Given the rapid evolution of AI technology, educational institutions are advised to engage in continuous evaluation and adaptation of AI tools. This process involves regular assessments of the impact of AI-powered learning platforms on student outcomes, with subsequent updates or modifications to these platforms to align with changing educational needs and advancements in AI technology. Furthermore, despite the advancements and integration of AI, it is crucial that education systems continue to emphasize and nurture critical thinking, creativity, and interpersonal skills. These skills are indispensable in preparing students to work effectively alongside AI technologies and in professions where human skills are paramount. The curriculum should, therefore, include subjects and activities that foster problem-solving, ethical reasoning, and emotional intelligence. Classrooms should be designed to be interactive environments that promote debate, collaboration, and the development of interpersonal skills.

REFERENCES

ADESHOLA, I. & ADEPOJU, A. P. 2023. The opportunities and challenges of ChatGPT in education. *Interactive Learning Environments*, 1-14.

AIVO. 2023. *Siglo 21 University improves their digital student experience with Aivo's Artificial Intelligence*

[Online]. Available: https://www.aivo.co/customer-stories/siglo-21#about [Accessed].

AKGUN, S. & GREENHOW, C. 2021. Artificial intelligence in education: Addressing ethical challenges in K- 12 settings. *AI and Ethics*, 1-10.

ALOISI, C. 2023. The future of standardised assessment: Validity and trust in algorithms for assessment and scoring. *European Journal of Education,* 58, 98-110.

ALPAYDIN, E. 2020. *Introduction to machine learning*, MIT press.

ASTHANA, P. & HAZELA, B. 2020. Applications of machine learning in improving learning environment.

Multimedia big data computing for IoT applications: concepts, paradigms and solutions, 417-433.

AI strategy, May 2024, “

BERRETT, D. 2013. English teachers reject use of robots to grade student writing. *Chronicle of Higher Education,* 59, A1-A4.

BULL, S. & KAY, J. 2016. SMILI☺: A framework for interfaces to learning data in open learner models, learning analytics and related fields. International Journal of Artificial Intelligence in Education, 26, 293-331.

CHUNG, C.-Y., HSIAO, I.-H. & LIN, Y.-L. 2023. AI-assisted programming question generation: Constructing semantic networks of programming knowledge by local knowledge graph and abstract syntax

tree. *Journal of Research on Technology in Education,* 55, 94-110.

DABBAGH, N., ATTWELL, G. & CASTAÑEDA, L. Personal learning environments track introduction. Ninth

International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'21), 2021. 487-491.

DIBBLE, M. 2023. *Schools Ban ChatGPT Amid Fears of Artificial Intelligence-Assisted Cheating* [Online].

Available: https://www.voanews.com/a/schools-ban-chatgpt-amid-fears-of-artificialintelligence-

assisted-cheating-/6958125.html [Accessed 5-12-2023 2023].

FARHAT, R., MOURALI, Y., JEMNI, M. & EZZEDINE, H. An overview of Machine Learning Technologies and their use in E-learning. 2020 International Multi-Conference on:"Organization of Knowledge and Advanced Technologies"(OCTA), 2020. IEEE, 1-4.

FENZA, G., ORCIUOLI, F. & SAMPSON, D. G. Building adaptive tutoring model using artificial neural networks and reinforcement learning. 2017 IEEE 17th international conference on advanced learning technologies (ICALT), 2017. IEEE, 460-462.

FERRER, X., VAN NUENEN, T., SUCH, J. M., COTÉ, M. & CRIADO, N. 2021. Bias and discrimination in AI: a cross-disciplinary perspective. IEEE Technology and Society Magazine, 40, 72-80.

GADHAVI, M. & PATEL, C. 2017. Student final grade prediction based on linear regression. *Indian J. Comput. Sci. Eng,* 8, 274-279.

GRUETZEMACHER, R. & WHITTLESTONE, J. 2022. The transformative potential of artificial intelligence. *Futures,* 135, 102884.

GUTIERREZ, F. & ATKINSON, J. 2011. Adaptive feedback selection for intelligent tutoring systems. *Expert Systems with Applications,* 38, 6146-6152.

HALDE, R. R. Application of Machine Learning algorithms for betterment in education system. 2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT), 9-10 Sept. 2016 2016. 1110-1114.

HE, Y., JIANG, F., CHU, X. & LI, P. Automated Chinese Essay Scoring from Multiple Traits. Proceedings of the 29th International Conference on Computational Linguistics, 2022. 3007-3016. HEARST, M. A. 2000. The debate on automated essay grading. *IEEE Intelligent Systems and their Applications,* 15, 22-37.

HSIAO, I.-H. & CHUNG, C.-Y. 2022. AI-infused semantic model to enrich and expand programming

question generation. *Journal of Artificial Intelligence and Technology,* 2, 47-54.

HUALLPA, J. J. 2023. Exploring the ethical considerations of using Chat GPT in university education. *Periodicals of Engineering and Natural Sciences,* 11, 105-115.

HUSSEIN, M. A., HASSAN, H. & NASSEF, M. 2019. Automated language essay scoring systems: A literature review. *PeerJ Computer Science,* 5, e208.

HUSSEIN, M. A., HASSAN, H. A. & NASSEF, M. 2020. A trait-based deep learning automated essay scoring system with adaptive feedback. *International Journal of Advanced Computer Science and Applications,* 11.

IONESCU, V. M. & ENESCU, M. C. Using ChatGPT for Generating and Evaluating Online Tests. 2023 15th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), 2023. IEEE, 1-6.

ISMAIL, M. & ADE-IBIJOLA, A. Lecturer's apprentice: A chatbot for assisting novice programmers. 2019

international multidisciplinary information technology and engineering conference (IMITEC), 2019. IEEE, 1-8.

JAVAID, M., HALEEM, A., SINGH, R. P., KHAN, S. & KHAN, I. H. 2023. Unlocking the opportunities through ChatGPT Tool towards ameliorating the education system. *BenchCouncil Transactions on Benchmarks, Standards and Evaluations,* 3, 100115.

KAMENSKIH, A. 2022. The analysis of security and privacy risks in smart education environments. *Journal of Smart Cities and Society,* 1, 17-29.

KASNECI, E., SEßLER, K., KÜCHEMANN, S., BANNERT, M., DEMENTIEVA, D., FISCHER, F., GASSER, U.,

GROH, G., GÜNNEMANN, S. & HÜLLERMEIER, E. 2023. ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and individual differences,* 103, 102274.

KILLAWALA, A., KHOKHLOV, I. & REZNIK, L. Computational intelligence framework for automatic quiz question generation. 2018 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), 2018. IEEE, 1-8.

KOK, J. N., BOERS, E. J., KOSTERS, W. A., VAN DER PUTTEN, P. & POEL, M. 2009. Artificial intelligence: definition, trends, techniques, and cases. *Artificial intelligence,* 1, 270-299.

KOKKU, R., SUNDARARAJAN, S., DEY, P., SINDHGATTA, R., NITTA, S. & SENGUPTA, B. Augmenting Classrooms with AI for Personalized Education. 2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 15-20 April 2018 2018. 6976-6980.

KORKMAZ, C. & CORREIA, A.-P. 2019. A review of research on machine learning in educational technology. *Educational Media International,* 56, 250-267.

KUČAK, D., JURIČIĆ, V. & ĐAMBIĆ, G. 2018. MACHINE LEARNING IN EDUCATION-A SURVEY OF CURRENT RESEARCH TRENDS. *Annals of DAAAM & Proceedings,* 29.

KULETO, V., ILIĆ, M., DUMANGIU, M., RANKOVIĆ, M., MARTINS, O. M., PĂUN, D. & MIHOREANU, L. 2021. Exploring opportunities and challenges of artificial intelligence and machine learning in higher education institutions. *Sustainability,* 13, 10424.

KURNI, M., MOHAMMED, M. S. & SRINIVASA, K. 2023. Chatbots for Education. *A Beginner's Guide to Introduce Artificial Intelligence in Teaching and Learning.* Springer.

LEE, U., JUNG, H., JEON, Y., SOHN, Y., HWANG, W., MOON, J. & KIM, H. 2023. Few-shot is enough: exploring ChatGPT prompt engineering method for automatic question generation in english education. *Education and Information Technologies*, 1-33.

LIRIWATI, F. Y. 2023. Transformasi Kurikulum; Kecerdasan Buatan untuk Membangun Pendidikan yang Relevan di Masa Depan. *IHSAN: Jurnal Pendidikan Islam,* 1, 62-71.

LU, O. H., HUANG, A. Y., TSAI, D. C. & YANG, S. J. 2021. Expert-authored and machine-generated shortanswer questions for assessing students learning performance. *Educational Technology & Society,* 24, 159-173.

LUKIC, A. & ACUNA, V. 2012. Automated Essay Scoring. *Rice University*.

MARCINKOWSKI, F., KIESLICH, K., STARKE, C. & LÜNICH, M. Implications of AI (un-) fairness in higher education admissions: the effects of perceived AI (un-) fairness on exit, voice and organizational reputation. Proceedings of the 2020 conference on fairness, accountability, and transparency, 2020. 122-130.

MARJANOVIC, O. & CECEZ-KECMANOVIC, D. 2017. Exploring the tension between transparency and datification effects of open government IS through the lens of Complex Adaptive Systems. *The Journal of Strategic Information Systems,* 26, 210-232.

MARTINEZ NEDA, B., ZENG, Y. & GAGO-MASAGUE, S. Using machine learning in admissions: Reducing human and algorithmic bias in the selection process. Proceedings of the 52nd ACM Technical Symposium on Computer Science Education, 2021. 1323-1323.

MOUSAVINASAB, E., ZARIFSANAIEY, N., R. NIAKAN KALHORI, S., RAKHSHAN, M., KEIKHA, L. & GHAZI SAEEDI, M. 2021. Intelligent tutoring systems: a systematic review of characteristics, applications, and evaluation methods. *Interactive Learning Environments,* 29, 142-163.

MULYATI, S. & SETIANI, N. 2018. IDENTIFYING STUDENTS'ACADEMIC ACHIEVEMENT AND PERSONALITY TYPES WITH NAIVE BAYES CLASSIFICATION. *Sebatik,* 22, 64-68.

NAFEA, I. T. 2018. Machine learning in educational technology. *Machine learning-advanced techniques and emerging applications*, 175-183.

NAGARAJ, M. B., NAMAZI, B., SANKARANARAYANAN, G. & SCOTT, D. J. 2023. Developing artificial intelligence models for medical student suturing and knot-tying video-based assessment and coaching. *Surgical endoscopy,* 37, 402-411.

NAVADA, A., ANSARI, A. N., PATIL, S. & SONKAMBLE, B. A. Overview of use of decision tree algorithms in machine learning. 2011 IEEE control and system graduate research colloquium, 2011. IEEE, 37- 42.

NG, D. T. K., LEE, M., TAN, R. J. Y., HU, X., DOWNIE, J. S. & CHU, S. K. W. 2023. A review of AI teaching and learning from 2000 to 2020. *Education and Information Technologies,* 28, 8445-8501.

OTTER, D. W., MEDINA, J. R. & KALITA, J. K. 2021. A Survey of the Usages of Deep Learning for Natural Language Processing. *IEEE Transactions on Neural Networks and Learning Systems,* 32, 604-624.

POH, N. & SMYTHE, I. To what extend can we predict students' performance? A case study in colleges inSouth Africa. 2014 ieee symposium on computational intelligence and data mining (cidm), 2014. IEEE, 416-421.

PARISER, E. 2011. The filter bubble: How the new personalized web is changing what we read and how we think, Penguin.

RAMALINGAM, V., PANDIAN, A., CHETRY, P. & NIGAM, H. Automated essay grading using machine learning algorithm. Journal of Physics: Conference Series, 2018. IOP Publishing, 012030.

RAO, G. N. & NAGARAJ, S. 2014. A Study on the Prediction of Student's Performance by applying straight-line regression analysis using the method of least squares. *International Journal of Computer Science Engineering,* 3.

REMIAN, D. 2019. Augmenting education: ethical considerations for incorporating artificial intelligence in education.

REGAN, P. M. & JESSE, J. 2019. Ethical challenges of edtech, big data and personalized learning: Twentyfirst century student sorting and tracking. Ethics and Information Technology, 21, 167-179

REVELLE, C. 2023. CHATGPT IS HERE TO STAY: USING CHATGPT WITH STUDENT TEACHERS FOR LESSON PLANNING. *OF TEACHER EDUCATION*.

RUAN, S., JIANG, L., XU, Q., LIU, Z., DAVIS, G. M., BRUNSKILL, E. & LANDAY, J. A. Englishbot: An aipowered conversational system for second language learning. 26th international conference on intelligent user interfaces, 2021. 434-444.

RUDOLPH, J., TAN, S. & TAN, S. 2023. ChatGPT: Bullshit spewer or the end of traditional assessments in higher education? *Journal of Applied Learning and Teaching,* 6.

SAGALA, T. N., PERMAI, S. D., GUNAWAN, A. A. S., BARUS, R. O. & MERIKO, C. Predicting Computer

Science Student's Performance using Logistic Regression. 2022 5th International Seminar on Research of Information Technology and Intelligent Systems (ISRITI), 2022. IEEE, 817 821.

SALIM, Y., STEVANUS, V., BARLIAN, E., SARI, A. C. & SUHARTONO, D. Automated English digital essay grader using machine learning. 2019 IEEE International Conference on Engineering, Technology and Education (TALE), 2019. IEEE, 1-6.

SALLAM, M. 2023. The utility of ChatGPT as an example of large language models in healthcare education, research and practice: Systematic review on the future perspectives and potential limitations. *medRxiv*, 2023.02. 19.23286155.

SAUNDERS, S. 2023. Rather than ban generative AI, universities must learn from the past. *University World News*.

SHRESTHA, S. & POKHAREL, M. Machine Learning algorithm in educational data. 2019 Artificial Intelligence for Transforming Business and Society (AITB), 2019. IEEE, 1-11.

SLAVUJ, V., KOVAČIĆ, B. & JUGO, I. Intelligent tutoring systems for language learning. 2015 38th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2015. IEEE, 814-819.

SOMASUNDARAM, M., LATHA, P. & PANDIAN, S. S. 2020. Curriculum design using artificial intelligence (AI) back propagation method. *Procedia Computer Science,* 172, 134-138.

SONG, S. & ZHAO, J. 2013. Automated essay scoring using machine learning. *Stanford University*.

SRIVASTAVA, A., SHINDE, S., PATEL, N., DESPANDE, S., DALVI, A. & TRIPATHI, S. Questionator-automated question generation using deep learning. 2020 International Conference on Emerging Trends in Information Technology and Engineering (ic-ETITE), 2020. IEEE, 1-5.

SWEENEY, L. 2000. Uniqueness of simple demographics in the US population. *LIDAP-WP4, 2000*.

TOPAL, M. O., BAS, A. & VAN HEERDEN, I. 2021. Exploring transformers in natural language generation: Gpt, bert, and xlnet. *arXiv preprint arXiv:2102.08036*.

UTO, M., XIE, Y. & UENO, M. Neural automated essay scoring incorporating handcrafted features. Proceedings of the 28th International Conference on Computational Linguistics, 2020. 6077- 6088.

VAN DEN BERG, G. & DU PLESSIS, E. 2023. ChatGPT and Generative AI: Possibilities for Its Contribution to Lesson Planning, Critical Thinking and Openness in Teacher Education. *Education Sciences,* 13, 998.

VERLEGER, M. & PEMBRIDGE, J. A pilot study integrating an AI-driven chatbot in an introductory programming course. 2018 IEEE frontiers in education conference (FIE), 2018. IEEE, 1-4.

VOHRA, R. 2011. Intelligent decision support systems for admission management in higher education institutes. *International Journal of Artificial Intelligence & Applications (IJAIA),* 2.

WATERS, A. & MIIKKULAINEN, R. 2014. Grade: Machine learning support for graduate admissions. *Ai Magazine,* 35, 64-64.

YANG, H., KIM, H., LEE, J. H. & SHIN, D. 2022. Implementation of an AI chatbot as an English conversation partner in EFL speaking classes. *ReCALL,* 34, 327-343.

YEUNG, K. 2019. 'Hypernudge': Big Data as a mode of regulation by design. The social power of algorithms. Routledge

ZHU, D., CHEN, J., HAYDAROV, K., SHEN, X., ZHANG, W. & ELHOSEINY, M. 2023. Chatgpt asks, blip-2 answers: Automatic questioning towards enriched visual descriptions. *arXiv preprint arXiv:2303.06594*.

Reflection processes for learning with digital media in higher education courses: A report on our experience

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ABSTRACT

The integration of digital media in university teaching has transformed the learning landscape, particularly in engineering disciplines. The students need digital competence to be able to use the media made available to them. Often these competences are not distinctive on a sufficient level. Therefore, this paper discusses an innovative educational initiative designed to integrate a reflection of digital actions with media for first-semester students. The given basic mathematics course in the first semester will be adapted through inputs such as questions for reflection in the e-learning platform, group and plenary discussions in the attendance parts. After the basic description of the course, initial experiences with its implementation are discussed. A main positive experience is the acceptance of the students with the new concepts through a clear communicated and recurring structure. An essential point for future improvements is the time management with the additional course content through the reflection phases. At the end, important requirements for the new course with reflection of digital actions are identified so that the concept can also be used in other areas of higher education.

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1 INTRODUCTION

Digital media are an integral part of university teaching and learning. Students use digital applications such as internet resources, video platforms like YouTube and mathematical work benches as WolframAlpha to support their learning in various engineering disciplines. Lecturers use learning platforms to provide subject-specific content and interactive assignments to get feedback about the learning progress. There is a wide range of possible tools and digital media that can be used to obtain information. In addition to standard tools, AI-powered programs such as ChatGPT and Google Bard hold significant potential. Especially, these tools also necessitate a critical approach to the content they generate. The study about learning with digital media by Marten and Thiele (2023) has revealed that there is a notable lack of reflection regarding their potential applications and the methods employed in digital learning.

Dealing with the selection of media and their content leads to better research results. Reflecting on these digital actions is the aim of the method.

The digital actions are considered embedded in a subject-specific framework (Berthold 2006). In the described context, the reflection method is embedded in the basic mathematics course of engineering degree programmes in the first semester. A digital action refers to the incorporation of computer-supported/digital media into learning processes within a subject-specific framework.

An essential part of the concept is to introduce a reflection on the digital activities. The reflection phase is followed by group and plenum discussion. By this, the students get a more critical view of their use of digital media and can start to adapt their behaviour. Already, Konrad (2014) described that the reflection of learning processes could support the learning outcome. Additionally, the classroom climate and the student motivation play a crucial role in effective teaching (Biggs and Tang 2011).

The concept is deliberately used at the beginning of the degree programme. In this phase, students seem to be open to new methods. They can benefit from it for their study. In this specific case, it is implemented in the mathematic class. It is an important but often challenging course for students. They therefore typically use digital media to understand and process the content. In this context, we initiate reflection on the use of digital media.This helps the students to be aware of the importance.

Marten and Thiele (2023) determined the students' behaviour with digital media in the course using interviews. Information about how digital content is used in a mathematical context was collected. These described practical solutions to learn with digital media by the students in the mathematics course are the basic for the future developments in the course. Based on these results, a specific programme for reflecting on digital activities in the basic mathematics course was developed and implemented. This paper will share the insights and experiences gained from the course.

2 METHODOLOGY

2.1 Concept of the current lecture

The concept is integrated, in a mathematic course for first year engineering students. It focuses on activating teaching and learning. Beside standard learning, flipped classroom (Kenner and Jahn 2016) and Just in Time Teaching (Novak et al. 1999) are integrated. The attendance parts of the courses are characterised by peer instruction and active communication with the lecturers. The lecturers attach great importance to a culture of open dialogue. There is an atmosphere in the courses, which makes it easy to address questions and understand weaknesses. Part of the self-learning phases of the course are weekly tasks which are assigned on an e-learning platform. The following questions were added to reflect on the mathematical content after completing the tasks on the e-learning platform.

Please answer one of the following questions. If you have questions about the content, you should answer the first question. The answer should consist of at least 3 sentences:
1. Explain what you did not realise about the topic. Which point did you not understand or where is the meaning not clear to you? What question should be clarified in the lecture? 2. Explain what you found most interesting. Why is the material worth learning? Can you think of an application for it?
3. What could an exam task look like that checks whether the content has been understood?

Fig. 1. Previous questions in the E-Learning platform for the reflection of the mathematical topics

Based on the concept of Just in Time Teaching, students note questions and difficulties with the content covered material to answer the questions in Fig. 1. The students have to reflect on difficulties they have. It helps to get a self-evaluation regarding the actual content. Furthermore, it serves as feedback for the lecturers regarding the subject-related difficulties. The answers are processed by the lecturer and incorporated into the subsequent lecture.

2.2 Introduction of reflection on digital media into the lecture

Digital competences are becoming increasingly important for students, especially in the first semester of university studies (Händel 2024). Higher education can be considered as part of the lifelong learning process. For the digital competences in the lifelong learning process, the "Digital Competence Framework for Citizens 2.2" according to European Commission et al. (2022) was developed.

The framework describes the competence fields and the individual competences in detail and offers the opportunity to place them in an application context. A whole range of digital competences are explained in the competence model. We have made a suitable selection from these.

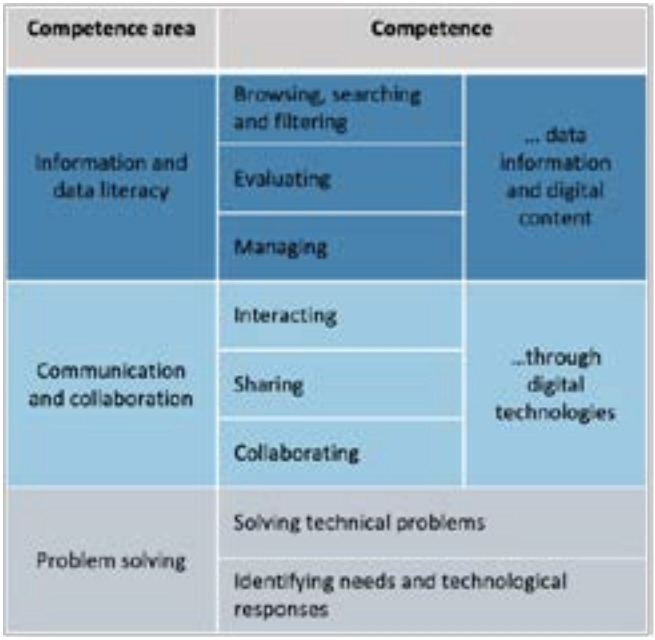

Fig. 2. Overview of the competences applied according to the DigComp 2.2 model (Vuorikari et al. 2022; Marten and Thiele 2023)

The competences shown in Fig. 2 form the basis for the reflection developed later. The focus is on three out of five skill areas from the competence model. It is information and data literacy, communication and collaboration, and problem-solving. The chosen competencies then provide the basis for a practical reference to the students' digital actions, which were already described in the study of Marten and Thiele (2023). In addition to digital actions, the study identifies key elements of media in the students' usage scenarios like online websites, learning videos, artificial intelligence, and digital communication. These key areas of the digital media and the associated digital actions of the students are now to be reflected on during the semester.

The motivation to engage with the reflection should be increased (Berthold 2006). This is done by reducing abstraction and concretising it based on references to the mathematical tasks. Therefore, the use cases are assigned to subject-specific topics of the maths course.

First year students are affected by many new impressions.In the first five lecture weeks they need to familiarise with the procedures in the university and in the course. Therefore, we start the reflection on digital media in lecture week six (LW 6). In table 1 there is the course content shown together with the allocated focus of digital actions.

Table 1. The digital actions in the mathematic lecture

Course content (Lecture week)	Focus of digital actions
Transformation of functions (LW 6)	Digital media (general)
Sequences and limits (LW 7)	Digital media (general)
Trigonometric functions (LW 8)	Digital media (general)
Rules of differentiation (LW 9)	Learning videos

Tangent and Taylor series (LW 10)	Websites
Techniques of integration (LW 11)	Artificial Intelligence
Complex numbers (LW 12)	Digital communication

For students in engineering education, it is less common to reflect on one's own actions and critically examine them within a group setting. Therefore, in LW 6 to LW 8, the focus is on the use of digital media in solving mathematical problems in general. The process of reflection and consolidation is practised in this phase. Uncertainties are resolved in this first general phase by a predefined structure that creates confidence to communicate. The specific areas of application are then addressed in the further course. The allocation of the reflection areas is based on the interview statements of the students (Marten and Thiele 2023).

The process of reflection is divided in four parts.The start is the weekly-based self-reflection on the e-learning platform. It is based on additional questions for the digital action reflection. Fig. 3 shows the questions added in the chapter “Rules of differentiation” to reflect the use of learning videos.
Please answer the following questions. The answer to each question should consist of at least 3 sentences.

1. If you have used a learning video to explain the derivation rules for this topic section, please answer this question with the corresponding link to the video. If you have not used a video, please search for a video explaining the derivation rules that you like. Send the link to the video here as well. Note: Please do not use just any learning video. It is important for the reflection in the lecture that you have learnt or could learn effectively with the corresponding video and its content.
2. Why did you choose this particular video? Justify your statement. For what reasons are you able to draw information particularly well from this learning video?
3. Do you regularly learn with learning videos or do you prefer other learning materials? Give reasons for your statement here too.

Fig. 3. Additional questions in the E-Learning platform to reflect the actions with learning videos

The questions encourage students to reflect on their behaviour in relation to the use of digital learning materials (Fig. 3). They give the answer on the e-learning platform, which should not take longer than 15–20 minutes. The answers are used as a base for the discussion and additional reflection in the lecture, which is divided in three phases. Here, approximately 35 min each time is planned.

The joint reflection is initiated by a presentation of common answers of the self-reflection by the lecturer, which also sets the focus on certain aspects. Student statements can be presented anonymously, for example, describing a specific action in relation to learning videos in the context of the rules of differentiation. This phase needs around 5–10 minutes, it depends on the previous online answers of the students and their need to discuss the topic before the group discussions.

For the subsequent group discussion (around 20 minutes) the students gather in groups of max. six person. Here a position is taken on the statements presented, and a discussion is held on how to optimise the procedure or alternative actions.

Students are encouraged to record essential results and aspects of their discussions on a whiteboard.

The notes on the whiteboards are the basis for the following plenary discussion (about 10 minutes). The plenary discussion serves to collect the most significant aspects and also to discuss differences between the group results. The aspects have been objectified through the previous group work. It is no longer about personal views and actions, but about the results of the group. The results are summarised by the lecturer and distributed to the students after the course.

An essential rule for the discussion is that critical remarks are allowed, but no final judgement is made. All participants respect the individuality of each person's approach. It is important to create an environment of confidence when discussing one's own behaviour. The small groups make it easier to discuss openly.

Nevertheless, the descriptive processes and the discussion will trigger reflection on the own approaches. The aim is to figure out different procedures, to critically examine them and to reflect them based on their actions in the context. In the end, serval students might adapt their ways to learn with digital media.

3 RESULTS

During the adapted course framework for mathematics in the summer semester 2023, we gathered valuable practical experiences, which are described in this chapter. The mathematic lecture takes place three times a week. The reflection on digital media took part ones a week. 25 students regularly attended the course. The time spent each week on reflection is closely linked to the progress of the subject content in the lecture.The insights reflect both the positive aspects and successful practices, as well as the challenges and areas for improvement that emerged over the semester. At the end, requirements for a possible application in other subjects of higher education teaching are presented.

3.1 Positive aspects

It was observed that the type of lecture is accepted by the students. Initially, there were reservations about the extra effort and scepticism about reflection and subsequent group discussions. This can be attributed to the fact that this type of engagement with students' own behaviour is rather unusual for engineering students. Through a clear structure and recurring procedures, the students became familiar with this approach. A trusting and communicative atmosphere was established, which facilitated a good exchange. All phases, self-reflection, group discussions and plenary discussions were carried out effectively and had positive results. The students showed a high level of participation by actively sharing their opinions and following the discussions. The topic of artificial intelligence particularly gave rise to very intensive discussions. It could be observed that there was a great need for dialogue among the students and that they actively took advantage of the opportunity to exchange ideas. The observations suggest that actions in this context were reflected particularly strongly as soon as there was a direct reference to current problems, in this case in mathematics, and these could be answered with digital support.

Another positive aspect was the acceptance of the self-learning phases, which were based on the concept presented from the first lecture onwards, on a weekly basis. Around 70% of the students regularly participated in the self-reflection phases. The introduction of the reflection questions for the digital activities in the e-learning platform was initially an additional effort. The students' overall reaction to them was positive throughout the semester.

3.2 Challenges

The intense commitment and willingness of the students to get involved in the discussion meant that we couldn't always meet the time limit. The need for dialogue became apparent. Significantly more time was needed, particularly regarding artificial intelligence. It is sometimes difficult to bring these phases to a reasonable conclusion in a reasonable amount of time.

Answering the reflection questions also places an additional workload on students. Some students showed only sporadic participation in the e-learning platform, despite the introductory events and repeated reminders of the importance of the reflection questions for their studies. This could be due to the high workload in the first semester. The introduction of additional content to reflect on digital media without reducing the subject-specific content could have a negative impact on morale and acceptance. Despite a high level of interest in digital media, students reported limited capacity for in-depth reflection on their approaches due to the high workload. In the future, the development of digital competences should be part of the curriculum and included in the semester planning.

3.3 Requirements for the application

There are certain essential requirements for a successful implementation of reflection processes in university courses to ensure effective integration into existing concepts and increase student acceptance.

It is necessary to create appropriate time slots. A balance must be found between subject-specific parts and the reflection of digital actions. If the program is successful, it can be anticipated that students will be more efficient in their use of digital media. In the end, this will reduce the workload for the students during their studies and beyond.

A central aspect of the method is a structure consisting of self-reflection, group discussions and plenary discussions. The establishment of such a structured process is necessary to integrate reflection processes both in self-study and during the lecture, and to familiarise students with this type of thematic discussion. A lack of a structured process could otherwise lead to a reduction in acceptance of the necessary feedback.

It is important that the first step of self-reflection is encouraged. In the concept shown, this could be linked to an existing e-learning programme. If such regular self-learning programmes are not available, other ways of providing feedback must be found. This is also possible, for example, on study organisation platforms such as Moodle. To increase the motivation to participate in these reflection processes, the awarding of additional points for the examination when relevant questions are answered can be considered.

Just in Time Teaching means that the lecturer has to analyse the students' feedback on the e-learning platform and decide what to do in the next course (Novak et al. 1999). The quality of the course depends on sufficient preparation. If there is a huge number of participants, it is sufficient to randomly review the students' responses (Riegler 2019). With increasing routine and experience, the time required is reasonable.

It is important that the additional tasks on digital media are directly related to the subject content of the course and are tailored to the students' learning processes. This is the only way to create direct added value for the students and encourage deeper reflection on the use of digital learning methods and media. The reference to current content increases students' motivation to engage with the topics.

4 DISCUSSION AND CONCLUSION

The paper demonstrates that reflection on the use of digital media can be integrated into the mathematics course in the first semester. It is beneficial for this reflection to take place very early in the studies, as students extensively use digital media for studying. Engineering students are often not accustomed to reflecting on and discussing their behaviour. Therefore, sufficient time and a solid structure are needed to integrate this into their studies. Due to the workload of the students, it was only tested in one year. The future plan is to implement it into voluntary courses on basic mathematics.

The concept described here can be implemented for all types of university courses, considering the points from chapter 3. Of course, the aspects mentioned, such as self-reflection in the e-learning platforms, may need to be supplemented to initiate multiphase self-reflection. The familiarisation phase of this new approach depends largely on the structure of the event, but also on the communicative atmosphere that needs to be created.

In fact, a long-term anchoring of the reflection of learning methods with digital media in the curricular would be an important step so that the reflection of the procedures can also take place and be applied in further courses. This would effectively promote the acceptance of the approach as well as the ability to study regarding a critical examination of student's own learning processes.

REFERENCES

Berthold, Kirsten. 2006. "Handlungskompetent durch Reflexion im Lerntagebuch: Fünf Thesen." *Bildung und Erziehung* 59 (2): 205-214

Biggs, J. and C. Tang. *Teaching for Quality Learning at University.* 4th ed. Maidenhead, England: SRHE and Open University Press, 2011.

European Commission, Joint Research Centre, Vuorikari, R., Kluzer, S., and Y. Punie. *DigComp 2.2: The Digital Competence framework for citizens – With new* *examples of knowledge, skills and attitudes.* Publications Office of the European Union, 2022. https://doi.org/10.2760/115376

Händel, M., Fritzsche E. S., and S. Bedenlier. 2024. "Digitale Kompetenzen zum Studienstart als Gelingensfaktor im ersten Semester?." Zeitschrift für Hochschulentwicklung 19 (1): 25-43. https://doi.org/10.21240/zfhe/19-01/02

Kenner, Alessandra, and Jahn, Dirk. "Flipped Classroom – Hochschullehre und Tutorien umgedreht gedacht". Paper presented at *Tutorienarbeit im Diskurs III – Qualifizierung für die Zukunft,* edited by Alexandra Eßer, Heike Köpke, and Heidemarie Wittau, 35-58. Münster: WTM Verlag für wissenschaftliche Texte und Medien, 2016. https://doi.org/10.25656/01:12962

Konrad, K. *Lernen lernen – allein und mit anderen. Konzepte, Lösungen, Beispiele.* Wiesbaden: Springer Fachmedien, 2014. https://doi.org/10.1007/978-3-658-04986-7

Marten, Nico, and Thiele, Kathrin. "Studieren mit digitalen Medien." Paper presented at *ASIM Workshop STS-GMMS-EDU, Magdeburg, 2023.* https://doi.org/10.11128/arep.21.a2115

Novak, Gregor M., Evelyn T. Patterson, Andrew D. Gavrin, Wolfgang Christian, and Kyle Forinash. 1999. "Just in Time Teaching." *American Journal of Physics* 67 (10): 937-938. https://doi.org/10.1119/1.19159

Riegler, Peter. *Peer Instruction in der Mathematik: Didaktische, organisatorische und technische Grundlagen praxisnah erläutert*. Berlin: Springer Spektrum, 2019. https://doi.org/10.1007/978-3-662-60510-3

A FRAMEWORK FOR IMPROVING THE LEADERSHIP BEHAVIOR OF GRADUATE STUDENTS

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Keywords: *Leadership education, reflection, e-portfolio, behavioral change*

ABSTRACT

In graduate school education, the acquisition of transferable skills is the basis for implementing social change and contributing to more wide-ranging career development for students. Specifically, these skills include problem-solving abilities, innovation, time management, career management, professional development, teamwork, leadership, and communication. Thus, this study focused on improving the leadership behavior of graduate students, especially among first-year master's students in science and engineering programs. For this purpose, we not only examined the acquisition of knowledge, but also the promotion of positive behavioral changes through the reflection of individual growth and related experiences. Specifically, we developed a framework and found that three elements can promote positive behavioral change in leadership: 1) Personal characteristics; 2) A place for leadership experience; and 3) Reflection process. Additionally, the students exchanged feedback with one another based on the actions recorded in their e-portfolios. Those who connected their peers' reflections with their own behavioral changes in "simulated experiences" and continually applied new learning to "actual experiences" significantly improved their leadership skills.

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1 INTRODUCTION

1.1 Transferable Skills

In graduate school education, the acquisition of transferable skills is vital for implementing social change and improving career development. Specifically, these skills include problem-solving, innovation, time management, career management, professional development, teamwork, leadership, and communication.

1.2 Leadership Skills

This study develops a framework for improving the leadership skills of graduate students. In this case, the term “leadership” refers to the ability to develop one’s strengths and encourage continuous self-transformation. In order to foster such skills, it is not only important to accumulate actual experiences, but to also reflect on such experiences. Thus, we propose a systematic educational program that demonstrates leadership and promotes self-transformation among graduate students.

2 TRENDS RELATED TO TRANSFERABLE SKILLS

According to a 2009 European Science Foundation report, transferable skills are defined as “skills that are acquired in one context and effectively applied in other contexts (e.g., research, business, employment).” In February 2020, the Ministry of Education, Culture, Sports, Science and Technology in Japan stated in the Council for Science and Technology’s Academic Subcommittee report titled, “Improving the Constitution of Graduate School Education,” that graduate schools are expected to play a central role in the development of future intellectual professionals. It also mentioned the importance of acquiring transferable skills.

After graduation, master’s and doctoral students not only work as researchers and professionals, but they also use their highly specialized knowledge to discover various issues, launch projects to solve them, and lead project teams to bring about social change. In this regard, expectations are high for such individuals. In the United Kingdom (U.K.), the British Research Council categorized the transferable skills that doctoral students and researchers should acquire into seven types and published the “Joint Statement of Skills Training Requirements of Research Postgraduates”' in 2001. Vitae (2011) further developed this joint statement and published it as the “Researcher Development Framework (RDF),” which describes the background and skills of high-quality researchers.

Although some of these transferable skills can be obtained through existing research activities, British graduate schools have incorporated learning opportunities into their curriculums, by using RDF as a reference. In this regard, transferable skills frameworks have been established in Europe, including the U.K., along with the required training.

However, in Japan, there are only a few examples of such training being incorporated into the curriculums of graduate schools, indicating that there is much room for research. For graduate students, society demands that they continue to develop and enhance their skills after graduation. In order to proactively develop one’s career, it is becoming increasingly important to cultivate leadership skills that encourage self-transformation.

3 LEADERSHIP EDUCATION DESIGN

3.1 Systematic Educational Program

In order to acquire soft skills, such as leadership, it is necessary to experience the real world by using one's body and sensibilities. Since 2008, we have been providing leadership education to first-year master's students in science and engineering graduate programs. In order to connect knowledge to practice, such education includes five modules: 1) Knowledge acquisition; 2) Experiential learning; 3) Practical application; 4) Reflection; and 5) Evaluation (see Fig. 1).

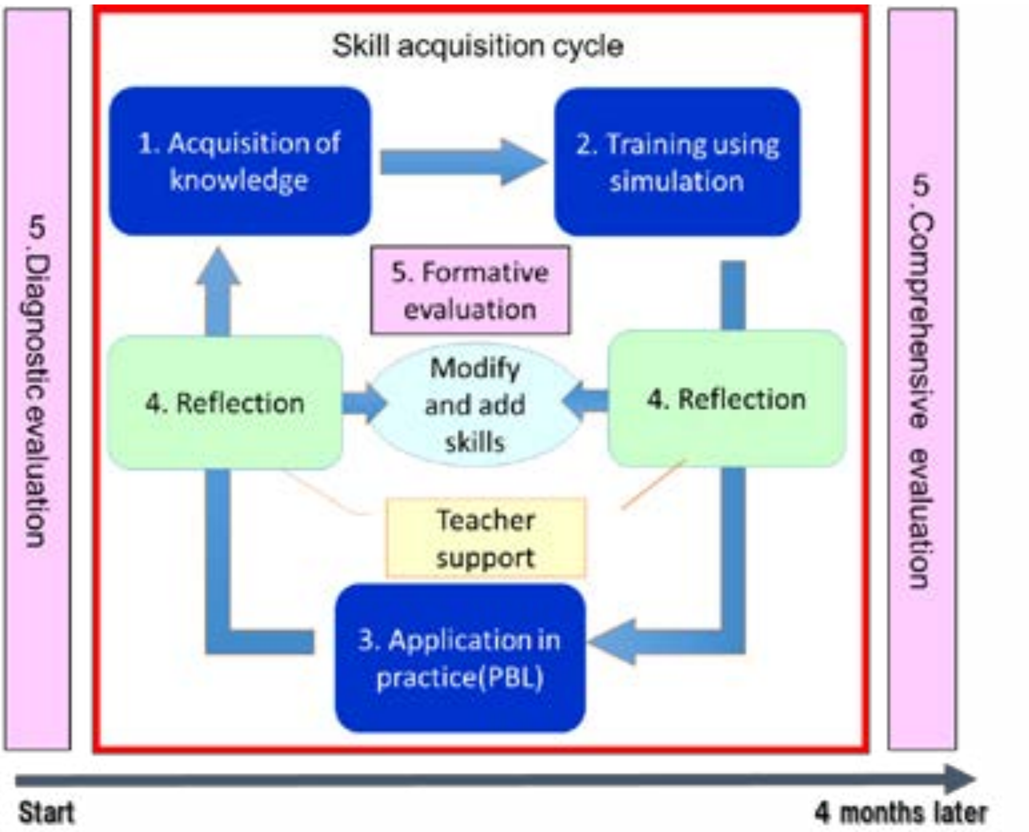

Fig. 1. Leadership Education Model

In this study, we employed a simulator to strengthen interpersonal relationships in the "Experiential learning" module and create a link from knowledge to action. In this regard, simulated experiences can serve as a bridge between knowledge and practice as well as improve leadership behavior. During the COVID-19 pandemic, the use of not only simulators, but also virtual reality, augmented reality, metaverses, e-books, etc., has attracted increasing attention from scholars and practitioners. Meanwhile, the development of experiential learning through these technologies can help expand the number of learning strategies and support students with diverse backgrounds.

Finally, there are differences in the quality of individual students' experiences in the "Practical application" module. In this case, some students tend to choose challenging experiences and recognize the need to transform themselves, while others prefer “safe” areas that do not place excessive stress on them. In this case, the quality of experiences also influences the quality of reflection.

3.2 Utilization of an E-portfolio

In this study, the graduate students reflected on their leadership behaviors, while using a simulator. For example, during “actual experiences,” the students examined their leadership behaviors in various activities, cycled through their experiences, and recorded the key details of their leadership experiences in an e-portfolio (see Fig. 2). Here, the students not only reflected on their own learning, but they also electronically stored records of the learning that occurred during the process. Although some students have the ability to continually self-evaluate and find areas for improvement, a mentor can track their progress and provide any necessary support during the program.

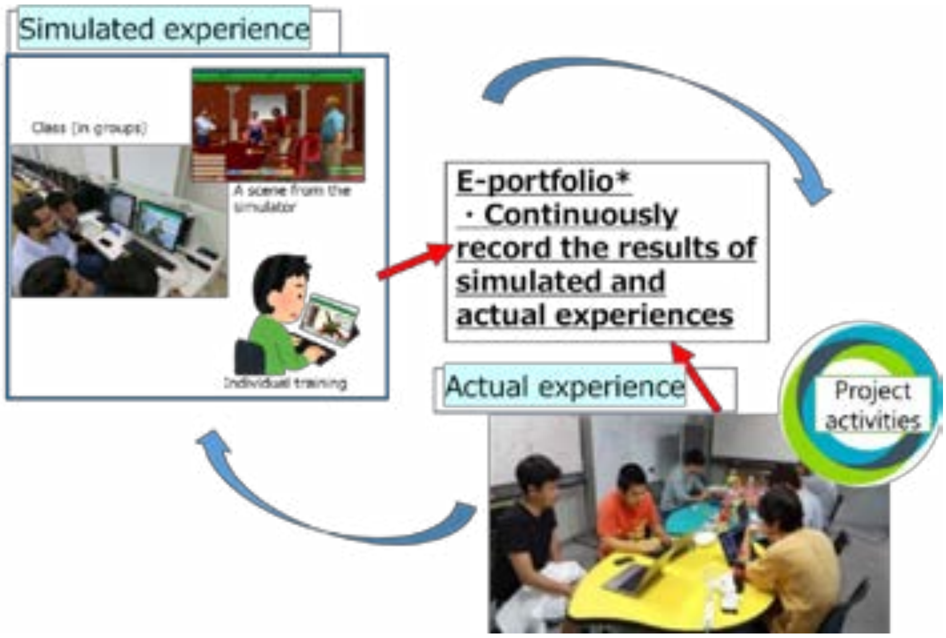

Fig. 2. Ongoing Recording of Experiences in an E-portfolio

4 RESEARCH HISTORY

To date, we have devised the contents of each module of the leadership education program and repeatedly improved them in related research. The timeline is as follows:

- We conducted leadership education by using active learning for first-year master’s students in science and engineering programs. Specifically, we introduced peer reflection in which the students exchanged feedback with one another based on the actions recorded in their e-portfolios. Those who connected their peers’ reflections with their own behavioral changes in “simulated experiences” and continually applied new learning to “actual experiences” significantly improved their leadership behaviors (Maruyama 2019).
- The students reflected on their own leadership experiences and conducted quantitative and qualitative evaluations based on their recorded e-portfolios.

After analyzing the evaluations, we conducted interviews with the students who showed positive changes in their leadership behaviors in order to determine how they carried out their reflections (Maruyama 2020).

- In 2020, the spread of COVID-19 made it difficult to hold face-to-face classes, after which different methods for conducting remote classes were explored. In this regard, we devised a virtual environment for leadership education and project-based learning activities. For the latter, 17 teams worked on various real-world problems relevant to local governments and businesses. We also investigated the improvement of online team formation development. The results indicated that team formation can be developed, even in a virtual environment (Maruyama 2021).
- Finally, based on the results of the students' quantitative and qualitative evaluations as well as our analysis and literature review, we proposed a reflection teaching strategy that promotes student growth (Maruyama 2023).

Based on these results, we created a framework that promotes behavioral change in leadership among graduate students (Maruyama 2020) (Maruyama 2022) (Inoue 2023).

5 A FRAMEWORK FOR PROMOTING POSITIVE BEHAVIORAL CHANGE IN LEADERSHIP

The three elements that make up this framework include: 1). Personal characteristics; 2) A place for leadership experience; and 3) Reflection process (see Fig. 3).

Fig. 3. Framework for Promoting Positive Behavioral Change in Leadership

(1) Personal characteristics

In general, students who make a positive behavioral change through reflection include the following characteristics.

< Use of reflection >

・The ability to recognize the importance of reflection to connect experiences to growth.

・The belief that something new can be generated from continuous reflection.

・The ability to not only analyze failures, but also successful results.

< Metacognitive ability >

・The ability to recognize and utilize one’s strengths.

・The ability to evaluate one’s abilities and discover the characteristics of one’s learning method.

・The ability to determine what is lacking and recognize the need for change.

< Attitude toward learning >

・The ability to consider learning opportunities as something special, instead of something taken for granted.

・The ability to realize that the time spent on learning can be meaningful by reflecting on knowledge/experience and connecting it to one’s personal growth.

・The ability to recognize that learning results are the responsibility of each individual.

(2) A place for leadership experience

During university life, students have limited opportunities to demonstrate leadership skills. However, students need a place in which they can feel safe and make mistakes in order to learn from them. In this leadership education for graduate students, we used a simulator in which the participants can hold meetings with avatars in a virtual environment to encourage leadership in project learning. There is also a need for opportunities of leadership experiences within the intended educational setting, as well as those in the real world that go beyond the framework of education. In order to encourage behavioral change, the quality of the experience (which is the subject of reflection) is important. In this regard, the question of what types of experiences can enable deeper reflection and encourage behavioral change will be a topic for future research.

(3) Reflection process

< Personal reflection >

・The importance of re-examining oneself, becoming aware of one’s learning, and reconsidering the learning process.

・The ability to monitor and determine whether one’s approach is working, and develop a growth mindset that encourages effort.

・In this case, metacognition is important for recognizing opportunities for improvement and having the mindset that such improvement will be successful. It is also important for determining how to adapt one’s learning and behavior to new situations and environments.

・The ability to determine how one’s involvement in the learning process can influence the interpretation of tasks and the selection of learning strategies.

< Reflection with others >

・The perspectives of others play an important role in promoting personal growth through reflection.

・By understanding the frameworks in which others view different aspects and comparing them with one’s perspective, it is possible to gain a broader perspective.

・When it is possible to independently choose what to learn through reflection, metacognition plays a significant role in individual learning. In this case, interactions with others are involved in the formation of metacognition.

・In addition to personal reflection, the process incorporates reflection with others who can provide critical feedback and support.

< Feedback from teachers >

・Instead of simply relying on the students to decide on how to interpret learning outcomes, it is important to convey other interpretations and different behavioral approaches from the instructor’s perspective.

・In this case, it is important to tell the students that there are various learning strategies and spend time considering which strategies are suitable.

・It is necessary to determine how the results of the reflection can be applied.

・In this process, a two-way interaction is required, instead of one-way feedback.

・Since there are limits to individual instruction, especially in large classes, it is desirable to introduce digital technology when responding to certain individuals.

By following this framework, students will not only develop essential leadership skills but also cultivate a mindset and approach that promotes continuous personal and professional development. This holistic approach ensures that students are well-prepared to take on leadership roles and navigate complex challenges in their future careers. Several expected outcomes are as follows.

The first is to improve self-awareness and metacognitive skills. Students learn to recognize their strengths and weaknesses, choose how to learn, and identify areas for improvement. They also develop a growth mindset that allows them to view challenges as opportunities for growth.

Second, students will understand the importance of reflection. Students will understand the importance of looking back to connect experiences to personal and professional growth. They will be able to draw lessons from both successes and failures. Students will learn to monitor their approach and adjust their behaviour.

Third, effective leadership skills can be developed. Through simulations and real-life leadership experiences, students practice and refine their leadership skills in a safe environment. Students gain confidence in leading project teams and managing projects.

6 Conclusion

In graduate school education, the acquisition of transferable skills is the basis for implementing social change and contributing to greater career development, since such skills can be useful for applying specialized knowledge to various situations. In this regard, it is important to develop the ability to reflect, which is the foundation for demonstrating one's strengths and self-transformation. Thus, this study focused on improving the leadership behavior of graduate students, especially among first-year master's students in science and engineering programs. Specifically, we developed a framework and found that three elements can promote positive behavioral change in leadership: 1) Personal characteristics; 2) A place for leadership experience; and 3) Reflection process. In addition, the students exchanged feedback with one another based on the actions recorded in their e-portfolios. Those who connected their peers' reflections with their own behavioral changes in "simulated experiences" and continually applied new learning to "actual experiences" significantly improved their leadership skills.

REFERENCES

Maruyama, T and Inoue, M. "Peer Reflection using an E-portfolio Improves Students' Leadership Behaviour." *Proceedings of SEFI 47th Annual Conference,* Budapest, Hungary,16th - 20th September 2019, pp.745-754.

Maruyama, T and Inoue, M. "Continuous Reflection using an E-portfolio Improves Students' Leadership Behaviour." *Proceedings of SEFI 48th Annual Conference,* Enschede, The Netherland,20th - 24th September 2020, pp. 1000-1009.

Maruyama, T and Inoue, M. "Leadership Behaviours in Virtual Teams to Achieve Project Goals." *Proceedings of SEFI 49th Annual Conference,* Berlin, Germany,13th - 16th September 2021, pp.1449-1453.

Maruyama, T and Inoue, M. "Pedagogical Strategies for Reflection that Promote Student Growth." *Proceedings of The 15th Asian Conference on Education,* Tokyo, Japan, November 22, 2023.

Vitae. "Vitae Researcher Development Framework (RDF) 2011. "Accessed March 31, 2024. https://www.vitae.ac.uk/vitae-publications/rdf-related/researcher-development-framework-rdf-vitae.pdf/view.

Maruyama, T and Inoue, M. "Design and Implementation of an Online Leadership Education." IEEE TALE 2020: *Proceedings of International Conference on Engineering*, Technology and Education, pp.239-242, Takamatsu, Japan, December 8-11, 2020.

Maruyama, T and Inoue, M. “Development of Reflection Ability Required as a Lifelong Learner.” *Proceedings of 25th International Conference on Interactive Collaborative Learning*, Vienna, Austria,27-30 September 2022.

Inoue, M and Maruyama, T. “Design and Implementation of Online Leadership Education Using Meeting Simulator and Peer Reflection.” *Proceedings of 25th International Conference on Interactive Collaborative Learning*, Vienna, Austria,27-30 September 2022

STUDENT ABSENTEEISM AT ENGINEERING DEGREES: A CASE STUDY AT BARCELONA SCHOOL OF INDUSTRIAL ENGINEERING

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ABSTRACT

In recent decades, the issue of university class attendance has gained significant attention due to its impact on institutional reputation and the need to enhance student engagement, especially in light of the European Higher Education Area's establishment in 2015. Extensive analyses of absenteeism determinants underscore its complexity, highlighting the necessity for tailored interventions to effectively address this issue. This study, conducted by a team of educators from Barcelona

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School of Industrial Engineering affiliated with the Universitat Politècnica de Catalunya BarcelonaTech (Spain), aims to assess absenteeism rates and propose mitigation strategies by examining factors influencing attendance and educators' perspectives. The study employs a mixed-method approach, incorporating surveys from students and educators, daily attendance records, as well as interviews and discussions.

Preliminary findings indicate elevated absenteeism rates, particularly in mass enrollment programs featuring more expositive teaching methodologies, attributed to perceptions of redundant class material and dissatisfaction with teaching methods. Notably, undergraduate students often seek supplementary instruction from private academies. Promising strategies include adopting contextualized teaching approaches and transitioning exams to non-standardized formats. However, the long-term effectiveness of these measures necessitates further evaluation.

The methodology and insights derived from this study have the potential to inform strategies aimed at addressing absenteeism in engineering-focused institutions and beyond.

1 INTRODUCTION

In recent decades, attendance in university classes has become a concerning issue, as noted by St. Glair and St. Clair in 1999, who highlighted the potential decline in institutional reputation if students could earn degrees without attending classes. The establishment of the European Higher Education Area in 2015 further emphasized the importance of enhancing student engagement and adopting a student-centered learning approach (European Commission 2015). Absenteeism not only hampers the learning process but also represents a misuse of economic resources, particularly in public university systems. Despite these concerns, a comprehensive global analysis of absenteeism remains elusive. Only specific studies provide insights into absenteeism rates. For example, Kousalya, Ravindranath, and Vizayakumar (2006) found absenteeism rates ranging from 30-50% in an Indian engineering college, a figure mirrored by Summers, Higson, and Moores (2021) among nearly 2000 undergraduate STEM (Science, Technology, Engineering and mathematics) and business students in the UK.

Similarly, research conducted at a chemical education program in Nigeria (Nja, Cornelius-Ukpepi, and Chinyere Ihejiamaizu 2019) revealed absenteeism rates ranging from 25% to 45%. Conversely, in a study by Vicéns Moltó, Hervás Avilés, and Zamora Parra (2019), absenteeism rates were reported to be as high as 70% during the initial year of an engineering degree, steadily escalating throughout the program and peaking at nearly 80% in the final year. These few cases of study highlight the widespread nature of the issue.

The correlation between attendance and attainment has been extensively studied, with literature suggesting a significant link (Credé, Roch, and Kieszczynka et al. 2010; Kassarnig et al. 2017; Keyser 2019; Moores, Birdi and Higson 2019; Rendleman 2017; Shaaban and Reda 2021). However, the causal relationship between attendance and attainment remains debated, with some researchers suggesting that poor attainment can lead to low attendance, and vice versa (Credé, Roch, and Kieszczynka 2010; Kahu 2013). Indeed, attendance alone does not imply active participation (Kassarnig et al. 2017; Moores, Birdi, and Higson 2019). This is the reason why mandatory policies do not have a clear positive impact on attainment (Rendleman 2017).

Various factors influence students' attendance decisions, including institutional policies, psychological factors, and socio-demographic characteristics. These factors interact in complex ways, producing sometimes apparently inconsistent results. For instance, research findings vary depending on the country, funding system, publication year, student demographics, class size, and discipline (Moores, Birdi, and Higson 2019). For instance, in a study carried out in an Indian engineering college (Kousalya, Ravindranath, and Vizayakumar 2006) and based on a multicriteria decision-making method, parents' involvement and counselling were the most relevant factors for absenteeism, followed by peer pressure and punishments for absence, in front of making lecture more attractive, improve the infrastructure or increase the coherence between the curriculum and the assessment. In (Al-Labadi et al. 2022), a quantitative study of roughly 15200 students in a Canadian university showed that the main reason for absence in class was to study and prepare for other courses, followed by the students' mental health and poor sleeping habits. In a Spanish study with nearly 1900 students from the Business Administration, Economics and Sociology degrees (Triado-Ivern et al. 2020), the main reasons for the absenteeism are student's own planning, teaching methodology, learning methodology, course characteristics and external sources.

In Qatar, difficulty reaching the learning center has been identified as a primary reason for absenteeism, prompting the implementation of measures like mandatory attendance rates and transportation services (Shaaban and Reda 2021). Gender differences in absenteeism have also been noted, with male students typically exhibiting higher rates (Al-Labadi et al. 2022; Nja, Cornelius-Ukpepi, and Chinyere Ihejiamaizu 2019). Other factors, such as balancing work and study or the availability of online materials, also impact attendance (Moores, Birdi, and Higson 2019; Rutherford and McGrath 2022).

The study reported by López-Bonilla and López-Bonilla (2015) states that the quality of teaching is a crucial factor influencing absenteeism, with students citing educators' teaching methods and competence as primary reasons for their absence. However, while poor-quality lectures may discourage attendance, high-quality lectures do not necessarily increase it. Aligning teaching and assessment practices may enhance the perceived value of classes (Moores, Birdi, and Higson 2019).

Social factors, including peer interactions and educator-student relationships, also influence absenteeism. Students tend to attend classes more if their peers do, particularly high achievers (López-Bonilla and López-Bonilla 2015; Kassarnig et al. 2017). In a study performed by Leufer and Cleary-Holdforth (2010) it was observed that large class sizes and perceived lack of interest from lecturers can discourage attendance, highlighting the importance of personalized attention and a sense of belonging in reducing absenteeism (Moores, Birdi, and Higson 2019; Webb and Cotton 2018).

In conclusion, absenteeism is a complex issue influenced by various contextual factors, necessitating tailored interventions for effective reduction strategies.

1.1 Aim and research questions

The Barcelona School of Industrial Engineering (ETSEIB) is one of the 17 schools of the Universitat Politècnica de Catalunya · BarcelonaTech (hereafter UPC), a Spanish public institution of research and higher education specializing in engineering, architecture, sciences and technology. ETSEIB's facilities accommodate more than 3,400 students, and 350 educators. The school offers 2 bachelor's and 13 master's degree programs, in addition to 5 InnoEnergy master's programs, which can be categorized into either mass enrollment or specialized degrees. Notably, mass enrollment programs are the bachelor's degree in Industrial Technology Engineering (GETI), and the master's degree in Industrial Engineering (MUEI), with about 1900 and 680 enrolled students each, while specialized degrees typically have less than 120 enrolled students.

Absenteeism rates at ETSEIB have been steadily increasing, causing concern among educators. The first attempt to evaluate absenteeism occurred in 2022 through a survey distributed to all students, yielding a 33% participation rate with 1060 valid responses (ETSEIB 2022). Analysis of GETI students' responses, with a participation rate of 67%, revealed that 78% of students do not attend all subjects equally, their attendance being contingent on perceived class relevance. Additionally, it was observed that a majority of the 22% who attend subjects equally do so for all subjects. The underlying reasons for the high absenteeism rate among the 78% of students need further investigation. Furthermore, the survey highlighted that absenteeism is notably higher in mass enrollment programs like GETI and MUEI, though this observation requires further validation due to the survey's approximate nature and the post-Covid-20 pandemic adjustment to in-person attendance. The survey's impact led to absenteeism becoming the central theme of the third ETSEIB teaching conference in 2023.

This study aims to assess the current absenteeism situation and propose mitigation strategies by addressing the following research questions (RQ):

1. What is the extent of absenteeism at ETSEIB, and which degree programs are most affected?
2. What are the underlying causes of absenteeism at ETSEIB?
3. Is there a correlation between attendance and attainment at ETSEIB?
4. Which teaching strategies do ETSEIB educators deem most effective in improving attendance?

Given the universality of absenteeism, the methodology and findings of this study may offer insights applicable to other institutions, particularly those specializing in engineering studies.

2 METHODOLOGY

The study is part of the ASAP-UPC teaching innovation project initiated in 2023. The project aims to identify active methodologies that promote a significant and in-person learning process. Fourteen educators are participating in the project, nine of whom teach at ETSEIB, with the others teaching at the Barcelona School of Nautical Studies. The educators at ETSEIB are involved in teaching the mentioned mass enrollment degrees (GETI and MUEI), as well as the bachelor's degree in Industrial Technologies and Economic Analysis (GTIAE), the master's degree in Automotive

Engineering (MAUTO), the master’s degree in Nuclear Engineering (MUEN), and the master’s degree in Energy Engineering (MUEE). This wide coverage across various degrees enables the team to gather substantial information from enrolled students and provide a comprehensive overview of absenteeism at ETSEIB.

A diverse set of data is gathered and analyzed to address the research questions. This includes surveys from both students and educators, daily attendance records, interviews, and discussions. The processing of this information follows a mixed methodology, combining quantitative and qualitative analyses. The main data from the surveys are detailed in the following sections. Interviews with students include both scheduled sessions with those who consistently miss classes and spontaneous discussions during or after lessons. Educator’s perceptions are gathered through surveys and supplemented with informal discussions among colleagues and debates during ASAP-UPC project meetings. Daily attendance is tracked for subjects taught by ASAP-UPC members and analyzed alongside students’ grades at the end of the first semester of the 2023-24 academic year.

2.1 Students’ survey

A survey was designed to identify the factors contributing to students’ absenteeism, strategies educators could employ to enhance attendance, the skills they deem most relevant for their profession, being this latest driven by the potential disparity between contents and students’ perceived relevance. The survey targeted students enrolled in subjects taught by members of the ASAP-UPC project during the second semester of the 2022-23 academic year. This encompassed 6 bachelor’s and 7 master’s subjects, totaling 563 students, constituting approximately 18% of ETSEIB’s student body. Students were prompted to complete the survey either during the final lessons of the semester or via the subjects’ online learning platform. The participation rate of 22.7% reflects a relatively low level of engagement, indicative of either students' limited interest or a saturation of surveys and emails from the institution.

2.2 Educator’s survey

Educators’ perceptions were collected through a survey where they were asked to focus on a single subject they teach. Initially, basic questions were posed regarding the subject type, whether attendance is compulsory, and the evolution of absenteeism over the years. Subsequently, more specific questions concerning potential actions to improve attendance were presented as open-ended inquiries, necessitating a thorough examination of responses and subsequent clustering. The survey was distributed to ETSEIB faculty by email, facilitated by the ETSEIB director. Eighty-eight educators responded, constituting 25% of the teaching staff at ETSEIB. Similar to the participation rate observed in the student survey, this relatively low level of engagement is noteworthy in itself. Among the responses, 67% correspond to GETI subjects, with MUEI subjects accounting for 10%, aligning with the distribution of enrolled students.

A second survey was conducted among the members of the ASAP-UPC project to collect information regarding ongoing modifications of their subjects aimed at boosting attendance. This survey presented a list of potential actions to implement, including new methodologies and assessment methods, which were selected based on team debates held during the initial months of the project. The participation rate for this survey was notably higher, reaching 93%.

3 RESULTS

3.1 Attendance rate

Results for each degree are presented in Table 1. In general terms, it can be asserted, and this is supported by the week-by-week data obtained, that absenteeism tends to be higher in the case of mass enrollment degrees and undergraduate courses. Notably, both MUEE and MAUTO exhibit very high attendance levels, attributed to their status as specialized masters' programs with a single group, fostering high student motivation. Regarding MUEI, a mass enrollment master's program, attendance levels vary depending on the specific subject, ranging from 65% to 22%. In the case of undergraduate degrees, absenteeism is more pronounce in mass enrollment programs such as GETI, compared to programs with a single group like GTIAE. Similarly to MUEI, attendance rates for undergraduate degrees depend on the specific subject analyzed but consistently remain below 60% across all studied subjects. These findings align with previously obtained data from 2022 (ETSEIB 2022).

Table 1: Attendance rates for each degree, 1st semester 2023-24

GETI	GTIAE	MUEI	MAUTO	MUEE
44.29%	65.13%	43.18%	96.67%	95.92%

3.2 Students' opinion

According to results presented in Figure 1, the primary reasons for absenteeism among students in mass enrollment bachelor's and master's degree programs are their preference for self-study and the perception that class materials are redundant as they are readily available online. In the case of bachelor's degree students, a third common cause of nonattendance is the need to retake the subject, while for master's degree students, it is dissatisfaction with educator's methodology. Consequently, students who do not attend classes perceive them as not being beneficial to their learning.

Specialized bachelor's degree students share the same primary reasons as mass enrollment students, with the addition of external work commitments emerging as a significant factor influencing absenteeism. Conversely, work commitments are the primary reason for non-attendance among specialized master's degree students, distinguishing them significantly from their mass enrollment counterparts.

The percentage of students selecting the 'other' cause for absenteeism in Figure 1 is notable. Through in-person interviews and informal discussions with students, it has been observed that one of the most common reasons is the perception that certain subjects are too challenging. Consequently, students opt to attend private academies to supplement their studies. Further research is necessary to delve deeper into and analyze these reasons comprehensively.

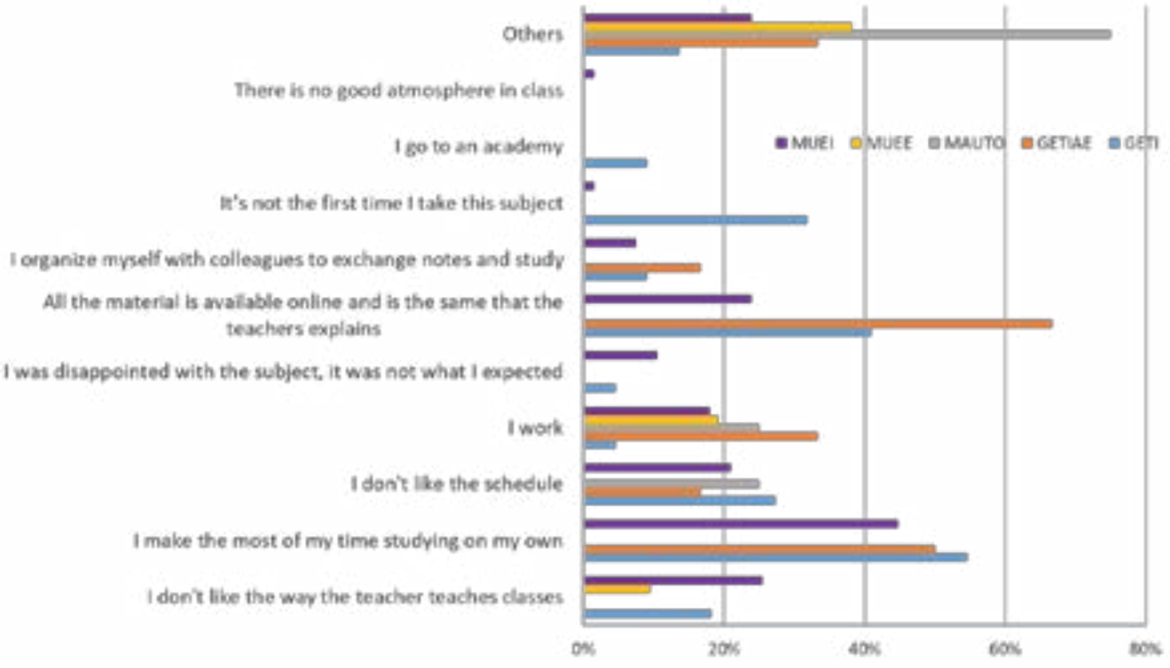

Fig. 2: Causes of absenteeism (according to students' responses)

Figure 2 illustrates factors that could potentially increase students' attendance. Contrary to expectations, methodologies aimed at increasing cooperative work or social interactions, utilizing ICT resources, or fostering connections with the degree program's environment are not perceived as motivating factors for students. Instead, students are primarily motivated to attend classes when they perceive them as contributing to their subject's approval and learning process.

Hence, there is a need to investigate and adjust methodologies and lesson content to encourage students to attend classes effectively.

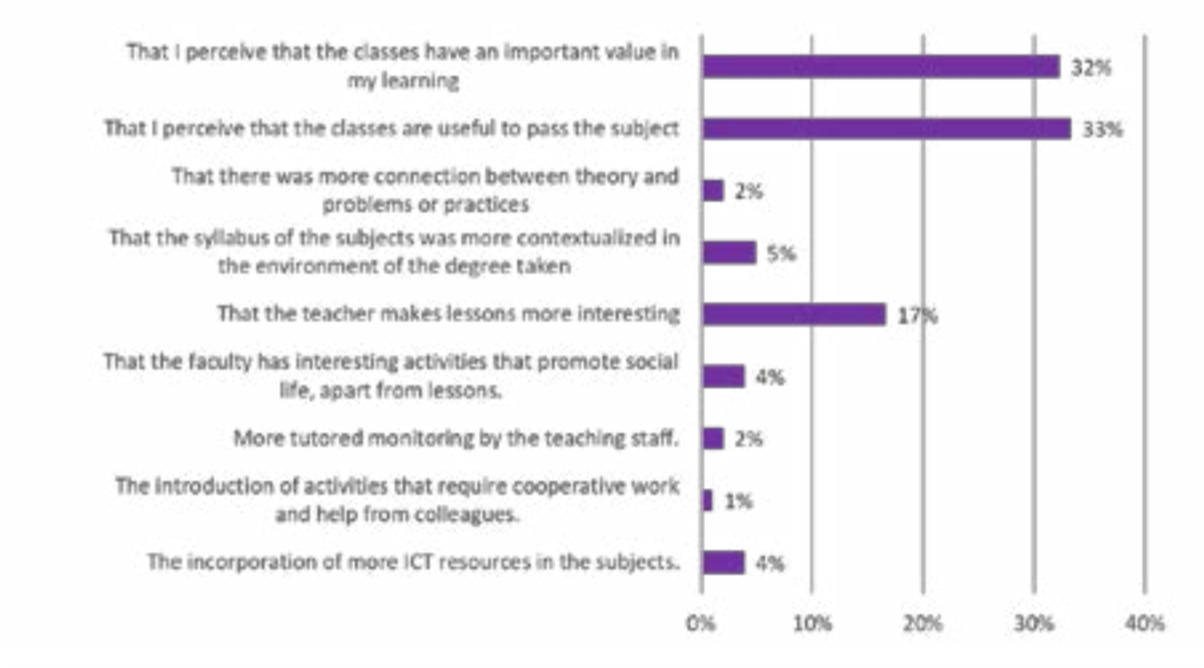

Fig. 3: Factors that could increase students' attendance (according to students' responses)

3.3 Educators’ opinion

Across all responses, it was found that 61% of lessons primarily focus on delivering theoretical knowledge, 25% are centered on problem-solving or exercises, and 14% involve laboratory experiences. However, this proportion varies among different degrees, being GETI, GTIAE and MUEI the ones with a higher proportion of expositive lessons. A surprising finding is the elective nature of the attendance, with 94% of expositive lessons, 92% of the problem-solving sessions, and 63% of laboratory experiences being non-mandatory.

Seventeen percent of educators have made adjustments to their teaching based on student satisfaction survey results at the end of the semester. The most common modifications (33%) include increasing the number of exercises solved during sessions and discussing the current absenteeism situation and the relevance of attending lessons. Additionally, 20% of educators focus on enhancing the relevance of learning outcomes to students’ professional lives.

In the subsequent survey conducted among members of the ASAP-UPC project, the proposal of exercises or problems to be done during the sessions is the most feasible mitigation strategy identified. In fact, 71% of ASAP-UPC members already incorporate student-solved exercises into their classes, a significantly higher percentage compared to the first survey. Furthermore, 91% of subjects include exercises resolution as part of the assessment system, with many educators planning to further enhance this aspect. Laboratory experiences are included in 65% of subjects, and 77% of educators aim to increase their number. Interestingly, only 50 % of the laboratory experiences are mandatory, even among ASAP-UPC members. Another noteworthy finding is that 35% of subjects are revising exams format to avoid standardized exams that can be solved without a deep understanding of the topic.

3.4 Absenteeism and attainment

Figure 3 depicts Gaussian curves representing the probability of achieving a particular grade based on attendance. A typical Gaussian shape is obtained for those students attending at least 50% of the lessons, with a mean grade of 7.5±1,01 out of 10. However, for students attending less than 50% of the lessons, an almost flat curve is obtained. This suggests that while attendance increases the likelihood of obtaining a higher grade, it is not the sole determinant of subject approval.

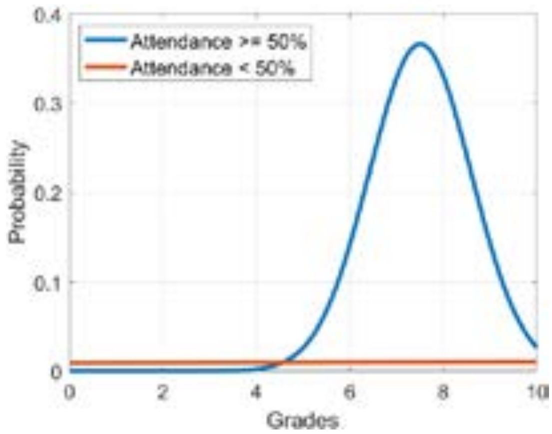

Fig. 4: Gaussian curves of the students’ grades based on their attendance

4 DISCUSSION

The findings indicate that absenteeism rates vary significantly across subjects, with an absenteeism higher than 40% in mass enrollment programs and undergraduate degrees. In these cases, students often skip lessons because they perceive them as unhelpful for passing exams. Coinciding with Triado-Ivern et al. 2020 and López-

Bonilla and López-Bonilla (2015) results, this perception stems from the believe that the material covered is already available online or dissatisfaction with the educator's methodology, leading some to opt for attending private academy to complement their learnings. These findings seem to demonstrate the existence of a casuistry typical of Spanish culture. Moreover, it has been demonstrated that attendance increases the likelihood of obtaining a higher grade also in the ETSEIB context.

Considering that (1) teaching is recognized in the same way regardless of the number of students enrolled, and (2) a direct proportion is associated between the educator's workload and the number of students enrolled, it is common to find a majority of expositive lessons in mass enrollment programs in the ETSEIB context. However, absenteeism tends to be more pronounced in expositive lessons, what indicates that a key absenteeism mitigation strategy is to minimize expositive lessons and maximize hands-on activities without increasing excessively the educator's workload. According to the results of the study, interesting mitigation strategies are: (i) the presentation of exercises or problems to be solved during class, with the specific guidance of the educator, (ii) the introduction of mandatory attendance at laboratory experiences, and (iii) the transformation of exams to a non-standardized format. All activities must be implemented so as the active participation of the students is considered in the assessment methodology. Also, if standardized exams are avoided, the fact that online materials are available, including a compendium of solved exams, should not penalize attendance.

These are the measures that ASAP-UPC members will implement. However, the effectiveness of these measures will ultimately be determined over time.

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REFERENCES

Al-Labadi, L., Advani, H.K., Holder, B., and Lim, K. "Education Influential Factors of University Attendance." Journal of Educational and Developmental Psychology 13, 1 (2022): 29. https://doi.org/10.5539/jedp.v13n1p29.

Credé, M., Roch, S.G., and Kieszczynka, U.M. "Class Attendance in College: A Meta-Analytic Review of the Relationship of Class Attendance With Grades and Student Characteristics." Review of Educational Research 80, 2 (2010): 272–95. https://doi.org/10.3102/0034654310362998.

ETSEIB. "Absentisme ETSEIB." Report (2022) https://etseib.upc.edu/ca/lescola/esdeveniments-anuals/jde/3ajde/Absentisme_ETSEIB.pdf.

European Commission. "ECTS Users' Guide." (2015)

Kahu, E.R. "Framing Student Engagement in Higher Education." Studies in Higher Education 38, 5 (2013): 758-775. https://doi.org/10.1080/03075079.2011.598505.

Kassarnig, V., Bjerre-Nielsen, A., Mones, E., Lehmann, S., and Lassen, D.D. “Class Attendance, Peer Similarity, and Academic Performance in a Large Field Study.” PLoS ONE 12, 11 (2017). https://doi.org/10.1371/journal.pone.0187078.

Keyser, R.S. “A Correlation Between Absenteeism and Course Grades in a Third-Year Industrial Engineering Class.” Research in Higher Education Journal 37 (2019). http://www.aabri.com/copyright.html.

Kousalya, P., Ravindranath, V., and Vizayakumar, K. “Student Absenteeism in Engineering Colleges: Evaluation of Alternatives using AHP.” (2006) https://doi.org/10.1155/JAMDS/2006/58232.

Leufer, T., and Cleary-Holdforth, J. “Reflections on the Experience of Mandating Lecture Attendance in One School of Nursing in the Republic of Ireland.” All Ireland Journal of Higher Education 2, 1 (2010). https://ojs.aishe.org/index.php/aishe-j/article/view/18.

López-Bonilla, J.M., and López-Bonilla, L.M. “The Multidimensional Structure of University Absenteeism: An Exploratory Study.” Innovations in Education and Teaching International 52, 2 (2015): 185–95. https://doi.org/10.1080/14703297.2013.847382.

Moores, E., Birdi, G.K., and Higson, H.E. “Determinants of University Students’ Attendance.” Educational Research 61, 4 (2019): 371–87. https://doi.org/10.1080/00131881.2019.1660587.

Nja, C., Cornelius-Ukpepi, B., and Chinyere Ihejiamaizu, C. “Educational Research and Reviews The Influence of Age and Gender on Class Attendance plus the Academic Achievement of Undergraduate Chemistry Education Students at University of Calabar” 14, 18 (2019): 661–67. https://doi.org/10.5897/ERR2019.3805.

Rendleman, C. M. “North American Colleges and Teachers of Agriculture (NACTA) Do Attendance Policies Improve Student Performance? The Relationship among Attendance, Class Policies, and Grades.” Journal 61, 4 (2017): 347–49. https://doi.org/10.2307/90021486.

Rutherford, P., and McGrath, D. “Supporting Student Attendance Institute for Teaching and Learning Innovation.” Institute for Teaching and Learning Innovation, The University of Queensland (2022).

Shaaban, K., and Reda, R. “Impact of College Provided Transportation on the Absenteeism and Academic Performance of Engineering Students.” Eurasia Journal of Mathematics, Science and Technology Education 17, 3 (2021): 1–7. https://doi.org/10.29333/ejmste/9727.

St Glair, K.L, and St Clair, S.L. “A Case Against Compulsory Class Attendance Policies in Higher Education.” Innovative Higher Education 23, 3 (1999).

Summers, R.J., Higson, H.E. and Moores, E. “Measures of Engagement in the First Three Weeks of Higher Education Predict Subsequent Activity and Attainment in First Year Undergraduate Students: A UK Case Study.” Assessment and Evaluation in Higher Education 46, 5 (2021): 821–36. https://doi.org/10.1080/02602938.2020.1822282.

Triado-Ivern, X., Aparicio-Chueca, P., Elasri-Ejjaberi, A., Maestro-Yarza, I., Bernardo, M., and Presas, P. "A Factorial Structure of University Absenteeism in Higher Education: A Student Perspective." Innovations in Education and Teaching International 57, 2 (2020): 136–47.

Vicéns Moltó, J.L., Hervás Avilés, R.M., and Zamora Parra, B. "El absentismo escolar, un problema en la Enseñanza de la Ingeniería. Análisis de la UPCT" in Redes de Investigación en Docencia Universitaria (2019): 189-201.

Webb, O.J., and Cotton, D.R.E. "Early Withdrawal from Higher Education: A Focus on Academic Experiences." Teaching in Higher Education 23, 7 (2018): 835–52. https://doi.org/10.1080/13562517.2018.1437130.

Utilizing flipped classroom approaches offered in a joint programme: opportunities and challenges

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Keywords: *Flipped classroom approach, Joint programmes, Technology enhanced learning*

ABSTRACT

This paper presents the lesson learnt the first implementation of an online course, 'Soil Mechanics', in a Joint International Education Programme in partnership between the University of Strathclyde (UK) and a Chinese University. While the original plan was to deliver this course face-to-face (F2F), the online mode of delivery was later adopted due to the spread of the COVID pandemic. This prompted the implementation of alternative pedagogical approaches, such as the flipped classroom approach (FLA), and offered to opportunity to assess new modes of learning. The new delivery method presents a number of learning and teaching challenges, such as the effectiveness of online resources, the language barriers of students, and the customization of traditional assessments based on the need for online courses. The paper discusses all aspects of teaching and learning strategies utilised in this module and compares them with a similar module taught F2F by the author in a traditional framework at the University of Strathclyde. Academic achievements (as demonstrated through assessments), students' satisfaction and engagement, and instructor reflection are among key measures used to evaluate the performance of the new approach. As the module is intended to be presented F2F class format in the upcoming years, the idea of maintaining the same teaching and learning strategy or revoking it will be discussed.

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1 INTRODUCTION

Joint international undergraduate programmes in STEM hold immense importance as they foster international collaboration among staff and students, promote cross-cultural competence, and prepare the workforce with innovative thinking, adaptability, and resilience. In pursuit of this objective, a collaborative joint international undergraduate programme has been established between the Civil and Environmental Department at the University of Strathclyde and a Chinese university. The plan was to develop a joint Civil and Environmental Engineering(CEE) curriculum in which some modules are delivered in Mandarin by Chinese staff and others are delivered by staff from University of Strathclyde. The start of this programme coincided with the spread of the COVID pandemic. To adapt to the educational restrictions, online mode of delivery has been selected for the first implementation of the module.

This allowed alternative pedagogical learning theories to be implemented. Among them, the flipped classroom approach (FLA) has been dominantly employed for this module, in which instructional videos, interactive virtual labs, and online quizzes have been provided to students as pre-class teacher-centered content, and they were actively engaging in the class for student-centered activities like questions and answers(Q&As) sessions and teachers' feedback and recaps (Akçayır and Akçayır 2018). It has been shown that the FLA is a cost-effective learning method that can generate high students' satisfaction and performance (Baytiyeh and Naja 2017, Prevalla and Uzunboylu 2019). Hardebolle et al. (2022) implemented FLA in engineering education and concluded that this method can eliminate the prior knowledge gap observed between different genders. However, effectiveness of FLA under the challenges associated with joint international programmes, such as language barrier and disparities in students' prior knowledge, remains to be addressed.

In this study, a comprehensive overview of the pedagogical methodologies employed for the administration and instruction of the Soil Mechanics module are summarized and discussed. Since the online mode of delivery has been adopted for teaching and learning activities, innovative teaching strategies such as virtual labs, virtual study groups, and online discussion forums have been created to enhance students learning experience.

2 METHODOLOGY

The soil mechanics module is among the fundamental modules taught in the early years of civil and environmental undergraduate studies. The purpose of the soil engineering module is to provide civil engineering students with an introduction to the physical and mechanical properties of soils used in construction and landscaping. A critical review of the existing curriculum between two universities has been performed to ensure academic rigour and standards across both universities. Upon reviewing the curriculum, it was found that there were a number of educational challenges. Particularly for the Soil Mechanics module, these challenges, along with the remedial pedagogical strategies, have been briefly reviewed.

2.1 Curriculum Alignment

The soil mechanics class is not the first module covering geotechnical engineering topics at University of Strathclyde. UK students have the chance to sit for the 'Fundamentals of Civil Engineering' module to briefly learn the basics of soils as engineering materials. However, this module was the first to aim at covering geotechnical engineering and geology at the Chinese University. To prepare Chinese students, the FLA has been implemented, in which preparatory materials (e.g., online videos and worked examples) have been provided to them before the live classes, and classroom time is then dedicated to interactive discussions, problem-solving, and collaborative activities. The use of online pre-class content also helped the program to be delivered in a compact version compared to the normal F2F program.

2.2 Language barrier of overseas students

The key obstacle for overseas students is the language barrier, which impacts students' ability to comprehend lectures, read module's materials, and complete assignments. Through communication with Chinese students, it was found that they experienced unequal language proficiency, affecting their academic performance (Zhu and O'Sullivan, 2022). As demonstrated by Fass-Holmes and Vaughn (2019), non-English-speaking students can achieve academic success if suitable teaching and learning strategies are implemented. One remedy was to provide transcripts of all oral materials, such as lectures and recorded videos, to allow students to have a self-paced learning experience. Also, various types of assessments, such as laboratories, online quizzes, and final exams, have been designed to provide equal opportunities for students with varying levels of language proficiency to showcase their learning capabilities. The laboratory assessments have been done in groups to establish peer support systems among students of different language levels.

2.3 Assessment and Grading Consistency

The traditional system of assessment has been replaced by a good diversity of assignments and feedback content such as mini-test quizzes, laboratories, and final exams. In all assignments, one of the main concerns was the lack of transparency, where students could not distinguish which learning outcomes were being measured (Hunt and Chalmers 2012). So the targeted learning outcomes have been vividly explained in the assignment descriptions. The questions of why we assess, what we assess, and how this assessment triggers learning opportunities were addressed. It was noted that Chinese students were not fully aware of Strathclyde policies on late submission, personal circumstances, and avoiding plagiarism. These details have been formally provided to them via the Strathclyde Online Learning Platform (MyPlace) and informally raised during the live class sessions.

2.4 Global pandemic challenges

The rapid spread of the COVID pandemic enforced the joint international programme to be delivered online. While overseeing digital tools has been established to assist students, limited hands-on activities and limited social interaction were feared to impact the success of these programmes. A key strategy employed for online instruction in soil mechanics involved leveraging the resources developed by University of Strathclyde's distance learning programme for integration into the current curriculum. The primary advantage here was breaking down the significant topics of each week into smaller segments, providing students with the opportunity to address and fill their specific knowledge gaps before live sessions. Another educational intervention was to develop virtual laboratories in which students watched the lab videos and worked out the laboratory report(May et al 2023). Here, interactive laboratory videos have been created in which informal quizzes along with instant feedback have been developed to assist students in their learning process. Interactive technologies have also been implemented in online quizzes (mini-tests), where instant feedback has been generated for MCQs to allow immediate clarification.

3 RESULTS AND DISCUSSION

To assess the success of the delivery, the assessment results and students survey have been analysed for the soil mechanics module taught in the joint international programme (referred to as the online module) and compared with the performance of UK students in the F2F educational setting (referred to as the F2F module). Similar assessments have been used in both online and face-to-face modules, which consisted of online quizzes (20%), laboratories (20%), and final exams (60%). Students were required to achieve 40% to pass the module. In order to determine student satisfaction, the results of a survey conducted in both online and F2F modules are depicted in Figure 1. It should be noted that a response rate of approximately 10% was recorded for both surveys. Students were overall satisfied with the taught modules in both programmes, but the level of satisfaction is higher in the online module with an embedded FLA. In the online module, they expressed the following comments for improvement:

‘Hopefully each test will give you a specific process, not just an answer’

‘Please add a detailed explanation to the answer to each section of the test. It might be helpful, thank you’

‘It is suggested to advance the opening time of tutorial.’

From these comments, it appears that students need further feedback for automated online quizzes and additional feedback on their laboratory reports. Also, it should be planned that learning materials for all teaching weeks, including online tutorial questions, are available at the start of the module. This will ensure that students have high preparation time before the class, which can foster higher level of thinking in the class. A similar observation was made by Sandnes et al (2006) regarding the delivery of modules from Western universities to Chinese universities, highlighting that students' language proficiency should be considered when designing course content.

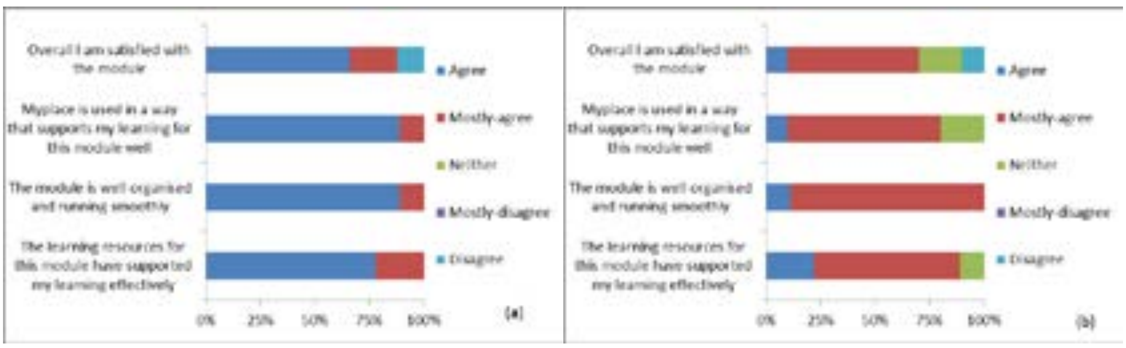

Fig. 1. The module evaluation survey in a) an online module b) a similar F2F module

The overall performances of students for two programmes is plotted in Figure 2a, where an average mark of 61% is achieved for F2F module compared to 59% in the online module. It should be noted that 93 students were participating in online module, compared to 101 students registered in F2F module. It can be seen that similar learning performance has been achieved among students attending F2F modules, which can be attributed to the opportunities for live interaction between instructor and students and the excess number of F2F sessions compared to online sessions. In the online module, it seems medium to high achieving students could efficiently use the online resources and achieve better performance with few non-engaging students noted in comparison to the F2F module. Overall, since similar average marks have been achieved between these two programmes, it can be confirmed that the FLA could be an effective alternative to the traditional F2F learning environment.

Among assessments, one laboratory was similar between the two modules and used here for comparing students' specific performance. The physical laboratory has been arranged in an F2F module, while this has been replaced with a virtual laboratory in online module. In both programmes, students could achieve high marks for this assessment, as shown in Figure 1b, with average marks of 83% and 76% recorded for the F2F and online modules respectively. Students' lack of familiarity with online labs and uncertainty about expectations can contribute to the low performance of Chinese students. (see May et al 2023). While the use of interactive videos with embedded Q&As features could promote an active learning experience, they need to be enhanced by allowing students to manipulate virtual apparatus, embedding adaptive learning paths in the videos, and including simulation-driven experiences.

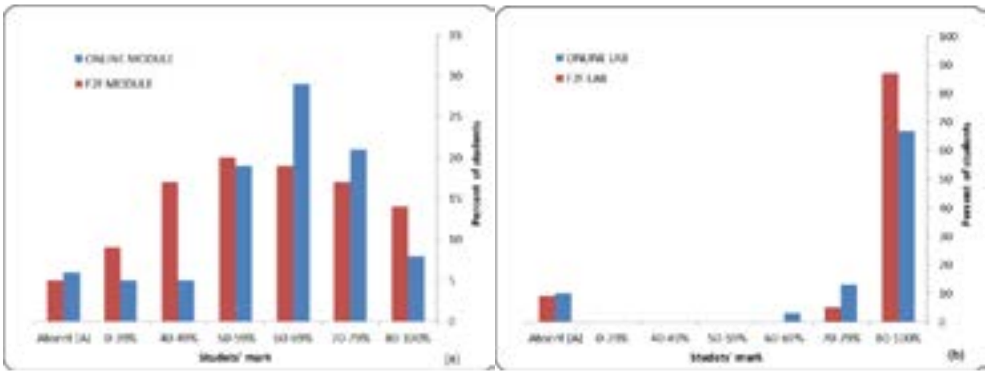

Fig. 2. Students' marks a) in overall assessment b) in Laboratory assessment

4 FUTURE PEDAGOGICAL IMPROVEMENTS

4.1 Technology enhanced learning environment

Students' survey revealed that STEM students are enthusiastic to see tangible engineering solutions used in real-world engineering practice. Although educational technologies have found their way into the soil mechanics module through the incorporation of virtual laboratories and interactive quizzes, their potential for reinforcing theoretical concepts with real-world practical applications, particularly through the rigorous implementation of engineering simulations, has yet to be fully harnessed. Due to a lack of prior knowledge in the early years of the undergraduate (UG) study, the integration of simulations into the curriculum will pose a challenge to a fundamental module like soil mechanics, as students have not been prepared for in-depth analysis of complex engineering problems in 3D.

One pedagogical approach here is to incorporate recent digital technology to allow students to explore and visualise real engineering problems without the necessity of prior knowledge (Rehman, 2023). In soil mechanics, students understand the flow of water in 1D and 2D. In the upcoming teaching period, it is intended to use ANSYS Discovery, a real-time FEM software, to expand the application of soil mechanics beyond simple 1D and 2D geometry. Although year 2 students are not fully aware of the theory behind FEM, they are still able to utilise ANSYS Discovery as this software requires a minimum number of input parameters, such as mesh types and sizes. For example, the multi-stage dewatering system has been taught in the class and students did a simple 2D simulation to estimate the flow of water in soils. Using ANSYS Discovery with extensive drawing tools, students can quickly build complex 3D geometry and obtain the total head and flow vectors without knowing the rigor mathematical framework, as shown in Figure 3.

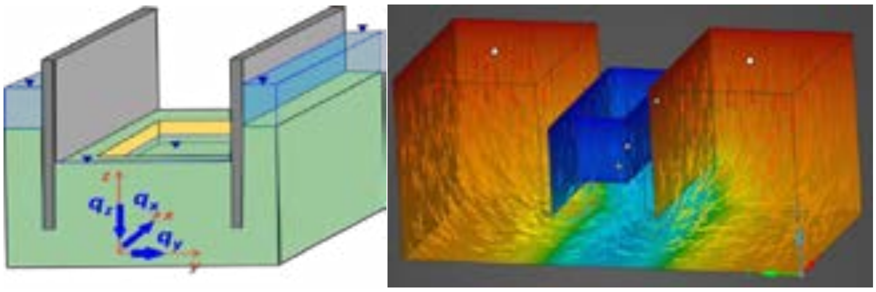

Fig. 3. Dewatering methods a) schematic representation b) numerical simulations

4.2 Revised methodologies for a F2F teaching module

The ongoing teaching round for this module is a F2F. It is essential to adapt existing pedagogical methods to accommodate this change for the future planning of engineering education. Examining various studies incorporating FLA in teaching, Van Alten et al (2019) indicated that students' perceptions and achievements can improve when FLA is integrated with F2F activities, rather than completely replacing them. This approach addresses a common drawback of FLA, where students often lack sufficient opportunities to ask questions during the lecture(see Hotle and Garrow 2016).Similarly, the author’s experience revealed that pre-class activities could offer accessibility and flexibility options to students and that they could use them to develop self-regulation skills. Also, students’ surveys confirmed that students prefer to have teaching materials in advance to use them as excellent revision tools for exam preparation. Therefore, it is planned to keep some pre-class resources, such as introductory videos for each subject and online quizzes. However, it is expected that more student-centred activities, like problem-based learning opportunities in laboratory sessions and extra tutorial sessions, can be organised in the new curriculum design. Also, the online virtual laboratories are worth being preserved even if teaching is delivered F2F round, and can be augmented with in-depth feedback sessions and ‘virtual’ teaching technology (e.g., simulation-driven software). This can create an autonomy-supported teaching environment, where students can change the design parameters and see instant outcome. The previous students’ survey was conducted by the university, which could not measure all aspects of teaching in a joint international program. A revised survey aims at measuring the students experience with the FLA, the influence of language barriers, students' preferences on keeping online resources for F2F teaching, and the use of technology-enhanced teaching has been prepared and attached in Appendix A.

5 CONCLUSION

The paper have addressed the educational methodologies and resources used for the first delivery of the soil mechanics module in a joint international programme involving the University of Strathclyde. The COVID pandemic imposed unprecedented restrictions and challenges on both instructors and students, which made traditional F2F classes an unfeasible option. The paper describes innovative educational solutions, such as using a flipped classroom approach and virtual laboratories, to overcome not only these challenges but also those typically faced in joint international programmes, such as language barriers and curriculum alignment between partnered universities. Since a similar F2F module has been run in Strathclyde, it has been used for comparing two different programmes in terms of assessment performance and students' engagements. Despite the challenges, similar students' performance in terms of overall assessment has been observed between the F2F module and the joint international module. However, it was clear that students experiencing physical laboratories could show better performance compared to those performing virtual labs in an online setting. A pedagogical remedy here would be to equip the soil mechanics module with a technology-enhanced learning framework. As an example of this technology, simulation-driven engineering software has been suggested, and its application in soil mechanics has been demonstrated. Finally, the revised teaching strategies have been suggested for future implementation of the class in a compacted F2F setting. Overall, the study offers empirical evidence regarding academic performance, student satisfaction, and engagement, aiding educators in making informed decisions regarding the adoption of FLA within challenging joint international programs.

REFERENCES

Akçayır, Gökçe, and Murat Akçayır. "The flipped classroom: A review of its advantages and challenges." Computers & Education 126 (2018): 334-345.

Baytiyeh, Hoda, and Mohamad K. Naja. "Students' perceptions of the flipped classroom model in an engineering course: a case study." European Journal of Engineering Education 42, no. 6 (2017): 1048-1061.

Fass-Holmes, Barry, and Allison A. Vaughn. "Evidence that international undergraduates can succeed academically despite struggling with English." Journal of International Students 5 (2019): 228-243.

Hardebolle, Cécile, Himanshu Verma, Roland Tormey, and Simone Deparis. "Gender, prior knowledge, and the impact of a flipped linear algebra course for engineers over multiple years." Journal of Engineering Education 111, no. 3 (2022): 554-574.

Hotle, Susan L., and Laurie A. Garrow. "Effects of the traditional and flipped classrooms on undergraduate student opinions and success." Journal of Professional Issues in Engineering Education and Practice 142, no. 1 (2016): 05015005.

Hunt, Lynne, and Denise Chalmers. "University teaching in focus." A learning-cenred approach. Abingdon: Routledge (2012).

May, Dominik, Beshoy Morkos, Andrew Jackson, Nathaniel J. Hunsu, Amy Ingalls, and Fred Beyette. "Rapid transition of traditionally hands-on labs to online instruction in engineering courses." European journal of engineering education 48, no. 5 (2023): 842-860.Prevalla, Blerta, and Huseyin Uzunboylu. "Flipped learning in engineering education." TEM Journal 8, no. 2 (2019): 656.

Rehman, Zia ur. "Trends and challenges of technology-enhanced learning in geotechnical engineering education." Sustainability 15, no. 10 (2023): 7972.

Sandnes, Frode Eika, Y. Huang, and H. Jian. "Experiences of teaching engineering students in Taiwan from a Western perspective." International Journal of Engineering Education 22, no. 5 (2006): 1013.

Van Alten, David CD, Chris Phielix, Jeroen Janssen, and Liesbeth Kester. "Effects of flipping the classroom on learning outcomes and satisfaction: A meta-analysis." Educational Research Review 28 (2019): 100281.

Zhu, Haiping, and Helen O'Sullivan. "Shhhh! Chinese students are studying quietly in the UK." Innovations in Education and Teaching International 59, no. 3 (2022): 275-284.

APPENDIX A-REVISED STUDENTS' SURVEY

Flipped classroom experience:

1. How effective did you find pre-class content in preparing you for in-class discussions and activities? Very effective-effective-neutral-not effective-not at all effective

2. During in-class sessions, how beneficial were the activities and discussions facilitated by the instructor in reinforcing the pre-class content? Very Beneficial-Beneficial-Neutral-Not Beneficial-Not at All Beneficial

3. To what extent do you believe virtual laboratories (LABs A and B) enhance your understanding of geotechnical engineering concepts? Significantly enhance -Enhance neutral- do not enhance- detract from understanding.

Language barrier:

4. Did you face any language barriers while engaging with the online content or live class? If yes, please elaborate.

5. What strategies do you personally use to overcome language barriers in your academic endeavors? (Select all that apply.) Seeking help from professors or tutors-collaborating with classmates- utilising language support services- Self-study and practice- other (please specify)

Keep online resources for FTF class (blended learning)?:

6. If you prefer to continue having online resources, what are the main reasons for your preference? (Select all that apply.) Flexibility in learning; access to recorded

lectures for review; convenience - Improved understanding of course materials;- Other (please specify)

7. If you are against continuing online resources, what concerns or drawbacks do you have? (Select all that apply.) Lack of personal interaction- technical issues Reduced engagement with course content- other (please specify)

Technology-enhanced learning:

8. Do you prefer to learn engineering software in the lecture to understand real-world problems such as water flow in 2D and 3D? strongly prefer - Prefer neutral- do not prefer -strongly do not prefer

9. Do you prefer to use engineering software instead of a physical laboratory? strongly prefer -Prefer- neutral-do not prefer- strongly do not prefer

Students' engagement and satisfaction:

10. How satisfied are you with the overall blend of live classes and online learning? very satisfied- Satisfied- Neutral-Dissatisfied, and Very Dissatisfied

Educating the whole engineer through dialogue, ethics, reflection and stakeholder analysis

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Conference Key Areas: *Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing; Engineering ethics education*
Keywords: *Engineering ethics, values*

ABSTRACT

This paper presents teaching and learning activities conducted throughout a one-year master's program with the aim of developing the whole engineer, so that students can engage on complex issues, and contribute to a sustainable and just world in their professional practice. In addition to technical knowledge, engineers

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must also possess professional ethics, critical thinking, an open attitude, advanced communication skills to navigate different stakeholders, as well as the ability to work in multidisciplinary team with diverse perspectives. The teaching and learning activities can be broadly categorised into four categories: strategic dialogue skills, engineering ethics, reflection and stakeholder analysis. Most students found strategic dialogue skills to be most useful to them in their personal development, while they perceived stakeholder analysis to be most useful for their graduation project. Majority of the students agree that the program has contributed to developing them into a more empathetic and responsible engineer. From students' feedback, these activities should be more integrated in an engineering context.

1 INTRODUCTION

The UN Sustainable Development goals (SDG) provide a list of urgent moral goals for innovation and applied science on a global scale (United Nations 2015). While all the goals are linked across the economic, social, environmental and governance pillars of sustainable development, the transition path to inclusive and environmentally sustainable economic development must come intensively from Science, Technology and Innovation (Walsh et al. 2020).

The SDG's can only be attained by confronting many complex and uncertain "wicked problems" that are facing the world. These problems are dynamic, multifaceted and involve many stakeholders with conflicting interests (Rittel and Webber 1973). Therefore, it is not sufficient for engineers to focus single-mindedly on finding technical solutions. The impact of engineers' work inevitably affects society. Poor design is responsible for many environmental and societal problems, so key design criteria, such as renewability, recyclability and nontoxicity, should be met (Wann 1996). The profession comes with a high burden of moral responsibility from the engineers themselves. On the other hand, the success or failure of certain outcomes may be influenced not only by the technical effectiveness of the solution but also by the public's subjective perception of risks and openness to innovation.

In order to contribute to a sustainable and just world, engineers must be able to combine fundamental technical knowledge with professional ethics. In addition, engineers must possess critical thinking, an open attitude and advanced communication skills to navigate different stakeholders, as well as the ability to work in multidisciplinary team with diverse perspectives.

The need to develop the modern engineer with such desired attributes has been addressed by the CDIO concept, which stands for Conceive-Design-Implement-Operate (Crawley 2007). One key aspect of the CDIO approach is the development of professional skills like teamwork and communication. The Hague University of Applied Sciences (THUAS) is a member of CDIO learning community of universities. THUAS technical programmes are implemented based on the CDIO framework, including an integrated curriculum, active learning and effective assessment.

Another educational approach, which has also been developed to achieve the goal of developing engineers that can navigate the complexities of the modern world and contribute positively to society, is to integrate engineering and the liberal arts (Hitt et al. 2023). There is a strong need for engineers to understand the social, ethical, cultural, political and environmental contexts of their work. It is proposed that integrative learning creates connections across liberal arts, disciplinary boundaries and professional domains, facilitating creative, interdisciplinary problem-solving.

This paper discusses comprehensive teaching and learning activities that are implemented regularly throughout a full-time, one-year Master of Science program (Next Level Engineering) at THUAS with the objective of educating responsible engineers, so that they can engage with care and curiosity on complex issues, and contribute to a sustainable and just world in their professional practice. The program is open to students with a bachelor degree from any technical discipline and has admitted the first cohort of students. The program aims to broaden the students' horizon by dealing with specific key enabling technologies, particularly applied data science, as well as developing their applied research skills. As part of the curriculum, students work on a design research project as a group in semester 1 and on an applied research graduation project individually in semester 2 with one of the THUAS research groups. The teaching and learning activities that were aimed at developing responsible engineers can be broadly categorised into four categories: strategic dialogue skills, engineering ethics, reflection and stakeholder analysis. It seems clear that value-sensitive design should be included (Cummings 2006), but a limitation of this work is that this topic was only briefly mentioned under ethics and not thoroughly covered.

2 IMPLEMENTATION

In academic year 2023-2024, the first cohort of students was admitted to the full-time, one-year master program. Out of the cohort of 23 students, roughly one-third of them have done mechanical engineering as their bachelor program, roughly one-third of them have done industrial design engineering as their bachelor program and the rest of the students come from other diverse technical bachelor programs, like information technology and health technology. 15 of the 23 students are local, Dutch students. Of the international students, 4 students have completed their bachelor studies in the Netherlands, while the other 4 students joined the program directly from abroad. In addition, 70% of the students are male and 30% are female.

The physical teaching space is a classroom with a maximum capacity of about 40, which is dedicated for the program. The tables are not fixed and can be flexibly arranged, usually in such a way that groups of 4 students can face one another in discussion and still see the teaching staff at the same time. Students are encouraged to form diverse groups of different (bachelor) backgrounds to provide different perspectives during discussions and to use the strengths of one another in group project. A whiteboard and markers are available for each group to write or sketch their ideas during their discussions. In addition, a "feature" of the learning environment is the extensive use of Post-it sticky notes. While the size of the cohort is conducive for engaging discussions, the use of Post-it notes is a low-barrier way for all students to freely express their opinions. Each opinion can be discussed objectively and fairly anonymously. More importantly, they can be moved around and clustered according to themes on a whiteboard.

In the beginning, as part of the introduction week activities, students learnt about ten categories of basic human values and selected top 3 values that represent themselves (Holmes et al. 2011; Schwartz 1992; Schwartz 2012). Students had to think about how they prioritise what is important to them, since everyone is motivated by all values but to different degrees. Values influence attitude, guide behaviour and motivate decision-making, especially in complex issues with conflicting interests. Meeting people where they are is important in engaging them, making it possible to work together to create common ground to reach a certain goal.

2.1 Dialogue

To that end, students are taught strategic dialogue skills. In this context, strategic dialogue is defined as a conversation between two or more people with clear purpose to gain new insights and solutions, through open exchange of experiences, knowledge and feelings, to reach a certain goal. It is in contrast to a debate, where opposing parties defend their own opinion, in order to win over an audience. As part of discussion on communication, students were asked to watch a documentary "Merchants of Doubt" (Kenner 2014), which exposes how a handful of scientists manipulated public perception on topics from tobacco to global warming. When asked how they felt, a student bluntly said "Disgusting". This brings up issues of professional ethics and moral responsibility.

2.2 Ethics

Ethics was dealt deliberately not from philosophical theory or analytical moral reasoning that do not meaningfully integrate into real-world engineering problems. Instead, ethics is discussed using examples in professional practice to engage technical students, especially on an emotional level. Firstly, the professional code of ethics was examined and applied to particular cases. Secondly, students were introduced to the notion that technologies are inherently value-laden (Van Grunsven et al. 2021). When students learnt that the low-hanging overpasses in New York in the beginning of the 20th century were low by design for the purpose of racial segregation (Winner, 1980), a collective gasp was palpable in the classroom. Thirdly, engineering ethics in practice was discussed using case studies to enhance students' understanding of the social dimension of the engineering profession (Martin et al. 2018; Martin et al. 2021). For the case studies to be impactful, they should be real, contextually relevant, and preferably recent or well-known. In addition, they should provide information to raise awareness of social and personal characteristics of engineering situations, as well as management pressure that can induce engineers to engage in misconduct (McGinn 2018; McGinn 2021). The case-studies should also address students directly, allowing them to identify themselves in the role of the engineer in a difficult situation, especially from the point of view of young starting professionals. It should be noted that Hitt et al. identified ethics education as a key future direction for integrating the liberal arts and engineering (Hitt et al. 2023).

2.3 Reflection

For students to tackle complex, difficult situations where not all factors are known, it is crucial for students to handle uncertainty in order to perform well. Alongside technical solutions, the approach of working and communicating with multiple stakeholders will be significant in contributing to an effective, overall solution. Therefore, students are coached on several tools available from "Reflexive Monitoring in Action" (Van Mierlo, B. and Regeer, B. 2010), which explains that system innovation projects benefit from a type of monitoring that encourages the 'reflexivity' of the project itself, the ability to affect and interact with the environment within which it operates. This lets them develop new ways of dealing with things, which makes the institutional context change too.

2.4 Stakeholder analysis

Students are taught to make a stakeholder analysis by mapping all potential stakeholders, prioritizing them according to their influence or interest, understanding their needs and if necessary, developing a plan to engage them. Furthermore, workshops were conducted on how to conduct interviews with stakeholders. Students apply the knowledge gained in their applied research graduation project, where they have to consider research ethics and intended, possibly unintended implications for different stakeholders. The technical solution or advice should take social, ethical, economic and sustainability issues into consideration, if applicable.

3 RESULTS AND DISCUSSION

The ten categories of human values (Schwartz 1992; Schwartz 2012) are illustrated in Figure 1. Based on descriptive keywords, such as *independent, curious, equality, protecting the environment, meaning in life* (Holmes 2011), which the students selected as most important to them, the top three categories of values turn out to be universalism, benevolence and self-direction. Universalism is defined as understanding, appreciation and protection for the welfare of all people and nature. Benevolence is defined as preservation and enhancement of the welfare of people with whom one is in frequent personal contact. Self-direction means independent thought and action. The categories least selected by students are hedonism, stimulation, conformity and tradition.

Theory postulates that values form a continuum of related motivations (Schwartz 2012). Adjacent values of universalism and benevolence share the motivational emphases of enhancement of others and transcendence of selfish interests, while adjacent values of self-direction and universalism share the characteristic of reliance upon one's own judgement and comfort with the diversity of existence. It is clear that the values that are important to the students show that they are open, curious, and intrinsically motivated to do good and contribute to a better world. They are least likely to be motivated by a desire for affectively pleasant arousal and would not likely subordinate themselves in favour of traditions or social expectations. It is gratifying to note that the values of this group of students closely align with the core values of THUAS, which are *Curious*, *Connecting* and *Caring*. These core values entail being open to others and curious about the world, embracing diversity and helping one another for a sustainable and just future. From these results, it is clear that the students are motivated to become responsible engineers from the outset and would be receptive to mastering professional skills.

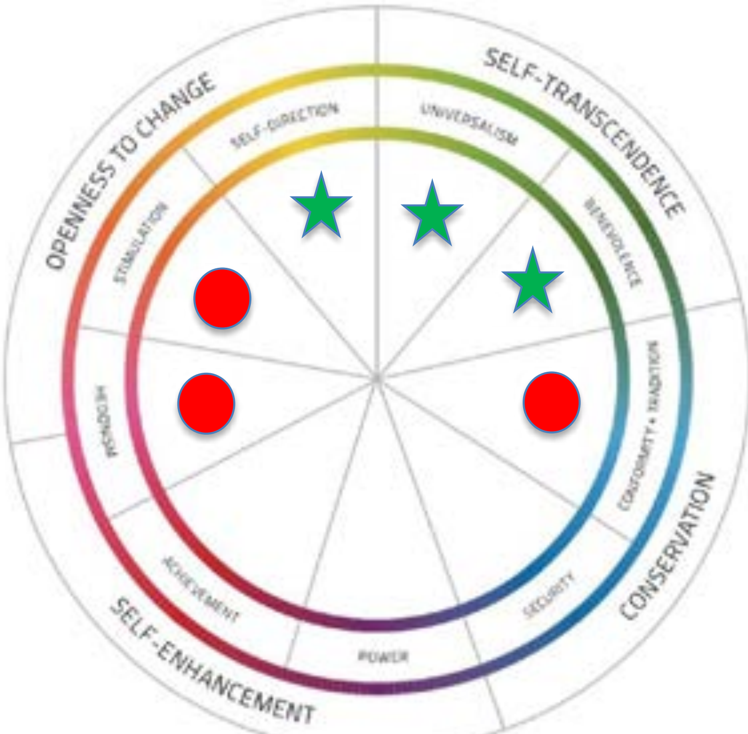
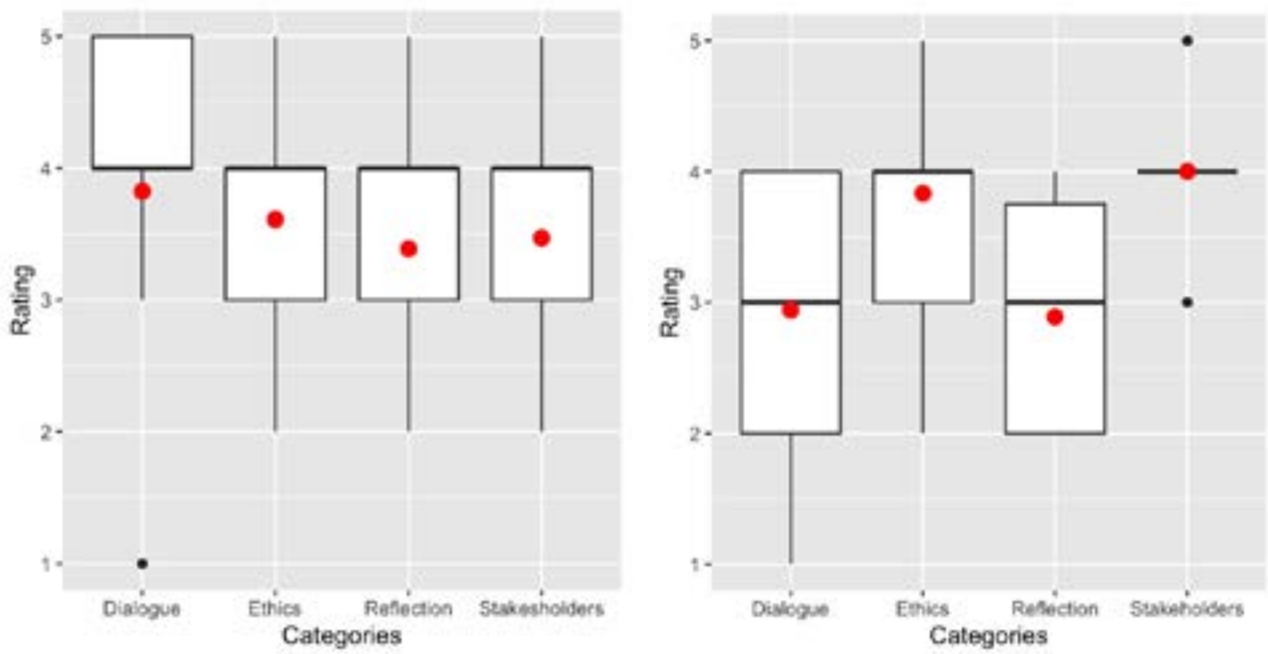


Fig. 1. The ten categories of basic human values as illustrated in The Common Cause Handbook (Holmes 2011). Green star symbols represent the values most selected by students and the red circle symbols represent the values least selected by students.

In order to find out the opinion of students regarding the 4 categories of teaching and learning activities mentioned in the previous section, a survey was carried out when students have approximately completed three-quarter of the academic year. Response was collected from 18 students out of a cohort of 23 (78% response). Students were asked if the teaching and learning activities mentioned in the previous section were useful to them in their personal development as a (socially)-responsible engineer or in their applied research graduation project. A 5-point scale was used with 1 representing “No, not at all” and 5 representing “Yes, very much”. Although the 18 respondents may not be representative of all engineering students in general, the results indicate a reliable trend within this group. Furthermore, their open-ended responses support the conclusion from the 5-point scale survey.

Figure 2(a) shows the box-plot representing the perception of students with respect to their personal development as a (socially-)responsible engineer and figure 2(b) shows their perception with respect to their applied research graduation project. Surprisingly, most students found strategic dialogue skills to be most useful to them in their personal development. The usefulness of ethics, reflection skills and stakeholder analysis to their personal development were rated very similarly. While strategic dialogue was deemed useful for their personal development, it was deemed less useful for their applied research graduation project. Students perceived stakeholder analysis to be most useful for their applied research graduation project. A student offered a tip on how some other students can be encouraged to be more receptive to strategic dialogue. *“Dialogue was more useful than expected, could have been framed as important to stakeholder communication.”*

In response to an open question that asked which activities students would like to have more of, ethics was mentioned by the most (6) respondents. 3 of them explicitly mentioned that they would like more of the case studies and debates. As a student aptly wrote *"Some ethical considerations I thought were surprising. As an engineer you have to think from your perspective but definitely <u>not</u> forget to think in someone else's perspective."* Another student wrote *"I enjoyed the workshop about ethics. I didn't expect it, but the legal aspect of the whistle blowers and who was found at fault at the trials was also interesting".*



(a) (b)

Fig. 2. Rating of students with respect to their (a) personal development and (b) graduation project. Red points represent the average rating. Black points represent outliers.

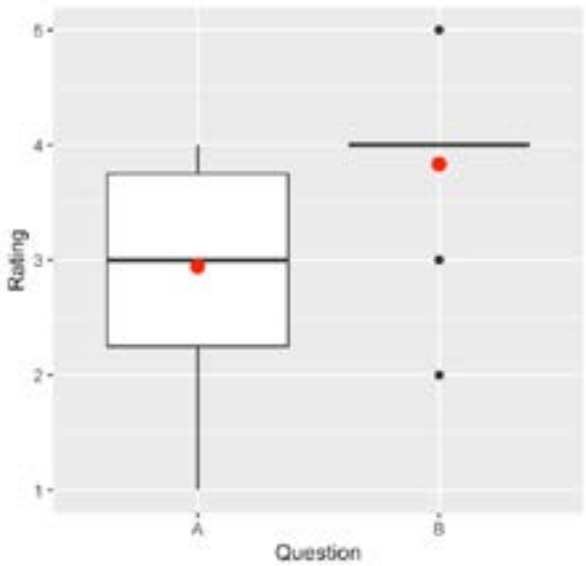


Fig. 3. Rating of students to Question A: "Did you expect before enrolment that the above activities would be useful?" and Question B: "Do you think that the program has contributed to developing you into a more empathetic and responsible engineer?"

Red points represent the average rating. Black points represent outliers.

Technical students remain resistant to time spent on non-technical content. At least 7 respondents mentioned something to the effect of *"less soft skills, more hard skills."* Figure 3 shows that although many students were neutral about the usefulness of dialogue, ethics, reflection and stakeholder analysis before enrolling in the program, it is encouraging that majority of the students agree that the program has contributed to developing them into more empathetic and responsible engineers.

In general, all four categories of teaching and learning activities can be adapted and implemented in different engineering programs. The primary objective of strategic dialogue, as part of general communication skills, is to foster an open exchange of ideas towards achieving a common goal. Reflection and stakeholder analysis are also not engineering discipline-specific. For ethics, it would be more interesting for students to discuss some relevant discipline-specific case studies. However, it is imperative to conduct such activities as interactive workshops in a classroom with no more than forty students to facilitate active discussion. A risk to the current program would be an unexpected increase in intake, such that there is a lack of suitable, dedicated classrooms and a teaching staff to student ratio that is impractical to facilitate discussions. In addition, appropriate projects that allow these activities to be embedded would enhance students' interest and learning. For instance, strategic dialogue and stakeholder analysis would be most useful when applied to technical projects that have significant societal relevance. Such projects often involve multiple stakeholders that students must interview and consider their interests. Regarding teaching hours, strategic dialogue, ethics and stakeholder analysis took around three 1.5-hour workshops each. For reflection, time is dedicated roughly once a week in semester 1 for coaching on several tools from "Reflexive Monitoring in Action" (Van Mierlo, B. and Regeer, B. 2010). The assessment of these professional skills takes place in the projects. For example, there are indicators in the assessment rubric that consider if students have considered the stakeholders in the formulation of their research objectives and if relevant ethical or sustainability perspectives are discussed.

4 CONCLUSION AND FUTURE PLANS

Although the results obtained from this short questionnaire are motivating, this is the first year of running a new master program and a lot of useful feedback has been collected from the first cohort of students. Majority of the students agree that the program has contributed to developing them into a more empathetic and responsible engineer. It is interesting that students perceive a difference in usefulness of dialogue, ethics, reflection, and stakeholder analysis to their personal development and for their applied research graduation project. Most students found strategic dialogue skills to be most useful to them in their personal development, while they perceived stakeholder analysis to be most useful for their graduation project. A student suggested to connect these activities directly *"to more engineering concepts would make it better in my opinion"*.

In future, these teaching and learning activities should be framed better to be more integrated in an engineering context, so that technical students who enjoy problem-solving can see more practical use of such activities in their applied research graduation projects. More concretely, value sensitive design (Cummings 2006) will be more explicitly incorporated in the curriculum, as this topic naturally involves values, ethics, reflection and stakeholder analysis.

REFERENCES

Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R. and Edström, K. *Rethinking Engineering Education. The CDIO Approach.* New York: Springer, 2007.

Cummings, M. L. “Integrating Ethics in Design through the Value-Sensitive Design Approach.” *Science and Engineering Ethics* 12 (2006): 701-715.

Hitt, S. J., Banzaert, A. and Pierrakos, O. “Educating the Whole Engineer by Integrating Engineering and the Liberal Arts.” *International Handbook of Engineering Education Research* (2023): 457-476. https://doi.org/10.4324/9781003287483-25.

Holmes, T., Blackmore, E., Hawkins, R. and Wakeford, T. *The Common Cause Handbook.* U.K.: Public Interest Research Centre, 2011.

Kenner, Robert. *Merchants of Doubt*. United States: Sony Pictures Classics, 2014.

Martin, D. A., Conlon, E. and Bowe, B. “A Constructivist Approach to the use of Case Studies in teaching Engineering Ethics.” *Teaching and Learning in a Digital World* (2018): 193-201.

Martin, D. A., Conlon, E. and Bowe, B. “Using case studies in engineering ethics education: the case for immersive scenarios through stakeholder engagement and real life data.” *Australasian Journal of Engineering Education*, 26, 1 (2021): 47-63. https://doi.org/10.1080/22054952.2021.1914297.

McGin, R. E. *The Ethical Engineer. Contemporary Concepts and Cases.* United States: Princeton University Press, 2018.

McGin, R. E. “Startup Ethics: Ethically Responsible Conduct of Scientists and Engineers at Theranos.” *Science and Engineering Ethics*, 28, 39 (2022). https://doi.org/10.1007/s11948-022-00393-2.

Rittel, H.W.J. and Webber, M.M. “Dilemmas in a general theory of planning.” *Policy Sci* 4 (1973): 155–169. https://doi.org/10.1007/BF01405730.

Schwartz, S. H.. “Universals in the content and structure of values: Theory and empirical tests in 20 countries.” *Advances in experimental social psychology,* 25 (1992): 1-65. http://dx.doi.org/10.1016/S0065-2601(08)60281-6.

Schwartz, S. H.. “An Overview of the Schwartz Theory of Basic Values.” *Online Readings in Psychology and Culture,* 2, 1 (2012): 1-20. https://doi.org/10.9707/2307-0919.1116.

United Nations. “Transforming our world: The 2030 agenda for sustainable development”, A/Res/70/1, 2015.

Van Grunsven, J., Marin, L., Stone, T., Roeser, S. and Doorn, N. “How to Teach Engineering Ethics? A Retrospective and Prospective Sketch of TU Delft’s Approach to Engineering Ethics Education”, *Advances in Engineering Education*, 9, 4 (2021): 1-10. https://doi.org/10.18260/3-1-1153-25254

Van Mierlo, B. and Regeer, B. *Reflexive Monitoring in Action. A guide for monitoring system innovation projects.* The Netherlands: Communication and Innovation Studies, WUR; Athena Institute, VU (2010).

Walsh, P. P., Murphy, E. and Horan, D. “The role of science, technology and innovation in the UN 2030 agenda.” *Technological Forecasting and Social Change,* 154 (2020): 119957. https://doi.org/10.1016/j.techfore.2020.119957.

Wann, D. *Deep Design: Pathways to a Livable Future.* Washington D.C.: Island Press, 1996.

Winner, L. “Do Artifacts Have Politics?” *Daedalus*, 109, 1 (Winter, 1980): 121-136.

VIRTUAL INDUSTRY VISITS USING IMMERSIVE 360º VIDEO: ENSURING ACCESS FOR ALL ENGINEERING STUDENTS

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ABSTRACT

The work presented in this practice paper illustrates how the use of immersive 360º video and photographs, viewed in virtual reality headsets or via 360º media players, can enhance and broaden student knowledge and experience when undertaking Project Based Learning (PBL) assignments. This paper will highlight an array of mediums in which a Virtual Site Visit (VSV) can be shared with students. By using coverage of real buildings, PBL assignments can be set for students which are real and innovative. This pedagogical approach allows educators to use particularly interesting or challenging buildings and case studies, once a VSV has been generated. This is particularly useful: for students who may have accessibility issues due to

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physical disabilities; the sharing/experiencing of interesting structures from around the world in a much more meaningful way; or for distance/online learning.

This practice paper will share the equipment specification for recording the VSV, a suggested workflow in preparing for the recording of the visit along with the video recording methodology and editing process, with proposed mechanisms for sharing the VSVs with students. Feedback was gathered and is shared in this paper from a cohort of students undertaking a Health and Safety module, in which a VSV video was used to share the building on which a PBL assignment was based.

1 INTRODUCTION

1.1 Project Based Learning and Virtual Site Visits

The work presented in this practice paper illustrates how the use of immersive 360^o video and photographs, viewed in virtual reality headsets or via 360^o media players, can enhance and broaden the student experience when undertaking Project Based Learning (PBL) assignments. It has long been a practice of setting civil engineering students a PBL assignment based on a field trip or site visit. The literature clearly links the use of PBL assignments as a means of enhancing the engineer's education by improving their technical skills, and providing context for real-life engineering issues and challenges (Ríos et al. 2010, Kokotsaki, Menzies, and Wiggins 2016). However, there is an ever-present problem around ensuring that all students have access to the visit material particularly where, for example they were sick on the day of the visit or have accessibility issues. Indeed, the recent COVID-19 pandemic clearly illustrated the need for an alternative to the physical 'site visit'. (Ríos et al. 2010, Kokotsaki, Menzies, and Wiggins 2016)

2 PROJECT MOTIVATION/BACKGROUND

Student visits to construction sites and manufacturing facilities are a key component in the education of engineers (Shojaei et al. 2023, Wang et al. 2021). Engineers Ireland, the accrediting body for engineers in Ireland, have identified seven programme areas that need to be addressed in the development and design of engineering programmes (Engineers Ireland 2021). Two of these programme areas, PA2 Discipline-specific Technology, and PA5 Engineering Practice, identify industrial or commercial site visits, and real-world-based case studies and projects, as key measures to meeting these two programme areas.

However, the question arises, in the design of programmes and the integration of such industrial visits, case studies or project-based learning assignments, how can the issue of limited or no access to such facilities be addressed? There could be students with limited mobility in a class cohort; there could be a site/industrial location with sensitivities around accessibility and confidentiality; or in an extreme situation, a general lockdown on movement as was seen during the COVID-19 pandemic. Moreover, restricting options to in-person site visits places limitations on the pool of structures that can be visited, and/or are expensive to conduct for entire student groups.

To address these issues since the onset of COVID-19 in March 2020, work has been underway within the Department of Civil, Structural and Environmental Engineering at

Munster Technological University (MTU) to develop a more innovative approach, with the development of the ‘virtual site visit’ (VSV).

There is a growing body of literature investigating how students learn from VR and 360º videos and their benefits/short falls (Marinelli et al. 2023, Wolf et al. 2023). Whilst these VSVs may not replace an actual site visit; they are an excellent substitute when site access is not permitted or possible. They aid the development of critical thinking, problem-solving, spatial awareness, demonstrate construction technologies etc.

To ensure accessibility for all within the class cohorts, research was undertaken to see if there was a more innovative approach than using 2D photographs and videos to preparing these VSV. This has resulted in the purchase of equipment and the development of immersive 360º videos. This work was prepared in partnership with MTU’s Technology Enhanced Learning unit (TEL).

3 PROJECT EQUIPMENT AND SOFTWARE

3.1 Previous Equipment for VSVs and software

Previous equipment used in creating 2D virtual visits included a Nikon Z50 digital camera, with a tripod and recording equipment. This equipment was used for a number of VSVs, and whilst the photo and video quality were excellent, there were several issues encountered. These included the tripod set-up: the setting up of the tripod for the 2D Nikon camera is difficult when visiting a live construction site with moving vehicles etc. It takes time to level the device, only to have a large machine move towards you and you must re-level it again. A gimbal is needed for capturing video, if the camera is not on the tripod. Walking with the camera – without a gimbal leads to very ‘jumpy’ video footage.

3.2 360º video equipment for VSVs

This project investigated a number of alternative 360º cameras with the Insta360 the preferred choice. The following is the equipment specification of what was used in this project.

- Insta360 X3 camera with a tripod and stand as illustrated in figure 1 below.
- InstaStudio: The purchase of the Insta360 camera is accompanied by a licence for the editing software, which is downloaded via an app to your smartphone and also to your computer/laptop.
- DJI wireless mic and receiver set as illustrated in figure 1 below.


Figure 1: Insta360 camera and DJI wireless mic set with receiver and charging case

The Insta360 was first developed in 2015, by Arashi Vision Inc. In 2018 they introduced the FlowState stabilisation algorithm into their cameras, thus enabling the user to shoot video as though using a gimbal (Arashi Vision 2024). The X3 model, which was used in this project, can record 5.7K 360° video, 360° photos or 180° field of view photos. The camera can be controlled from an app on your smart phone or via the camera itself. Whilst the small screen on the back of the camera makes it slow to use, the mobile app has an excellent user interface. The recorded video can be shared as a 360° video on, for example, YouTube or the video can be reframed in the Insta360 studio for the best angles.

The camera has a ¼ inch (6mm) socket at the bottom which allows the camera to be mounted on a selfie stick or a tripod. If using the camera remotely outside, it is possible to mount the camera on an extension, or 'selfie' stick and use a heavy base plate for stability.

3.3 360° video software for VSVs

The Insta360 camera is linked to the user's mobile phone via the Insta360 app. This app allows the user to remotely operate the camera for either photos or videos. The user can edit the photos and videos recorded via the app – using the Snap Wizard, or import them into the InstaStudio on their laptop via the SD card or USB connection.

Captured photos and videos can also be shared on the users' social media accounts of Instagram and Facebook directly from the app or they can be uploaded to the Insta360 Album and can be accessed whilst not connected to the camera. Photo and video can also be mixed with music before sharing. All this is managed within the App or in InstaStudio. If wishing to combine videos for more detailed post-production then each Intsa360 video can be exported from InstaStudio as an MP4 file and imported into video editing software like Adobe Premiere Pro or Adobe Rush.

4 INSTRUCTIONAL DESIGN AND WORKFLOW METHODOLOGY

The instructional design approach for these VSV using immersive 360° video integrates multiple theoretical frameworks to enhance the learning experience for students. The ADDIE model underpins the development of these visits, ensuring a comprehensive process from initial analysis through to evaluation. This has been complemented by Mayer's Cognitive Theory of Multimedia Learning, which advocates for the integration of words and pictures to deepen understanding and retention. The rich media utilised in this project aligns with Mayer's principles by engaging both visual, spatial and auditory channels, thereby facilitating a more robust learning experience. Additionally, Constructivist Learning Theory informs the pedagogical strategy, emphasising the importance of learners constructing knowledge through authentic, experiential activities.

4.1 ADDIE Model

Each phase the Addie Model (A - Analyse; D- Design; D – develop; I -Implement; E – Evaluate) will be expanded in the following sections explaining how each of these steps have been conducted on the preparation of the VSVs.

4.2 Analyse phase – the need for VSVs

The VSVs were 1st developed within the Department to support student learning during the COVID-19 pandemic. They were used in various PBL assignments across structural engineering, civil engineering, architecture, architectural technology, and programmes in Building Information Modelling (BIM). They included modules in: Project Management; Health and Safety; Construction Technology; and Structures.

However, with the emergence for more 360º video technologies and the use of VR in engineering, the decision was made to explore and develop immersive 360º VSVs which could be used for PBL assignments. There are also some students in a department with accessibility issues, and thus not able to visit the site. In selecting the case study site, a public building was identified which was easy to understand from a structural engineering perspective, with an exposed structural frame etc. Recording a public building ensured that there are no copyright issues regarding the sharing of the building's images, and also the tender drawings for the structure were available on the eTenders website (Procurement 2024).

The selected building was a new public building in Cork, the Central Hall or 'Red Shed' at Cork's new Marina Park 2.

Figure 2: 'Red Shed' - Central Hall, Marina Park, Cork

The 'Red Shed' project and the VSV material have formed the basis for a PBL in a Health and Safety module. Students were tasked with undertaking a risk assessment and preparing a method statement for the construction of the Red Shed at a (hypothetical) site on the University's campus..

4.3 Design Phase - Scripting/pre-production

When preparing a video, and getting the line-up and script ready there are a number of questions which need to be addressed: what is the purpose of the video; what is it trying to share; who is the audience; what is the message that we want them to take away from it; have we many audiences – if so, does the video need to be more generic? This will influence the script/storyline of the video. What is the optimum length of the video? What length will students watch?

Always answer each of these before preparing your video structure and script. In the example of the case study for this paper, the primary focus was to capture a building so that students could understand how it was made, and that they could replicate it on campus.

4.4 Development Phase – video capturing and sound recording

There are several items to consider when preparing for video recording. The primary one which had an impact on the preparation of this video was the weather, with many lessons learnt. This video was to be recorded during the month of November, however with the low angle of the sun and if you have a bright day, the 'invisible' stick supporting the camera will cast a shadow on the ground, which will be very visible in your video.

The DJI independent voice recorder was used in making the case study video, as the wind etc can interfere with the sound captured in the Insta360 (see section 3.2 above). A recording device could be fitted to the Insta360 camera – like a receiver for the DJI speakers, but this receiver would then be very visible in the video. Also ensure that there is a windscreen fitted to the microphone to ensure as little wind interference in the recording as possible.

Editing and post-production

Premiere Pro from the Adobe suite was used in the post-production of this video. This was used over InstaStudio as it allows multiple clips to be edited together, providing students with a more contextual visit of the site.

4.5 Implementation phase – sharing of 360º immersive videos

There are several options to share the videos with students. In this instance YouTube was chosen as the sharing medium of this project as seen in Figure 1. A channel was set up and made public. It is important to note, that when editing and publishing 360° video you will be dealing with very large files. For example, depending on the export settings, one minute of video at 4K will be in typically be in excess of 1GB of file storage.

The case study site for this project has been shared via YouTube and the Matterport app, which uses Artificial Intelligence (AI) to generate a virtual walkthrough or 'Dolls House' of the building. Access to this walkthrough is then shared with the students via a link on Canvas, the University's learning management system (Canvas 2024).

Figure 1: YouTube video and QR for access to video

Matterport is an online 3D data platform which allows a space to be scanned and a 3D walkthrough developed (Matterport 2024). A Matterport licence was purchased for this project. The licence permits you to prepare a digital twin of the case study space. The licence includes an online account and a smart phone app. This smart phone app then communicates with the Insta360 camera which scans the case study building. The data is uploaded to Matterport and after some processing time, your 'dolls house' of the case study space is ready.

4.6 Evaluation phase – The Student Survey and their feedback

A survey of 47 students in the department who have participated in the PBL assignment using the Red Shed VSV was undertaken, with the survey receiving Human Research Ethics (HRE) approval, HREC-MR-23-059. Students were asked to evaluate each of the options of learning about the 'Red Shed'. These included 2D photographs, 2D video, a narrated slideshow on YouTube using 360º video clips or the fully immersive 360º video on YouTube and the Matterport walkthrough.

Regarding 2D material for the Red Shed, students were asked which gave them the best understanding of the structure. They ranked 2D photos as best, followed by 2D videos, engineering drawings and architect's drawings.

Regarding the 3D material for the Red Shed, students were again asked to rank which medium gave them the best understanding of the structure. They ranked the Matterport walkthrough as the best followed by the 360º YouTube video, which they viewed using their own phones. The MetaQuest 3 headset was also used during the survey to share the 360º YouTube video. There were several issues encountered with using the headset. These included a lack of connectivity for the headset, the need for an additional lecturer to share the headset with students, and students not wishing to use the headset citing health issues – vertigo and migraines. In total 10 students got to use the headset in the one hour lecture slot versus all 47 being able to undertake the Matterport walkthrough and view the YouTube 360º video.

Students were asked to *'Describe any specific aspects of the* 360º *immersive videos that you found particularly helpful or challenging in understanding the site / building',* with some very insightful responses. They particularly appreciated the personal independence of being able to check out the area they were interested in. Because they can use their own phones to undertake the virtual walkthrough it is so easily accessible for all of them.

'Being able to see all around'
'getting a better idea of the size of the structure, more realistic look on it'
'I like that you can look/move to wherever you want.'
'Having a free view of what I wanted to look at'
It is the closest you can get to being there through media so it is very effective'
'It's very helpful providing digital prototypes of designs'
(Mary Moloney 2024)

The immersive nature of 360° video allows students to interact with realistic environments, fostering problem-solving and critical thinking skills essential for engineering education. This multi-faceted approach not only addresses diverse learning needs but also enhances accessibility, providing all students with the opportunity to engage with complex, real-world engineering contexts.

5 SUMMARY AND ACKNOWLEDGEMENTS

This pedagogical approach of using 360º video could allow educators to use particularly interesting or challenging buildings / case studies, once a VSV has been generated, allowing access for all. This project was developed with support and funding from the National Forum for Teaching and Learning under the Strategic Alignment of Teaching and Learning Enhancement Funding in Higher Education (SATLE) call and the Erasmus+ project 2021-1-FR01-KA220-HED-000035699.

REFERENCES

Arashi Vision, Inc. . 2024. "Insta360." accessed 4.4.2024. https://www.insta360.com/about.

Canvas. 2024. "CANVAS." https://community.canvaslms.com/t5/Canvas/ct-p/canvas.

Engineers Ireland. 2021. Accrediation Criteria. Dublin: Engineers Ireland.

International Engineering Alliance. 2021. Graduate Attributes and Profssional Competencies International Engineering Alliance,.

Kokotsaki, Dimitra, Victoria Menzies, and Andy Wiggins. 2016. "Project-based learning: A review of the literature." *Improving Schools* 19 (3):267-277. doi: 10.1177/1365480216659733.

Marinelli, Melissa, Sally A. Male, Andrew Valentine, Andrew Guzzomi, Tom van der Veen, and Ghulam Mubashar Hassan. 2023. "Using VR to teach safety in design: what and how do engineering students learn?" *European Journal of Engineering Education* 48 (3):538-558. doi: 10.1080/03043797.2023.2172382.

Mary Moloney, Jeremiah Spillane. 2024. Virtual Site Visits: Immersive and Accessible Learning for Civil Engineering through 360-Degree Video. edited by Student Survey.

Matterport https://matterport.com/.

Procurement, Office of Government. 2024. eTenders Website,. edited by Department of Public Expenditure and Reform: European Dynmaics,.

Ríos, Ignacio de los, Adolfo Cazorla, José M. Díaz-Puente, and José Luis Yagüe. 2010. "Project–based learning in engineering higher education: two decades of teaching competences in real environments." *Procedia - Social and Behavioral Sciences* 2:1368-1378.

Shojaei, Alireza, Reachsak Ly, Saeed Rokooei, LLC SplusM, and Ahmed Al-Bayati. 2023. "Virtual site visits in Construction Management education: A practical alternative to physical site visits." *Journal of Information Technology in Construction (ITcon)* 28 (36):692-710.

Wang, C., Q. Shao, X. Li, W. Mao, and L. A. Roberts. 2021. "Promoting STEM Learning through an Interdisciplinary Video Project." 2021 19th International Conference on Information Technology Based Higher Education and Training (ITHET), 4-6 Nov. 2021.

Wolf, Mario, Florian Wehking, Heinrich Söbke, Michael Montag, Steffi Zander, and Christian Springer. 2023. "Virtualised virtual field trips in environmental engineering higher education." *European Journal of Engineering Education* 48 (6):1312-1334. doi: 10.1080/03043797.2023.2291693.

ZOOM Corporation. 2024. https://zoomcorp.com/en/jp/field-recorders/field-recorders/f2andf2-bt/.

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INTEGRATING IMMERSIVE TECHNOLOGY SOLUTIONS IN ENGINEERING EDUCATION AT UNIVERSITY LEVEL

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ABSTRACT

This paper explores the use of Virtual Reality (VR) and Augmented Reality (AR) in university-level engineering education, particularly within Mechanical and Manufacturing Engineering fields. It highlights the potential of these immersive technologies to enhance student's understanding of complex engineering principles and develop essential transversal skills, thus preparing them for the diverse challenges of today's workforce. This paper investigates various VR and AR applications, from improving public speaking and communication skills to facilitating

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hands-on learning of engineering principles in a risk-free, simulated environment. It also covers the use of AR in interactive design challenges, which helps students visualise and manipulate engineering concepts in real time, leading to a better grasp of mechanical and manufacturing concepts. The paper argues that VR and AR technologies have the potential to significantly transform engineering education and recommends a strategic approach to their integration into the curriculum. By offering insights into the benefits and challenges of using immersive technologies in education, the paper aims to provide a roadmap for universities to enhance the preparation of future engineering professionals with a blend of educational and technical skills.

1 INTRODUCTION

AR and VR technologies provide a three-dimensional (3D), interactive learning environment that allows for a more experiential learning process that enhances spatial understanding, problem-solving, and engagement (Kozov, Ivanova and Ivanov 2019). However, the adoption of these technologies in engineering education faces hurdles such as technological barriers, high costs, and resistance to change (Boyle, et al. 2022). The paper aims to assess the incorporation of immersive technologies into engineering curricula through an undergraduate degree course currently in progress under the Rethinking Engineering in Education (REEdI) (Rethinking Engineering Education in Ireland 2024) program at Munster Technological University (MTU). It will propose strategies for integrating these technologies, considering accessibility, curriculum design, faculty training, and student feedback. The paper seeks to recommend best practices and solutions for educators and institutions, propose pedagogical approaches, and suggest areas for future research.

2 LITERATURE REVIEW

Immersive technology is increasingly being utilised within education contexts as a tool for increasing student learning outcomes such as knowledge retention and engagement (Kaur, et al. 2022). These technologies have been proven beneficial in imparting knowledge or providing experiences in scenarios where a demonstration in the real world is not possible or feasible (Dinis, et al. 2018). Kaur, et.al. examine several use cases of these technologies in the education context and conclude that they "*have been tested and proven to be beneficial in the engineering education domain*" (Kaur, et al. 2022).

Dinis, et. al. illustrates how the use of VR can allow users to visit environments and view elements that are typically hidden within the classroom environment (Dinis, et al. 2018). In this paper, an Interactive Virtual Environment (IVE) was created based on an existing building. Users can visit this virtual building and view or hide elements of the environment to observe hidden details, such as the rebar hidden within concrete slabs. This experience is intended as an introductory education piece for prospective civil engineering students (Dinis, et al. 2018).

VR has also been used to increase student engagement and foster creativity within existing curricula (Krajčovič, et al. 2022). Krajčovič et. al. examine an existing assignment and retrofit it with the addition of a VR-based experience that students could access both in class and in their free time (Krajčovič, et al. 2022). The assignment tasked students with suggesting optimizations to a workplace based on an existing space. This case study resulted in increased student engagement, with 90% of students within the study group interested in working on the assignment outside of classes as compared to previous years' 10-20%. Additionally, the average number of optimisations increased from previous years, with a significant amount of those optimisations relating to ergonomics within the space. The paper's authors hypothesise that this is due in part to the fact that the VR experience gave the students the ability to view the space from an employee's perspective, which was not possible in previous years (Krajčovič, et al. 2022).

Kozov et. al. finds that the use of immersive technologies in mechanical engineering education enhances student concentration by isolating them from distractions and providing a dedicated learning environment (Kozov, Ivanova and Ivanov 2019). Kozov et. al. outlines the use of 3D models, virtual simulations, and motion-tracking technologies to enable students to engage in hands-on activities and interactive learning experiences, and can incorporate game-based approaches to education, making learning more engaging and facilitating faster knowledge absorption (Kozov, Ivanova and Ivanov 2019). Kozov et. al. conclude that immersive learning focuses on creating realistic virtual environments for experiential learning, which aim to enhance student understanding, retention, and practical skills in mechanical engineering education (Kozov, Ivanova and Ivanov 2019).

Problem-solving skills are a critical tool for engineering. According to Roopaie et. al. immersive technologies provide the ideal solution to help students develop problem-solving skills (Roopaei and Klaas 2021). For instance, immersive technology gives students the ability to control the pace of their learning, allowing them to spend more time on challenging concepts and move quickly through familiar topics. Furthermore, immersive environments allow students to make mistakes in a controlled setting where they can learn from them without consequences, fostering a growth mindset and resilience in problem-solving. Immersive technologies are not limited to engineering concepts and principles. Graduate engineers are expected to be well-rounded employees who also possess soft and transversal skills. Roopaie et. al suggests that students can develop various social and emotional skills using immersive technology by enhancing collaboration among educators and students by engaging them in interactive and motivating virtual environments, where they can share experiences and work together on challenging tasks (Roopaei and Klaas 2021). Furthermore, by exploring new cultures and environments through immersive technology, students can develop a sense of respect and appreciation for diverse cultures and people, fostering empathy and cultural understanding. Through immersive experiences that simulate real-world scenarios, students can practice emotional regulation and coping strategies in a safe and controlled environment.

While immersive learning methodologies offer numerous benefits in terms of student engagement, understanding, and accessibility, they also present challenges related to teacher preparation, technological limitations, and assessment practices (Boyle, et al. 2022). Effective implementation of these methodologies requires careful planning, support, and ongoing evaluation to maximise their potential impact on student learning outcomes.

3 REEDI: CASE STUDIES AND IMPLEMENTATION EXAMPLES

The REEdI initiative presents a pioneering undergraduate program in engineering that embodies agility and innovation and integrates an advanced approach to disseminating knowledge through immersive technologies.

The curriculum was designed from the ground up and is currently in its second year of delivery. Figure 1 shows the extent to which immersive technologies are incorporated across various modules throughout the 4-year degree course, constituting 55.6% of the curriculum, and is discussed in detail in this paper. For instance, Gadgeteer, an off-the-shelf solution is used in *Engineering Challenge 1,* to simulate real-world engineering challenges and settings. Students also present their final year project – *Engineering Challenge 2* - in VR using the ENGAGE (Engage XR 2024) platform. Similarly, *Professional Development 1 & 2* leverage VR technologies to simulate environments conducive to the development of soft or transversal skills. *Production Engineering* introduces students to AR technologies, providing hands-on experience in constructing a LEGO Technics motorcycle (A/S, LEGO System 2024). This approach employs AR tools such as the Microsoft HoloLens v2 (Microsoft 2024), enriched with overlay information including images, videos, audio, and animations, as opposed to traditional paper-based instruction manuals.

Year 1		Year 2		Year 3		Year 4	
Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
Mathematical methods for Engineers 1	Mathematical methods for Engineers 2	Mathematical methods for Engineers 3	Mathematical methods for Engineers 4	Mathematical methods for Engineers 5		Data Science	
Fundamentals of Engineering Science		Materials Engineering		Materials Engineering 2			
Design Engineering		Design Engineering 2					
Fundamentals of Engineering Science	Mechanical Engineering	Mechanical Engineering 2				Maintenance and Reliability Engineering	
Fundamentals of Engineering Science		Process Engineering		Applied Thermofluids			
Fundamentals of Engineering Science			Facilities Engineering			Future Engineering	
Engineering Technology	Production Engineering		Manufacturing Engineering	Production Systems	Problem Solving	Lean Engineering	Process Improvement
	Quality Engineering		Validation Engineering				
Electrical & Electronic Engineering				Advanced Electrical and Electronic Engineering			
	Automation Engineering		Automation Engineering 2			Robot Perception and Sensing	
Engineering Challenge 1	Engineering Challenge 2	Professional Development 1	Professional Development 2				
% AR/VR							
67	50	67	50	50		50	

Figure 1. Integration of immersive technologies throughout the 4-year Mechanical and Manufacturing degree course

3.1 Hardware

Each student is given a META Quest 2 headset, which they keep for their studies. This headset was chosen for its relatively inexpensive price point, technical support and documentation, content availability, hand tracking, standalone capabilities, and ease of use. These devices allow students to explore interactive 3D environments, exploring engineering concepts in a safe, virtual setting.

This method extends beyond mere visualisation, enabling practical application in simulations that replicate real-life scenarios. AR devices like the Microsoft HoloLens v2, are available to students in limited numbers and under supervision due to their high cost. HoloLens v2 enhances real-world environments with digital information, making educational content more engaging.

Furthermore, students get to interact with immersive technologies in the VR Suite (Agritech Centre of Excellence 2024) at MTU, a purpose-built virtual and physical collaboration space that hosts an array of AR, VR, and other platforms, enabling students and educators to explore and work differently in a unique technology-rich environment.

Figure 2. Students interacting with various hardware solutions such as the META Quest 2 and Microsoft HoloLens 2 in the VR Suite.

3.2 Software

The REEdI program implements numerous software solutions and is in the second year of the newly designed curriculum. A few of these use cases are outlined by highlighting case studies.

Bodyswaps (Bodyswaps 2024) is integrated into *Professional Development 1 & 2*, offering soft skill training through VR, emphasising the importance of communication, teamwork, and leadership, alongside technical abilities. Students actively use the pre-designed and approved modules to prepare them for interview training and workplace conflict resolution.

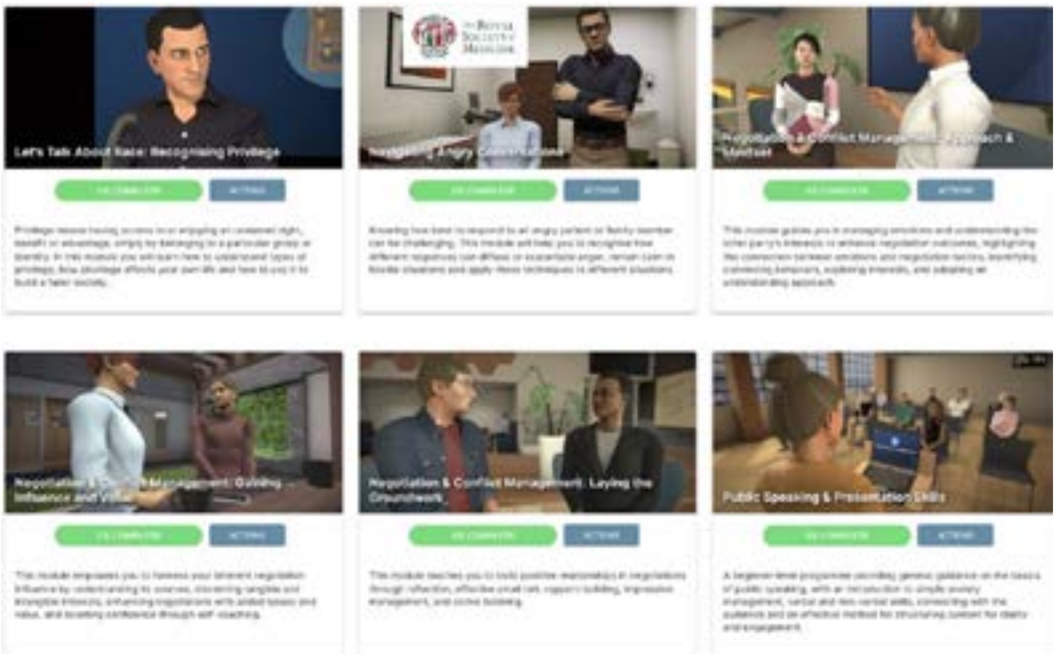

Figure 3. Bodyswaps offers an array of simulations, rich analytics, and gamification.

PNX Labs (PNX Labs 2024), offers off-the-shelf content, as well as bespoke or highly customised VR applications. Various engineering simulations are utilised throughout various modules, including a highly customised Tensile Strength Testing

Lab as part of the *Quality Engineering* module. Additional VR labs available to students include Bending SS Beam, Bending Cantilever Beam, Torsion and Rockwell hardness Testing; Force, Mass, Acceleration, and Rotational Mechanics; and Metallography. Additional VR labs will support the students while geographically dispersed include SEM Microscope, EDAX Experiment, AFM Microscope Lab, Laser 3D Printing, Fluid Flow in Pipework, Ventilation and AC, Heat Exchanger, Steam Distribution, and Porosity Characterization. Students and educators will be able to participate in these virtual labs remotely, which not only makes it more engaging and effective but also safer and more cost-efficient.

Engage (Engage XR 2024) is being implemented as a collaborative VR tool. Engage is a multi-platform application with a library of spaces and 3D models that students and educators can access in public experiences, private groups, or individually. Students can access Engage through their desktop/laptop, mobile, or using their VR headset. Engage is used for *Engineering Challenge 2* where students present their final year projects in an Engage VR space. A remote Masterclass Series was introduced with a guest lecturer in preparation for 3rd-year students' remote work placement and remote VR lectures. Furthermore, REEdI is working on various solutions that will be launched in 2025 which include a space to showcase MTU and the REEdI program to prospective students containing past student works, and interactive immersive lab experiences.

Figure 4. Prototype of public showcase space within Engage

Gadgeteer (Metanaut Labs Inc. 2024) simulates complex machinery and systems in *Engineering Challenge 1*, enabling students to build and interact with a digital Rube Goldberg machine featuring components like dominoes, balls, catapults, and funnels. It provides a safe virtual space for students to explore physical principles and machinery dynamics, observing cause-and-effect relationships without physical limitations or damage risks. The platform supports detailed component behaviour, such as using a pen as a pusher or simulating a hammer's pendulum motion, and allows for the integration of timing elements, such as triggering an E-stop system. Students' machine reliability is tracked and graded through multiple runs to emphasise the importance of repeatability and reliability.

Figure 5. Module requirements (left) and student implementation (right)

Gravity Sketch (Gravity Sketch 2024) offers an immersive, hands-on learning experience that enables students to design, visualise, and manipulate 3D models in a virtual environment, and is introduced as part of Engineering Technology. Learners are tasked to design a more ergonomic headband for their META Quest 2 headsets through a combination of LiDAR scans, CAD, and Gravity Sketch.

4 CONTENT INTEGRATION AND IMPLEMENTATION STRATEGIES

Universities wishing to implement immersive technologies should adopt a strategic roadmap that starts with integrating affordable, widely available devices like the META Quest 2. The META Quest 2 is chosen due to its [relative] affordability, which makes it accessible for educational institutions with limited budgets. Currently, the META Quest 2 retails at €249.99 (Meta 2024), compared to the recently launched Apple Vision Pro which retails at € 3,257.08 (converted from USD) (Apple 2024). Furthermore, the META Quest 2 has widespread availability for procurement and replacement. Additionally, the META Quest 2 offers extensive support and a content library, which is estimated at 2,860 apps including the newly available App Lab content (RoadToVR 2024). Best practices for educators include starting with pre-made content to facilitate quick integration and gradually developing bespoke materials as proficiency increases. This will ensure enhanced learning experiences while managing costs and resources efficiently (Kaur, et al. 2022) (Dinis, et al. 2018). Furthermore, the strategic guidance provided through examples like the LEGO Technics motorcycle assembly using Microsoft HoloLens v2 and the use of Engage for immersive guest lectures illustrate how immersive technologies can be seamlessly woven into curricula with minimal effort.

Curriculum design should embed immersive technologies into core modules, leveraging VR for simulations and AR for interactive projects. Faculty training is crucial; educators should participate in workshops and ongoing professional development to effectively use these tools. Gathering regular student feedback through surveys and focus groups will help refine the implementation process, ensuring that the technology meets educational goals and student needs. Pedagogical approaches should focus on hands-on, interactive learning experiences that mirror real-world scenarios, fostering critical problem-solving skills.

5 NEXT STEPS AND FUTURE DIRECTIONS

Future research into the impact and effectiveness of the immersive technology tools currently being used as part of the REEdI program is planned, which will be measured by feedback gathered from both students and lecturers. They will be asked about their experience using immersive technology, for instance, "*How difficult/easy it was to use these tools, any negative health effects experienced from the use of immersive technology, and the impact of these issues on their teaching/studies",* or *"How they felt immersive technology tools impacted their experience/engagement, benefits/disadvantages, and their preference between real-world and immersive-technology-based learning/teaching*".

Additionally, the immersive technology tools used within the REEdI program are being investigated for their effectiveness in other educational fields. This includes the MTU Veterinary Nursing department integrating BodySwaps and introducing a VR-based veterinary skills training application, titled "*VetSkill Companion Animal OSCE Practise Stations*".

6 CONCLUSION

Through evidence-based implementation and research, the REEdI program has concluded that pre-made immersive technology content stands out as the optimal method for seamless integration into engineering education due to time, cost, and other constraints. Moreover, the META Quest 2 headset emerges as the preferred choice for this purpose due to its affordability, widespread availability, and comprehensive support in terms of content and resources. This research paper highlights the transformative impact of immersive technologies on engineering education, identifying critical gaps in implementing immersive technologies in curricula, and offering insights for educators, curriculum designers, and policymakers. The study advocates for a strategic framework for integrating immersive technologies into curricula, acknowledging challenges such as technological accessibility, curriculum integration, and educator training. It emphasises the importance of strategic implementation and support for overcoming these barriers. Ultimately, this study serves as a call to action for educational institutions to adopt immersive technologies strategically, ensuring engineering education remains innovative and effective in preparing students for future challenges.

REFERENCES

A/S, LEGO System. 2024. *Motorcycle.* Accessed 04 07, 2024. https://www.lego.com/en-us/product/motorcycle-42132.

Agritech Centre of Excellence. 2024. *The 'ACE Suite'.* Accessed 06 11, 2024. https://agritechexcellence.com/the-ace-suite/.

Apple. 2024. *Buy Apple Vision Pro.* Accessed 06 06, 2024. https://www.apple.com/shop/buy-vision/apple-vision-pro.

Bodyswaps. 2024. *Soft skills training, reinvented.* Accessed 04 07, 2024. https://bodyswaps.co/.

Boyle, Fiona, Moolman Johannes H., Rian Stephens, and Joseph Walsh. 2022. “REEdI-Rethinking Engineering Education in Ireland.” In *Learning with Technologies and Technologies in Learning*, by Michael E. Auer, Andreas Pester and Dominik May, edited by Michael E. Auer, Andreas Pester and Dominik May, 303 - 334. Springer Cham. doi:https://doi.org/10.1007/978-3-031-04286-7.

Dinis, Fábio Matoseiro, João Poças Martins, Bárbara Rangel Carvalho, and Ana Sofia Guimarães. 2018. “Disseminating Civil Engineering through virtual reality: An immersive interface.” *International Journal of Online Engineering* 14 (5): 225-232. doi:10.3991/ijoe.v14i05.7788.

Engage XR. 2024. *Engage Homepage.* Accessed April 8, 2024. https://engagevr.io/.

Gravity Sketch. 2024. *Gravity Sketch.* Accessed 04 07, 2024. https://www.gravitysketch.com/.

Kaur, Deepti Prit, Amit Kumar, Rubina Dutta, and Shivani Malhotra. 2022. “The Role of Interactive and Immersive Technologies in Higher Education: A Survey.” *Journal of Engineering Education Transformations* 36 (2): 79-86. doi:10.16920/jeet/2022/v36i2/22156.

Kozov, Vasil, Galina Ivanova, and Aleksandar Ivanov. 2019. “Flipped Classroom Model and Immersive Learning in The Mechanical Engineering Education.” *2019 18th International Conference on Information Technology Based Higher Education and Training (ITHET).* Magdeburg: IEEE. 1-5. doi:10.1109/ITHET46829.2019.8937335.

Krajčovič, Martin, Gabriela Gabajová, Marián Matys, Beáta Furmannová, and Ľuboslav Dulina. 2022. “Virtual Reality as an Immersive Teaching Aid to Enhance the Connection between Education and Practice.” *Sustainability (Switzerland)* 14 (15). doi:10.3390/su14159580.

Meta. 2024. *Meta Quest 2.* Accessed 04 07, 2024. https://www.meta.com/ie/quest/products/quest-2/tech-specs/.

Metanaut Labs Inc. 2024. *Gadgeteer.* Accessed 04 07, 2024. https://gadgeteergame.com/.

Microsoft. 2024. *Microsoft HoloLens 2.* Accessed 04 07, 2024. https://www.microsoft.com/en-us/hololens.

PNX Labs. 2024. *PNX Labs.* Accessed 04 07, 2024. https://pnxlabs.com/.

RealWear. 2024. *RealWear Navigator 500.* Accessed 04 07, 2024. https://www.realwear.com/devices/navigator-500.

Rethinking Engineering Education in Ireland. 2024. *REEdI Homepage.* Accessed April 8, 2024. https://reedi.ie/.

RoadToVR. 2024. *The Number of Discoverable Quest Apps Has More Than Tripled With the Merging of App Lab.* Accessed 06 05, 2024. https://www.roadtovr.com/meta-quest-app-lab-merge-app-count/#:~:text=With%20App%20Lab%20apps%20now%20included%20in%20the,apps.%20That%20more%20than%20triples%20the%20original%20count.

Roopaei, Mehdi, and Emilee Klaas. 2021. “Immersive Technology in Integrating STEM Educatio.” *2021 IEEE Integrated STEM Education Conference (ISEC).* Princeton, NJ: IEEE. 159-164. doi:10.1109/ISEC52395.2021.9764112.

FLEXIBLE LEARNING IN HIGHER EDUCATION: DRIVING FUTURE SKILLS DEVELOPMENT AND EMPLOYMENT OPPORTUNITIES

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ABSTRACT

The world is rapidly changing due to the evolution of society and technological developments; these, together with the challenges from the Sustainable Development Goals (SDGs), demand new knowledge and skills for future employment. Making engineering education more flexible increases students' choices to enrol in the labour market successfully. From the perspective of students, lecturers, and institutions, flexibilization in higher engineering education can take a dimension to *(1)* develop lifelong learning skills, *(2)* create individual learning paths by providing choices, *(3)* generate mobility, *(4)* support the learning process regardless time and location; *(5)* meet individual learning demands as students have diverse backgrounds (age, previous education, work experience, nationality, etc.), different needs (learning style, learning pace, etc.) and intrinsic motivation and ambitions to learn (job motivation, themes, etc.). Universities and higher education

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institutions (HEIs) look for ways to integrate flexibilization in the curriculum and the provision of study programs. In this study, an investigation of the role of HEIs in developing engineering skills to join the labour market successfully takes place through the lens of three universities by mapping the model of Education 4.0 from the World Economic Forum 2020 report and the 2019 framework for enhancing students' success. Results indicate the various approaches and practices each university offers to elucidate how flexibility can be leveraged to enhance skills development and meet the dynamic needs of the labour market (employability). Finally, the developed model used to map flexibilization strategies is a suitable tool to capture examples of flexibilization in engineering education.

1 INTRODUCTION

The education field is dynamic and changes based on each generation's unique socio-cultural, economic, and technological challenges and by industries' requirements. To guarantee a sustainable society and economy and fulfil students' expectations and industries' requirements, two things need to be accomplished: *(i)* understand the challenges brought by each generation to re-shape/change academic teaching approaches and *(ii)* ensure that our graduates are provided with the tools and skills to thrive in the 21st century. As mentioned, each generation brings its challenges and expectations. Generation X are individuals born between 1965 and 1980. They tend to be more independent. They value flexible workplaces and a healthy work-life balance. Compared to other generations, Generation X employees tend to be more concerned about an uncertain future. Generation Y, known as millennials (born 1981-1996), is the first generation to grow up with personal technological advances; however, they engage more by connecting their learning with real-world applications. Their expectations evolve around opportunities to use their skills to gain experience, a guaranteed income, and to work in a caring, well-being environment (Sezin Baysal Berkup 2020). Generation Z (born 1997-2012) is the first generation to grow up in an entirely digital world. A short attention span and a preference for digital and interactive learning experiences characterize it (Chillakuri 2020; Caratozzolo et al. 2021). To meet their expectations, an investment in digital resources is required. They prefer flexible working hours and an environment where social responsibility and diversity are prioritized (Impact. 2022). To contribute to the overall success of students across generations, academics need to understand each generation's expectations and make necessary changes in the curriculum and teaching approaches to meet the diverse needs and expectations of each (Gómez Puente 2020). These changes must guarantee the involvement of an inclusive learning environment to foster a sense of belonging and the embedment of global awareness to understand global challenges and promote ethical and cultural sensitivity.

The ever evolution of society and technology and the dynamic challenges of daily life demand to move from a conventional structural education, which was designed for an industrial-era model, to a flexible education, which aligns with the Fourth Industrial Revolution, where a workforce with versatile skills is needed to guarantee a sustainable society and economy. These skills, which are sought to be reached by employers by 2025, include critical thinking, creativity, emotional intelligence, and complex problem-solving (World Economic Forum 2022; 2020b). Flexible learning serves as a nurturing ground for the development and refinement of these skills previously mentioned and other skills such as global citizenship (e.g., Collaborative Online International Learning, COIL) (Munoz-Escalona et al. 2022), technology skills, and personalized and self-paced learning, where learning must be based on the diverse learner's needs and flexible enough to enable each learner to progress at their own pace (World Economic Forum 2020a).

Flexible learning accommodates individual learning styles, where learners can tailor their educational experience to suit their needs, pace, and preference learning style to succeed in a volatile job market, where resilience and adaptability are crucial to targeting new opportunities/job paths for professional growth. It also provides opportunities for an inclusive and diverse environment and enables lifelong learning and national/international collaborations, among others (Brennan 2021). However, it must be highlighted that flexible learning requires a balance of power between institutions and students and must be economically viable and appropriately manageable for both parties (AdvanceHE 2019). Also, the social perspective of flexibility towards contributing to economic development, the institutional view, and the financing aspects are important elements to realize flexibility (Brennan 2021). Furthermore, a pivotal role in the realization of flexible education/distance education is the integration of digital technologies, online learning platforms, virtual classrooms, etc.

The authors had previous academic collaborations as co-authors at the following international conferences: SEFI2022 (related to a comparison of institutional practices), SEFI2023 (a comparative study of Continuing Engineering Education frameworks), EDUCON2024 (related to the future workforce), and IACEE2024 (with a taxonomy for Continuing Engineering Education), and they were co-authors in an article in Education Sciences Journal, in November 2022 (exploratory and comparative study of Challenge-Based Learning practices).

This study investigates how different universities integrate the concept of flexibilization in their educational practices from various perspectives, e.g., employability, work-related learning, flexible learning, and globalization; and compares three universities from different countries, Tecnologico Monterrey (Mexico), Eindhoven University of Technology (TU/e) (The Netherlands), and Glasgow Caledonian University (United Kingdom), to answer the research questions about the role of flexibilization in HE in developing future skills and full employment.

The Research Questions are:

RQ1: To what extent will training students in technology skills facilitate future work-related learning?

RQ2: To what extent does teaching global citizenship skills facilitate flexible working in the future?

2 THEORETICAL CONSIDERATIONS

Higher education institutions (HEIs) are essential in preparing students as future employees to develop the skills needed to join the labour market. Within this rationale, preparing students for professional life emphasizes developing generic "transferable" skills in the workplace on the one hand (Mason, Rincon-Aznar, and Venturini 2020). Flexibility in higher education refers to providing opportunities for education as there are diverse types of students with different ambitions and interests, regardless of time, distance, and space. Flexibility in the curriculum, the learning environment, and the provision of content and spaces for developing skills become a vehicle for meeting the ambitions of diverse learners. Flexibilization is deeply rooted in educational theories that emphasize how students learn and, more specifically, the learning environment that may affect the development of competencies (Mathou, Sarazin, and Dumay 2023). As an example, *Situated learning* theory and *Cognitive Apprenticeship* center around the relationship between learning and the social situation in which, for instance, the learning of a skill occurs (Julien 2021). In situated learning, social co-participation activities in which social engagements occur are favourable elements to provide a context and facilitate learning. In this regard, creating learning experiences in which real-life activities resembling and taking place in practical work environments are suitable contexts that promote deep learning and develop skills. Likewise, *self-regulated learning* theories are guided by reflecting on one's learning. In self-directions, students become conscious of their learning strengths and weaknesses. They can make use of a variety of strategies to reflect upon and monitor the learning process and be able to generate change in study attitude and progress (Yan 2020). Curriculum transformation to accommodate students' ambitions and learning goals, together with approaches to teaching and learning and the support of technologies and digitalization in education, make possible flexibilization of learning to empower students by offering them choices in how, what, when, and where they learn: the pace, place, and mode of delivery (Halverson and Graham 2019). Differentiation, individualization, and flexibility constitute the current challenges of education, which are critical elements to give form in the study programs (Talip et al. 2020)In this regard, digitalization, blended learning, and hybrid education facilitate flexibilization in higher education, which supports knowledge and skills development to meet future employment demands.

3 METHODOLOGY

The methodology chosen for the study included a brief overview of Education 4.0 as outlined in the WEF 2020 report (World Economic Forum 2020a), emphasizing its focus on shifting learning content and experiences toward future needs and the comparison to the Essential Frameworks for Enhancing Student Success from the AdvanceHE 2019 report (AdvanceHE 2019), highlighting its significance in promoting student success within higher education. Table 1 contains the answers to each of the proposed Research Questions.

Table 1. Mapping of WEF and Essential Framework for Enhancing Students about employability and flexible working

WHAT	Employability	Flexible Working	HOW	Employability	Flexible Working

Global citizenship skills	Developing global citizenship skills, fostering cultural competence, and effectively communicating across cultures prepare individuals to thrive in diverse, interconnected professional environments.	Flexible education equips individuals with the intercultural competencies, adaptability, and communication skills necessary to thrive worldwide in diverse and dynamic work environments.	**Personalized and self-paced learning**	Allowing individuals to tailor their educational experiences to specific skill sets and learning preferences fosters adaptability and autonomy.	Personalized and self-paced learning empowers individuals to acquire skills and knowledge tailored to their needs, fostering adaptability to work effectively in diverse professional settings.
Innovation and creativity skills	Equipping students with the ability to think critically, contribute to innovative solutions, and compete in a rapidly evolving and competitive job market can significantly increase their employability.	Including innovation and creative skills training in HE cultivates students' ability to think outside conventional boundaries and find inventive solutions, enabling them to excel in diverse professional environments.	**Accessible and inclusive learning**	Diverse skill sets, cognitive adaptability, and inclusivity awareness are all crucial attributes employers value in an increasingly diverse and dynamic global workforce.	Empowering students with diverse learning styles and equipping them with adaptable skills and broad perspectives fosters a future workforce that can thrive in flexible, professional environments.
Technology skills	Providing students with the expertise to navigate a technology-driven job market enhances their versatility and readiness to contribute to various industries and professions.	Technology skills significantly empower students to leverage digital tools, collaborate remotely, and adapt to evolving technological trends, ensuring they are well-prepared for flexible work environments.	**Problem-based and collaborative learning**	Cultivating critical thinking, teamwork, and problem-solving skills prepares students to navigate complex professional challenges and enhances graduates' future employability.	Cultivating effective communication and collaborating across diverse perspectives equip students with innovative problem-solving and teamwork skills to cope with tasks' uncertainties and ambiguities.
Interpersonal skills	Training students in interpersonal skills sharpen their ability to communicate effectively, collaborate seamlessly, and build positive relationships in diverse professional settings.	Interpersonal skills nurture students' capacity to communicate persuasively, collaborate seamlessly, and adapt to diverse team dynamics.	**Lifelong and student-driven learning**	Cultivating a proactive and adaptable mindset, encouraging continuous skill acquisition, and instilling a commitment to ongoing personal and professional development, ensuring graduates remain competitive in the ever-evolving job market.	Instilling a proactive and adaptable student mindset empowers them to acquire new skills continuously, stay abreast of evolving industry demands, and navigate the dynamic nature of flexible work environments.

4 RESULTS

Considering the mapping developed in Table 1, Table 2 shows the results of the approaches taken by each university to increase employability, and Table 3 shows the approaches taken to foster flexible learning.

Table 2. Approaches taken by each university to increase employability.

WHAT	Tecnologico de Monterrey* (Mexico) Total Students: 50,400 International students: 4,800	Eindhoven University of Technology (TU/e)* (The Netherlands) Total Students: 11,000	Glasgow Caledonian University (United Kingdom)* Total Students: 15,500 International students: 2,800

	Faculty Staff: 6,300	**International students: 3,200** **Faculty Staff: 1,000**	**Faculty Staff: 750**
Global citizenship skills	• Embedded Collaborative Online International Learning (COIL) in modules • Opportunities for international exchange • Multicultural campus fostering DEI. • Participation in international events and competitions.	• 'Sustainability' as a theme in courses • Organizing 'challenges' with other universities and industries meeting SDGs • Organizing learning communities to create interaction and exchange ideas with national and international peers.	• Embedded Collaborative Online International Learning (COIL) in modules • Opportunities for international exchange (Virtual and physical mobility) • Multicultural campus, fostering EDI. • Participation in international events and competitions • Follows SDGs • Promotes different societies. • Participates in Engineers without border
Innovation and creativity skills	• Interdisciplinary collaboration that promotes innovation, critical thinking, and problem-solving, • Provide dedicated spaces to foster hands-on practical labs to foster creativity skills. • Offers entrepreneurship programs. • Collaborations with industry partners in each CBL course expose students to real-world challenges and opportunities.	• Challenge-Based Learning (CBL) • Interdisciplinary collaboration that promotes innovation, critical thinking, and problem-solving. • Internships, practical labs, extracurricular activities, collaboration with industry or research institutes.	• Interdisciplinary collaboration that promotes innovation, critical thinking, and problem-solving. • Provide dedicated spaces to foster hands-on practical labs to foster creativity skills.
Technology skills	• Labs AI, VR/AR; Blockchain; Internet of Things (IoT) and Cybersecurity). • Interactive simulations, Avatar Professor, digital platforms, and remote laboratories. • Offers external data science and analytics courses.	• Technology design and programming. • Integration of technology skills into school curricula. • Artificial Intelligence (AI) in education.	• Offers courses on learning digital technology. • Provide laboratory sessions in robotics, VR/AR, programming, cybersecurity, etc.
Interpersonal skills	• The Challenge-Based Learning (CBL) approach encourages collaboration, teamwork, group projects, discussions, and interactive activities. • Encouragement to participate in extracurricular activities. • Compulsory 480 hours of community service • Peer Mentorship • Implement an Ambassador Program to promote the institution. • Storytellers Program.	• Diversity, Equity & Inclusion (DEI) policies and educational practices integrated into existing curricula. • Persuasive writing and presentations in a public setting. • Professional and Personal Development programs.	• Diversity, Equity & Inclusion (DEI) policies and educational practices integrated into existing curricula. • Teamwork along the degrees • Multidisciplinary work across the university • Courses in academic writing. • Encouragement to participate in extracurricular activities. • Engages students in the delivery of public engagement and outreach activities.

*Updated data extracted from https://www.topuniversities.com/world-university-rankings

Table 3. Approaches in each university to foster flexible learning to facilitate flexible work.

HOW	Tecnologico de Monterrey* (Mexico) Total Students: 50,400 International students: 4,800 Faculty Staff: 6,300	Eindhoven University of Technology (TU/e)* (The Netherlands) Total Students: 11,000 International students: 3,200 Faculty Staff: 1,000	Glasgow Caledonian University (United Kingdom)* Total Students: 15,500 International students: 2,800 Faculty Staff: 750
Personalized and self-paced learning	• Competency-based education model, • Access to digital libraries and materials in all disciplines. • Gamification approaches. • Students can create individualized learning plans in collaboration with academic advisors. • Online and blended learning formats.	• Elective courses. • Extra-curricular activities (Student teams). • Competencies development. • Access to digital platforms and materials in all disciplines. • Coaching individuals and groups of students, including coaching on competencies. • Adopting personalized learning. • Professional and Personal Development of competencies at different levels/paths.	• Elective courses • Access to digital libraries and materials in all disciplines. • In an exchange program, students can take courses online of pre-requisite modules not delivered by host institutions.
Accessible and inclusive learning	• DEI policy • Training staff on accessibility best practices • Hotline platform – integral well-being through Emotional Counselling.	• DEI policy • Train staff/organize learning communities on DEI, sustainability topics, etc.	• DEI policy (Recommended adjustment pages) • Training staff on accessibility best practices. • Well-being support
Problem-based and collaborative learning	• Challenge-Based Learning (CBL) involves team-based assignments and projects where students work together in real-life challenges. • Industrial partners in every course. • Interdisciplinary and Collaborative learning.	• Challenge-Based Learning (CBL) as an educational concept • CBL as curriculum and course/project level.	• Challenge-based learning (CBL) is offered in a few modules. • Interdisciplinary and Collaborative learning in different modules. • Attend guest talks virtually or face-to-face.
Lifelong learning & student-driven learning	• Opportunities for internships, co-op programs, and industry projects. • Program mentors guide students in making informed decisions about their learning paths.	• Courses for industry professionals. • Continuous Professional Development (CPD) learning pathways for teachers.	• Graduate apprentice scheme (students are employed in industry while studying) • Part-time courses

*Updated data extracted from https://www.topuniversities.com/world-university-rankings

5 DISCUSSION, CONCLUSIONS, AND FUTURE WORK

The three universities involved in the study are examining the methods they use to enhance students' employability to create individual learning paths and offer opportunities to select elective courses or activities to provide work experience. Typical offerings to deploy practical experience are via internships (placements), paying attention to the internationalization of education (e.g., exchange programs, mobility, and similar measures), or creating a link between education and research as a vehicle of learning and innovation. Flexibilization in education implies allowing students to take greater responsibility for their learning and engage in learning activities that meet their needs”.

In this regard, flexible learning is strongly linked to student-centered learning. In implementing flexibilization, the concept does not stand alone. Flexibilization in higher engineering education offers multifaceted benefits, catering to students, lecturers, and institutions' diverse needs and motivations. By fostering lifelong learning skills, creating individualized learning paths, promoting mobility, and accommodating diverse backgrounds and learning demands, universities can better prepare students for success in the labour market. The study demonstrates how three universities leverage the Education 4.0 model and the 2019 framework for enhancing students' success to explore their respective roles in equipping learners with the necessary future skills for successful integration into the workforce. Although the number of universities is limited, it is an interesting exploration that will be extended to the consortium with other universities already working on similar themes. The findings underscore universities' pivotal role in fostering skills development and enhancing employability, offering valuable insights into innovative approaches and practices. As higher education institutions embrace flexibility, they prepare the way for a more responsive and inclusive educational landscape, poised to meet the dynamic demands of the labour market. Despite the universities being different in focus, e.g., engineering (Tecnologico Monterrey and TU/e) and broader disciplines (Glasgow Caledonian University) all follow a similar educational approach to integrating flexible education in the curriculum, in the programs, and at the course level to promote employability. Regarding the framework used to map flexible learning and future skills in these institutions has proven to be a suitable resource for mapping experiences in universities and engineering education institutions. This framework supports the mapping of institutions from both a learning and technology perspective.

Future research will focus, therefore, on analyzing strategies to facilitate skills development while studying the learning and technology approaches of the HEIs, exploring the long-term impact of flexible learning environments on student outcomes and career trajectories, and including comparative studies across different regions -particularly in Europe- and educational systems that could provide deeper insights into the effectiveness and scalability of these flexible learning models. Another avenue for future work involves investigating the role of emerging technologies, such as artificial intelligence and virtual reality, in enhancing flexible learning and skills acquisition. Finally, in the context of Industry 4.0 transitioning to Industry 5.0, future research will also explore how educational frameworks need to adapt to this evolution, including initiatives regarding human-centric solutions, sustainability, and resilience, and going beyond the automation and digitalization focus of Industry 4.0.

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REFERENCES

AdvanceHE. 2019. “Essential Frameworks for Enhancing Student Success.” 2019. https://www.advance-he.ac.uk/advance-he-essential-frameworks-enhancing-student-success.

Brennan, John. 2021. “Flexible Learning Pathways in British Higher Education: A Decentralized and Market-Based System.” Report for the IIEP-UNESCO. Southgate House, Southgate Street, Gloucester, United Kingdom: International Institute for Educational Planning.

Caratozzolo, Patricia, Eugenio Bravo, Claudia Garay-Rondero, and Jorge Membrillo-Hernandez. 2021. “Educational Innovation: Focusing on Enhancing the Skills of Generation Z Workforce in STEM.” In *2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC)*, 488–95. https://doi.org/10.1109/WEEF/GEDC53299.2021.9657304.

Chillakuri, Bharat. 2020. “Understanding Generation Z Expectations for Effective Onboarding.” *Journal of Organizational Change Management* 33 (7): 1277–96. https://doi.org/10.1108/JOCM-02-2020-0058.

Gómez Puente, Sonia M. 2020. “Internationalizing a Master Curriculum: Students’ Perspectives on Online Education.” *International Journal for E-Learning Security* 9 (1): 617–23. https://doi.org/10.20533/ijels.2046.4568.2020.0077.

Halverson, Lisa R., and Charles R. Graham. 2019. “Learner Engagement in Blended Learning Environments: A Conceptual Framework.” *Online Learning* 23 (2): 145–78.

Impact. 2022. “Generational Expectations in Today’s Workforce.” August 17, 2022. https://workwithimpact.co.uk/news/generational_expectations_in_workforce/.

Julien, John. 2021. “Explaining Learning: The Research Trajectory of Situated Cognition and the Implications of Connectionism.” In *Situated Cognition*. Routledge.

Mason, Geoff, Ana Rincon-Aznar, and Francesco Venturini. 2020. “Which Skills Contribute Most to Absorptive Capacity, Innovation and Productivity Performance? Evidence from the US and Western Europe.” *Economics of Innovation and New Technology* 29 (3): 223–41. https://doi.org/10.1080/10438599.2019.1610547.

Mathou, Cécile, Marc A. C. Sarazin, and Xavier Dumay. 2023. “Reshaping the Teaching Profession: Patterns of Flexibilization, Labor Market Dynamics, and Career Trajectories in England.” In *The Palgrave Handbook of Teacher Education Research*, edited by Ian Menter, 185–210. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-16193-3_59.

Munoz-Escalona, Patricia, Zulay Cassier de Crespo, Mara Olivares Marin, and Meg Dunn. 2022. “Collaborative Online International Learning: A Way to Develop Students’ Engineering Capabilities and Awareness to Become Global Citizens.” *International Journal of Mechanical Engineering Education* 50 (1): 89–104. https://doi.org/10.1177/0306419020934100.

Sezin Baysal Berkup. 2020. “Working With Generations X And Y In Generation Z Period: Management Of Different Generations In Business Life | Mediterranean Journal of Social Sciences,” August. https://www.richtmann.org/journal/index.php/mjss/article/view/4247.

Talip, Dyg Siti Nurshamira Awg, Zaiton Hassan, Mark Kasa, Surena Sabil, and Dayang Kartini Abang Ibrahim. 2020. “The Relationship of Work Life Balance and the Quality of Life among Employees Studying Part Time.” *International Journal of Academic Research in Business and Social Sciences* 11 (14): Pages 270-284. https://doi.org/10.6007/IJARBSS/v11-i14/8573.

World Economic Forum. 2020a. “Schools of the Future: Defining New Models of Education for the Fourth Industrial Revolution.” World Economic Forum Switzerland, Geneva.

World Economic Forum. 2020b. “The Future of Jobs Report 2020.” 2020. https://www.weforum.org/reports/the-future-of-jobs-report-2020/.

World Economic Forum. 2022. “Catalysing Education 4.0: Investing in the Future of Learning for a Human-Centric Recovery.” World Economic Forum. 2022. https://www.weforum.org/publications/catalysing-education-4-0-investing-in-the-future-of-learning-for-a-human-centric-recovery/.

Yan, Zi. 2020. “Self-Assessment in the Process of Self-Regulated Learning and Its Relationship with Academic Achievement.” *Assessment & Evaluation in Higher Education* 45 (2): 224–38. https://doi.org/10.1080/02602938.2019.1629390.

IMPACT OF AN INTERNATIONAL EXPERIENCE ON STUDENTS' GLOBAL COMPETENCES

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ABSTRACT

Global engineering competences and skills have become increasingly vital to the practice of engineers. Consequently, developing these competences becomes an imperative in today's engineering education. This research explores how an international project-based learning experience, involving solutions to engineering problems provided by different industries, allowed students to enhance global competences and skills.

Specifically, the aim of this research is to explore students' perception of personal benefits gained from attending a one-week multidisciplinary international experience, and secondly, to explore how self-set goals align to Global Competences for Engineers (GCEs) and World Economic Forum (WEF) Education 4.0 skills. The study involved the delivery of an online survey which intersected both GCEs and (WEF) Education 4.0 Framework.

The initial results show the significant impact of international experiences on students' development of global citizenship, through exposure to a diverse cultural context, with participants describing how the experience allowed them to develop awareness and appreciation of cultural differences. Furthermore, the study highlights tangible improvements in various engineering competences, including problem-solving, communication, and interpersonal skills.

1 INTRODUCTION

The World Economic Forum Education 4.0 Framework has identified skills/competences that are essential to address economic and societal issues. These skills are divided in two main groups: **Group 1: Skills for adaptation** include: i) global citizenship skills, ii) innovation and creativity skills, iii) technology skills and iv) interpersonal skills and **Group 2: Skills of leveraging innovative pedagogies** include: i) Personalized and self-paced learning, ii) Accessible and inclusive learning, iii) Problem-based and collaborative learning, and iv) Lifelong and student-driven learning (World Economic Forum, 2020). This research will focus just on Group 1 skills, as the context of this research is focused on an international exchange week focused on team-based problem solving.

1.1 Skills for Adaptation

For Group 1, i) Global citizenship skills: Physical mobility contributes significantly to the development of global citizenship skills as it offers individuals the opportunity to engage with diverse cultures, perspectives, and environments. In some cases, individuals may face constraints that limit their ability to travel or relocate due to financial constraints, family responsibilities, work commitments, and when this occurs, virtual mobility through experiences such as Collaborative Online International Learning (COIL) can be used to enhance students' abilities to develop as responsible global citizens, allowing them to develop their intercultural competences and international perspectives without the associated logistics and costs of travel (Kayumova AR, Sadykova GV, 2016).

ii) Innovation and creativity skills: these are crucial skills for engineers enabling them to develop new solutions to complex problems and to adapt to changing circumstances. Creativity is the ability to generate new ideas, while innovation is the ability to turn those ideas into reality (Nagai, Y et. al, 2020). In the context of engineering, creativity and innovation are essential for developing new technologies and improving existing ones. Engineers who possess these skills are better equipped to develop solutions that are both effective and efficient, and can be adapted to different contexts and cultures.

iii) Technology skills: In today's world, technology is an integral part of engineering, and engineers must be proficient in a wide range of technologies to be effective. Technology skills include knowledge of software, hardware, and other tools that are used in engineering. Technology skills are essential for communication and collaboration, which are critical for global engineering projects (Ortiz-Marcos et.al, 2021).

iv) Interpersonal skills: these skills determine the ability that the engineer must have to communicate and interact effectively with other people. These skills include communication, leadership, teamwork, effective listening, and empathy. It is not enough to have the technical skills of the profession, increasingly more importance is given to the relationships and human interaction with which the engineer works. Developing these skills favors professional and social success and encourages cross-cultural humility. Although interpersonal skills may be related to innate personality traits, they can be taught and developed through experiences and innovative teaching methods (Willmot, P. and Colman, B, 2021).

The World Economic Forum’s (WEF) Education 4.0 Framework is designed to apply to all disciplines. Within the field of Engineering, a similar framework of Global Competences for Engineers ((Ortiz-Marcos et.al, 2021) (see Table 1 below) has been used as a lens to explore the attributes needed by today’s engineers to thrive in an interconnected world, where engineering projects and teams often span multiple countries and cultures. While technical expertise remains important, engineers must possess a range of competences beyond technical skills to be successful in the global engineering profession. These competences include cultural awareness, communication skills ethical decision-making, and leadership abilities, among others and align to the WEF Education 4.0 Framework.

1.2 Developing Skills for Adaptation through International Study Opportunities

Our previous work (Munoz-Escalona et al., 2023) explored how engineering programmes in different countries attempted to develop these skills and competences in student engineers. The work highlighted the importance of international study opportunities in fostering the development of these skills. In this paper, we set out to explore student perceptions of international study through the following research question:

‘How do self-set goals set in an international study opportunity align to Global Competences for Engineers and WEF Education 4.0 skills?’

In the current study we aim to investigate how engineering students' self-set goals in an international learning opportunity align with Global Competences for Engineers and WEF Education 4.0 skills. Our findings reveal that while students' goals strongly align with skills around global citizenship, teamwork, and communication, there is less emphasis on competences such as systems thinking, innovation, and creativity.

2 METHODOLOGY

The adopted methodology for this exploratory study is largely quantitative, based on a pre- and post-survey method with students self-assessing their perceived level of competence and confidence in a range of skills. Ethical approval was sought, and granted from the authors' institution. Respondents were from a range of backgrounds, nationalities and disciplines (engineering, computing and physics programmes) participating in-person in an international project week from around the world, although as the event was hosted at one European university there were more students attending from the host country. An invitation to contribute to the surveys before and after this International experience was circulated to all students. Surveys were administered through MS Forms. Gender, age and degree level were not included, as these were not aspects to be measured in this research.

The questions from the survey focused on the skills/competences which are essential to address economic and societal issues, as outlined in Section 1. In addition, the instrument explored respondents' previous experience of learning. In the survey students were asked to articulate two goals each related to their: i) learning and ii) wider experience during the international project week; students were not guided in setting goals and were not aware of the WEF or GEC categories. The authors mapped the answers for these questions against the four categories related to World's Economic Forum's Education 4.0 Framework, specifically the Skills for Adaptation (World Economic Forum 2020) which were also aligned to the Global Competences for Engineers (Ortiz-Marcos et.al, 2021). Table 1 shows the mapping of these categories.

Table 1. World Economic Forum's Education 4.0 Framework aligned to Global Competences for Engineers

WEF Education 4.0 Framework (Skills for Adaptation)	Global Competences for Engineers
1. Global Citizenship skills	GC1: Communication GC2: Communication in a foreign language GC10: Understand the connectedness of the world
2. Innovation and Creativity skills 3. Technology skills	GC3: Holistic system thinking GC7: Problem solving
4. Interpersonal skills	GC4: Negotiation GC5: Conflict management GC6: Cooperation GC8: Encourage and motivate others GC9: Teamwork GC11: Decision making

3 RESULTS

The survey was sent to 1327 students, from 10 countries with overall 13 universities participating in the experience. A total of 137 (10.32%) students completed the before-experience survey, while 75 (5.65%) students completed the after-experience survey. Despite the low response rate, the data offers valuable insights into students' before and after experiences during their participation in the event.

3.1 Students background

Table 2 shows participants' backgrounds, as well as whether they had engaged with previous international experiences, and whether this was a compulsory or voluntary participation. Results show that 43 (54.4%)/79 of first-time participants are attending the international experience voluntarily. This seems to indicate that students realise how much they can gain from an international experience and how they can develop GECs and skills from opportunities like this. Note that a substantial proportion of the participants in this international experience were from the host institution (1175 (85.5%)/1327) where repeated participation in these international project weeks is compulsory. For information, Table 3 shows the number of times participants have attended an international event and type of participation for those not attending for the first time (n=58).

Table 2. Students' backgrounds

Nationality	Is your 1st International Experience?	
	YES	**NO**
-European - 127 (92.7%)	79 (57.6 %)	58 (42.4%)
-Asian - 8 (5.84%)	36 (45.6%) - Compulsory	38 (65.5%) - Compulsory
-American - 1 (0.73%)	43 (54.4%) - Voluntary	20 (34.5%) – Voluntary
-No answer – 1 (0.73%)		

Table 3. Times participants attended an international event and type of participation

Times attending international event	Type of participation
2 times: 35 (60.3%)	Compulsory: 21 (60%) Voluntary: 14 (40%)
3 times: 12 (20.7%)	Compulsory: 7 (58.3%) Voluntary: 5 (41.7%)
4 times: 5 (8.6%)	Compulsory: 4 (80%) Voluntary: 1 (20%)
≥ 5 times: 6 (10.4%)	Compulsory: 4 (66.7%) Voluntary: 2 (33.3%)

3.2. Results related to learning and wider international experience

Table 4 shows the results related to goals achieved by the participants (after event). The goals were mapped towards the WEF adaptive skills and GCEs provided on Table 1, Methodology section.

Table 4. Goals related to learning and to the wider international experience mapped against WEF skills for adaptation and GCEs

WEF Education 4.0 Skills for adaptation	Global Engineering Competences	Goals related to learning	Goals related to the wider experience
1.Global citizenship skills	GC1: Communication	23	11
	GC2: Communication in a foreign language	19	13
	GC10: Understand the connectedness of the world	4 (Culture) 3 (Network) 26 (Skills for adaptation)**	23 (Social) 21 (Culture) 28 (Network) 3 (New City) 12 (Skills For Adaptation)**
2. Innovation And creativity skills	GC3: Holistic system thinking	1	0
3. Technology Skills	GC7: Problem solving	18	5
4. Interpersonal skills	GC6: Cooperation	6	1
	GC9: Teamwork	31	5
	GC4: Negotiation	0	0
	GC5: Conflict management	7	2
	GC8: Encourage and motivate others	3	1
	GC11: Decision making	1	1
Didn't answer/uncategorised answer		25	26

Sample of **students comment related to Skills for adaptation:

"Learn how to identify and rectify mistakes" (R34)

"Talk freely about my opinions and gained more confidence to speak for my ideas" (R39)

"To be able to interact extensively and connect with strangers" (R65).

"Work on my social anxiety"(R67)

"Step out of my comfort zone (R125)

"I'd like to stop being afraid of traveling alone to a city I don't know". (R130)

4 DISCUSSION

This study set out to explore engineering students experience of an international learning opportunity with reference to 'How do self-set goals set in an international study opportunity align to Global Competences for Engineers and WEF Education 4.0 skills?'

Overall results show that self-set goals aligned well to WEF Education 4.0 Group 1 skills, and the Global Competences for Engineering. There is stronger alignment to skills around global citizenship and soft skills such as team-work and communication, as well as traditional, easily conceptualised competences such as problem-solving. Given the project-focused nature of the international experience, then students setting problem solving goals, that reflect a systems approach would be expected. In contrast, few students articulated goals that mapped to more nuanced competences such as systems thinking, innovation, creativity, negotiation and decision making. Further work would be needed to determine whether these competences are valued even if not recorded in the goals collected here.

The data collected in this study is not without its limitations. Ensuring the anonymity of participants, a priority for this research, inadvertently compromised the ability to map responses before and after the intervention, as some participants forgot the code they were asked to remember. Additionally, the heterogeneous nature of the study population presents another challenge; the study included small numbers of voluntarily participating students from numerous individual institutions and a large cohort of students from the host institution, for whom repeated participation was compulsory. This mix potentially skews the data. Moreover, as this study relied on self-reported data, it may not fully capture the perspectives of students who had less positive experiences. Despite these limitations, the international context of this study is unique and offers valuable insights into student experiences across diverse educational settings. However, the methodology used here could be adapted and repeated in different contexts to explore the broader applicability of these findings in a range of different international study opportunities.

5. CONCLUSIONS AND FUTURE WORK

The experiences reported do illustrate how engaging with diverse communities and perspectives allows students to gain an appreciation for cultural differences and similarities, fostering the development/enhancement of a range of GCEs, particularly communication, cultural awareness and teamwork and how could the design of these experiences be further developed to more closely support the development of the full range of competences and skills defined in the CGE and WEF Education 4.0 Framework.

It is important to acknowledge potential biases in the interpretation of the data collected. One significant limitation is the low response rate, with only 10% of participants completing both surveys. This low participation rate raises concerns about the representativeness of the findings, as those who voluntarily chose to respond may differ in significant ways from those who did not. It is plausible that participants who were more engaged or had stronger opinions were more likely to complete the surveys, which could skew the results. Therefore, while the data provides valuable insights, it should be interpreted with caution, and future studies should aim to increase response rates to enhance the reliability and generalizability of the findings.

This ongoing project will next address the research question: ‘What personal benefits do students’ perceive that this international study opportunity provides? And analysis of the quantitative data related to students' perspectives of their own competencies before and after their participation in order to determine the impact of international experience on addressing GCEs and WEF Education 4.0 skills. Additionally, we plan to refine and extend the research instruments to more closely explore the full range of GCEs and WEF Education 4.0 framework skills in future studies, for example, through semi-structured interviews. By extending our methodological approaches, we aim to gain a deeper understanding of how international experiences contribute to the development of these critical competencies and skills.

REFERENCES

Kayumova AR, Sadykova GV. Online collaborative cross-cultural learning: students’ perspectives. *J Org Culture Commun Conflict* 2016; 20: 248–255.

Nagai, Y., Shimogoori, A., Ariga, M., & Georgiev, G. V.. Future Learning and Design Creativity Competency. Proceedings of the Design Society: International Conference on Engineering Design, 1(1), 499-508. (2020) doi: [10.1017/dsi.2019.54](https://doi.org/10.1017/dsi.2019.54)

Ortiz-Marcos, I., Breuker, V., Rodríguez-Rivero, R., Kjellgren, B., Dorel, F., Toffolon, M., Uribe, D., & Eccli, V. A Framework of Global Competence for Engineers: The Need for a Sustainable World. Sustainability, 12(22), 9568. (2021) doi: [10.3390/su12229568](https://doi.org/10.3390/su12229568)

Munoz-Escalona, P., Medina, L., Marquez, M., Murzi, H., Smith, C., & Milligan, C. (2023). Developing Global Engineers- A Comparison Between Scotland, USA and Chile. Technological University Dublin. DOI: 10.21427/9SBM-QX96 (https://arrow.tudublin.ie/sefi2023_prapap/1/)

Willmot, P. and Colman, B. Interpersonal skills in Engineering Education. Proceedings in AAEE 2016 Conference. Available at: https://repository.lboro.ac.uk/articles/conference_contribution/Interpersonal_skills_in_engineering_education/9552260

World Economic Forum 2020 report. Schools of the Future. Defining New Models of Education for the Fourth Industrial Revolution. Available at: https://www3.weforum.org/docs/WEF_Schools_of_the_Future_Report_2019.pdf . Accessed 22/01/23

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Bottlenecks in Thermodynamics: Bridging Gaps in Energy Balance Derivation between Experts and Students

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Conference Key Areas: *Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing; Building the capacity and strengthening the educational competences of engineering educators*
Keywords: *Decoding the Disciplines, Thinking aloud, Bottleneck*

ABSTRACT

This study investigates obstacles hindering effective thermodynamics education, especially focussing on the bottlenecks imposed by setting up system boundaries and deriving energy balances. Methodologically, the study employs decoding interviews with experts and thinking aloud interviews with students. By comparing both perspectives, significant disparities in problem-solving approaches emerge. For

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example, experts travel intuitively between different levels of abstraction, while students tend to adopt a more linear approach. Interventions to address identified challenges include a memory game to reinforce symbol-component associations and online exercises with immediate feedback on suitable system boundaries, thus explicitly targeting different levels of abstraction while introducing physical modelling.

1 INITIAL SITUATION & APPROACH

Obstacles in educational processes that restrict the effective transfer of knowledge and learning success are referred to as “bottlenecks” and can have negative impact on learning success. Like threshold concepts, bottlenecks relate to students’ learning difficulties. However, bottlenecks as part of the Decoding the Disciplines method are analysed from an expert perspective to make this knowledge available for the design of learning activities (Wiemer and Kenneweg 2021).Bottlenecks can be identified by empirical observations (Middendorf and Shopkow 2018). In the STEM discipline of thermodynamics, bottlenecks can be imposed by insufficient comprehension of basic physical concepts (Foroushani 2019) or by the perception of thermodynamics as a purely theoretical subject without seeing the relevance of the systematics for real tasks and applications.

A bottleneck specific to problem solving in the field of thermodynamics can be defined as follows:

“Students regularly face difficulties in applying decision criteria for setting up meaningful system boundaries and for deriving energy balances.”

To address this bottleneck, the following steps were taken and investigated methodically (numbers relate to respective paper sections):

2) Design of a typical example task to investigate expert and student perspectives, and suitable to observe the identification of system boundaries

3.1) Interviews with teachers/experts to uncover their solution strategies for the task (Method: Decoding the Discipline)

3.2) Interviews with students to uncover their mental steps in solving the task (Method: Thinking aloud)

4) Synthesis: Comparing expert and student approach

5) Suggested implementations to improve overcome the observed bottleneck

2 EXAMPLE TASK

Here, a laboratory test rig with different components and different fluids was chosen as a typical exercise which requires the application of system boundaries:

> *“In a testing plant, a fan with a power of 250 W draws in an air mass flow rate of 0,119 kg/s at an ambient temperature of* 2 °C *and an ambient pressure of 1,05 bar and heats it to an outlet temperature of 50 °C in the downstream air/water heat exchanger. The heating water for the heat exchanger is heated in a storage tank using an electric heating rod. In steady-state operation, the water exits the tank at a temperature of 55 °C, is then pumped with a power of 100 W,*

and after passing through the heat exchanger, it is returned to the tank. (Material properties given.)

a. What is the heat flow absorbed by the air flow in the heat exchanger? Draw the boundaries of the subsystem you are considering in the sketch.
b. What is the electrical power of […]"
c. [… following subtasks c. to d., not relevant for this paper]

According to the theory of situated learning (Anderson et al. 1996), learning is an active construction process of learners that occurs in a realistic and context-bound manner. It is assumed that students, depending on their preferred learning strategies, approach tasks in thermodynamics differently and require varying degrees of situatedness or abstraction. Learning strategies are behaviours that can be used to master learning tasks. They include strategies for selecting, organising, and integrating information. Here, the focus is on the cognitive learning strategies of elaboration and critical thinking (Wild 2005). Therefore, the visualisation of the testing plant was designed in two alternative ways, "Near to reality" and "Abstract" (see Fig.1).

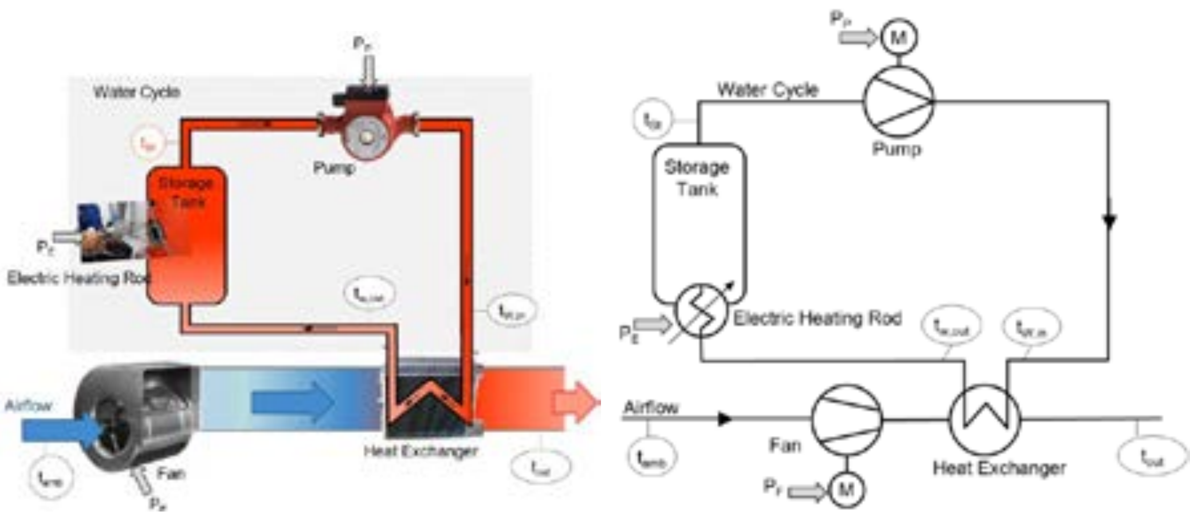


Fig.1: Visualisations of testing plant: "Near to reality" (left) and "Abstract" (right)

3 EXPERT AND STUDENT PERSPECTIVE

For the investigation of the bottleneck in focus, experts as well as students were asked to solve the example task.

3.1 Expert perspective: Decoding the Disciplines

The expert strategy related to the bottleneck was revealed using the method "Decoding the Disciplines". By explicating the expert strategy with the help of decoding interviews, implicit discipline-specific knowledge can be brought out in a structured way and thus made available for teaching (Riegler 2020). Therefore, Decoding the Disciplines can be used to narrow the gap between expert and novice thinking. Two experts completed the example task while external interviewers questioned them about their approach to decode their expertise and background knowledge.

3.2 Student perspective: Thinking Aloud

In order to analyse the mental actions used by students while working on the same exercise as the experts, interviews were conducted using the “thinking aloud” method. The goal was to analyse how students approach the exercise, which solutions they use and which obstacles they encounter. The research method known as thinking aloud requires test subjects to verbalise their thought processes, decisions, and considerations to make them traceable (Charters 2003). The students were also asked to assess the difficulty of the task and its comprehensibility. All participating students have signed a declaration of consent for the collection and processing of interview data for research purpose. The interviews were conducted with seven students in the middle to lower-middle range of performance which were identified using data from previous assessments competed within the course. As the teacher involved in the project was not present during the interviews and all personal data was anonymised during transcription, it was not possible to draw any conclusions about the identity of the students while evaluating the interviews.

4 SYNTHESIS: COMPARISON OF EXPERT AND STUDENT PERSPECTIVE

Both the expert interviews and the student interviews were analysed using inductive and deductive categories according to Mayring (Mayring 2015). The solution strategies were visualised in flow diagrams (see examples in Fig. 2) to compare the approach of students as novices and professors as experts. These steps towards a solution also include side aspects such as search iterations for missing information or solution approaches that were not continued or necessary for this case (yellow boxes in Fig. 2).

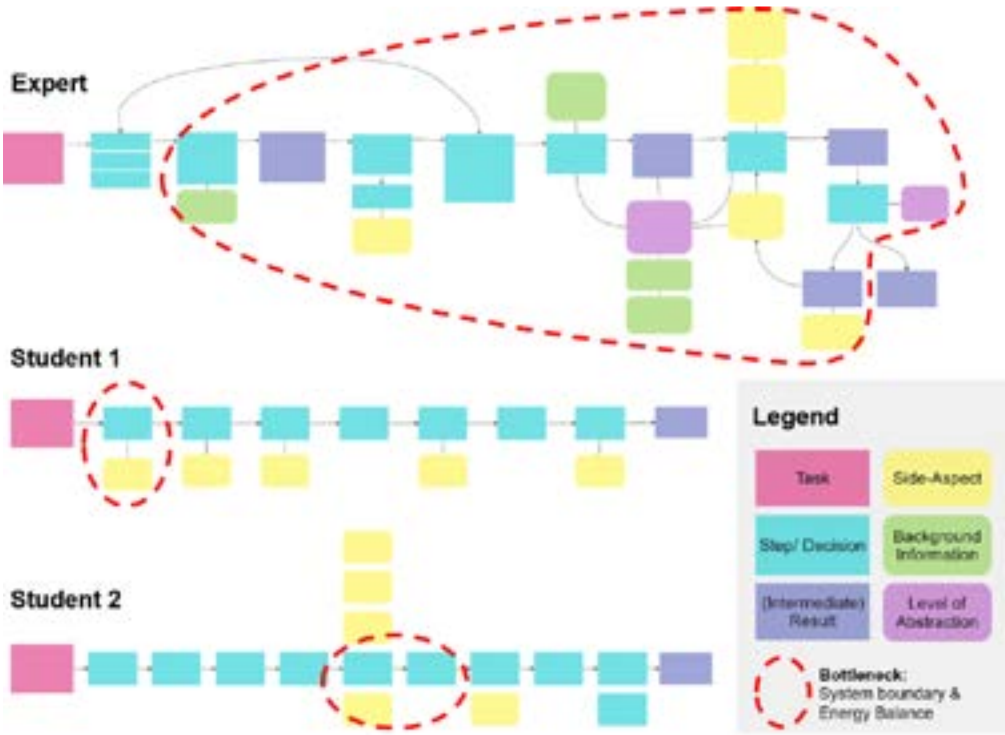


Fig. 2. Visualisation of solution strategies for example task: expert (top) and students (below)

Through analysis and visualisation of the decoding interviews, several aspects of the expert strategy stood out, mainly:

1. Experts in thermodynamics draw on several details of real-world knowledge and physical modelling expertise to identify subsystem boundaries, despite the subject's abstract nature, and they travel freely between different levels of abstraction. This marks a vital aspect of the solution strategy, which was only made explicit by the decoding interviews (purple boxes in Fig. 2). The process of differentiating between important and unimportant information to achieve a meaningful level of abstraction is second nature to the expert and as she/he is familiar with the various semantics of different modelling approaches and abstraction levels such as mathematical and physical modelling in various disciplines. The different languages which are used to articulate the respective modelling in include symbols and conventions (such as used in Fig. 2 / right) but reach far beyond graphical representations and simplifications of reality.
2. Defining suitable (sub)system boundaries is not a linear but an iterative process that involves defining and redefining the subsystems. Adjusting is as necessary if values are missing for a successful calculation.

In contrast to the experts, the students try a more linear approach, draw less on background information, and do not distinguish between different levels of abstraction. This is clearly visible when comparing the flow diagrams that visualise the solution process for the same task for experts and students (see Fig. 2). The comparison also highlights the proposed bottleneck: The attempts of the students to identify meaningful system boundaries are rare. In the end, this led to incomplete energy balances and – ultimately – wrong solutions of the task.

In the following section, key observations from the interviews are highlighted by exemplary extracts from the interviews.

4.1 Starting point: variables and given values

Starting from a look at the given values in the task, the expert considers the broader picture, the student looks for a procedure:

> Expert: *“[…] able to avoid setting up several subsystems […] Then I have two systems and I can cope with that.”*
>
> Student 2: *“I would have a look at the formulary now. Before I do that now, I would first ask myself the question, what do we actually want?”*

Observation: The expert combines the view on the given values with the determination of suitable system boundaries. Students try to replicate common formulae or look for formulae that contain the given values. Sometimes doubts arise as to whether the assumptions are correct (e.g. Student 3, Student 5). Student 1 is struggling to understand the overall system.

4.2 Identifying system boundaries

Fig. 3 shows all possible system boundaries that were sketched by the students. The results reveal that three students could find suitable subsystem boundaries. Student 1 set up two subsystems, one containing the fan and the other the heat exchanger, which can also lead to a correct solution. However, none of the students was able to apply the choice of system boundaries when setting up an energy balance: All the students neglected the power of the fan.

Decoding Interviewer: “Okay,[...] do I understand you correctly, […] you sort out for yourself what could be subsystems? So, regardless of the task up there, you start by

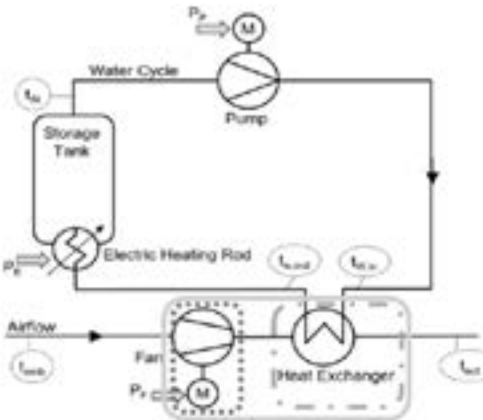
putting a kind of [...] search algorithm over it, what are subsystems? [...]"
Expert: "Mhm" ("yes").

Student 1: "I didn't quite understand where the water and air and everything comes from. [...] I wonder why there's such a zigzag in the heat exchanger, what that's supposed to tell me?"

Student 2: "In this case, an airflow system, that's clear, OK, there's an airflow and in order for this airflow to be produced, a certain amount of power has to be applied. So that this airflow is produced at all. […] I don't know myself exactly what it was, but perhaps it's simply the overflow of system components that makes you ask yourself the question, where do you start to develop a strategy that makes you say OK."

Observation: The expert automatically uses her or his "search algorithm", while the students struggle with system understanding or fail due to oversimplification due to the reason in the last paragraph (looking for formulae suitable for given values).

Student 1 has problems with the symbolic representation of the heat exchanger in process flow charts. Student 2 may have difficulties with the difference between heat flow and total enthalpy flow and the fact that all types of energy can be converted.



Student	System: Fan Only	System: Heat Exchanger Only	System: Fan + Heat Exchanger (Air Duct)	Correct Energy Balance?
Student 1	suitable	suitable		no
Student 2			suitable	no
Student 3		unsuitable		no
Student 4			suitable	no
Student 5		unsuitable		no
Student 6			suitable	no
Student 7		unsuitable		no
Total	1	4	3	0

Fig. 3. Choice of system boundary by the students

4.3 Applying the energy balance to the specific problem

As can be seen from Fig. 3, students struggled to use the information in the task and their view on the (sub)systems to come up with a meaningful energy balance (first law of thermodynamics).

> Student 2: "*[....] the first law of thermodynamics? But that's also a topic. So we're working on that at the moment* (i.e. in the course)*, I definitely wouldn't work on that yet, so I always leave it aside."*
>
> Interviewer: *"With the energy balance?"*
>
> Student 2: *"Yes, exactly, I mean, I know roughly how it works, but setting that up now...!"*

Student 3 performed quite well, but in the end her or his solution ended up too simple, due to the previously assumed unsuitable system boundary. Others did take decisions such as simplifying the problem but could not give physical explanations for their validity.

Observation: Students had only practised energy balancing on small problems previously. Hence, they are afraid of using and applying the energy balance on a general level thus out ruling the most central tool for tackling the task.

Overall, it became clear that setting up meaningful system boundaries as a first step to arrive at a suitable energy balance was not yet fully practiced and appreciated by the students. Although they were all active participants of courses that introduce and use energy balancing for simple thermodynamic problems, they had difficulties to take an approach that looks like an algorithm to the expert but requires a firm overview of the different levels of abstraction. It is concluded that using the different "languages" implicitly used to model a system must be learnt and introduced more explicitly.

5 IMPLEMENTATIONS TO IMPROVE LEARN SETTING

From the findings of the previous sections, it can be deduced that the first step in training energy balancing should include sketching system boundaries and setting up the energy balance in its task-specific form but should not be combined with calculations of specific numerical values. The latter is required for the final solution process, but if focussed too early, this misleads students to the start with looking for appropriate equations of state instead of getting the energy balance straight first. To be able to sketch system boundaries the reading and understanding of process flow diagrams is important.

5.1 Development of a memory game for process flow diagrams

A memory game was developed to improve the assignment of standardised symbols to real components and to bridge the gap between abstract thinking and the need for knowledge about the real components (see Fig. 4). The game is now used as an icebreaker in exercises to introduce the topic of process flow diagrams and was well received by the students due to the playful learning approach.

Fig. 4. "MemoR&I": Game to train standardized symbols used for energy systems

5.2 Designing learning exercises with JSXGraph in STACK

Exercises in online Learning Management Systems (LMS) can provide immediate feedback on individual errors. For the LMS moodle and ILIAS, the STACK plugin (STACK 2024) can be employed for this purpose. STACK is connected to a computer algebra system (CAS) that can verify equations such as energy balances. STACK also offers the possibility to integrate JSXGraph for interactive graphs. This allows both aspects, the proof of the equation of the first law of thermodynamics via STACK and the sketching of system boundaries via JSXGraph, to be carried out online with immediate feedback.

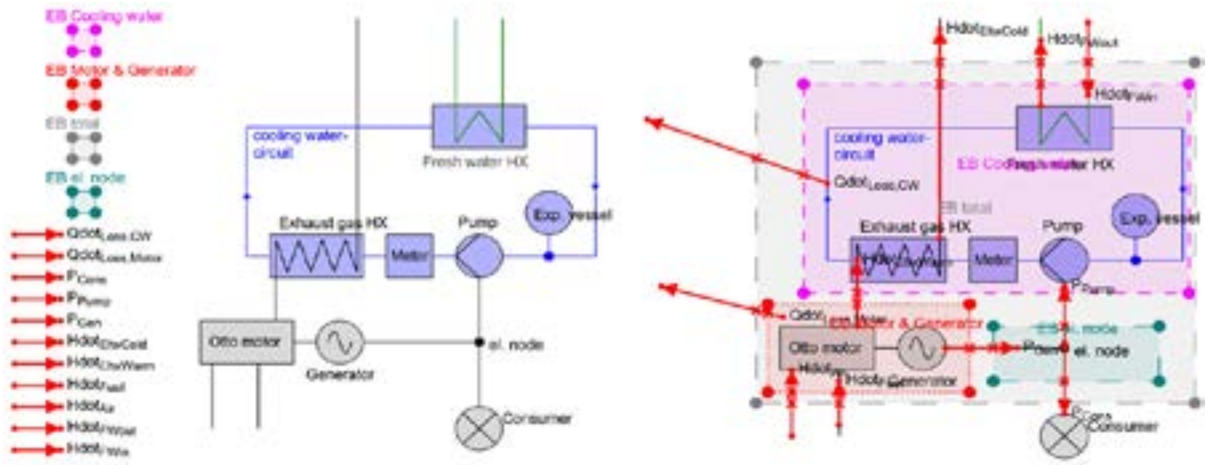


Fig. 5. STACK-JSXGraph task for balancing a micro-cogeneration unit. Left side: exercise layout, right side: solution.

Fig. 5 provides an example of a STACK-JSXGraph question that is now used as an exercise prior to a larger lab task in which students must derive an energy balance of a micro-cogeneration unit.

The students must identify where energy flows occur and move the corresponding arrows to the respective locations. In addition, the system boundaries must be dragged to appropriate positions. STACK is used to check whether the arrows are in the correct positions, have the correct direction and whether the energy flow exhibits correct intersection with the corresponding system boundary (represented by red crosses in the graphic on the right side of Fig. 5).

The authors are also working on experimenting with different forms of learning settings such as flipped classroom, learning diaries, group work etc. to direct more attention to the arguing needed in setting up system boundaries and energy balances. By this the interaction between experts and students is increased and the different techniques used in modelling thermodynamic systems can be made more explicit.

6 SUMMARY AND CONCLUSIONS

Obstacles hindering effective thermodynamics education are successfully targeted in this paper, particularly focusing on challenges related to system boundaries and energy balance derivation. The detailed analysis of expert and student approaches to problem solving highlighted significant differences: Experts demonstrated a nuanced understanding, leveraging real-world knowledge to define subsystem boundaries iteratively. In contrast, students exhibited a more linear approach, often overlooking crucial interactions between components on different levels of abstraction and struggling with symbolic representations. The findings highlight the necessity to tackle simple engineering tasks /exercise with a suitable modelling approach rather than with a procedure. For this purpose, it can be helpful to explicitly address the levels of abstraction and their role in problem solving, as it is common in computer sciences, see for example (Waite et al. 2018). For the bottleneck addressed here, at least three levels of abstraction can be identified: Focus on “reality” to extract system information, “physical modelling” to decide for relevant dependencies and “black boxes” to obtain a system overview. Such distinction is also relevant for other subjects e.g. classic physics of motion as addressed in (Lindsey et al. 2012).

The comparison between expert and student strategies underscores the need to rehearse the art of problem solving on all levels of abstraction. Proposed practical implementations include a memory game and online exercises dealing with system boundary identification with immediate feedback, thus improving the understanding and appropriate modelling of the problem before calculating absolute values. The excises can be further improved by using adaptive feedback to typical errors and an adaptive solution process as shown in (Alteri et al. 2020).

The common bottlenecks in thermodynamics are often related to subject specific terms such as understanding heat, internal energy, and enthalpy etc., see (Foroushani 2019). The bottleneck to decide for relevant system boundaries can be tackled by learning the language of system modelling. This learning process can be improved by decoding solution strategies of both expert and student. The findings and interventions presented here are also relevant in all disciplines that require abstract modelling from free boy diagrams (mechanics) to conservation laws in fluid mechanics.

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REFERENCES

Altieri, M., J. Horst, M. Kallweit, K. Landenfeld, and M. Persike. “Multi-Step Procedures in STACK Tasks with Adaptive Flow Control.” *Contributions to the 3rd International STACK Conference* 2020. TTK University of Applied Sciences: Tallinn, Estonia. https://doi.org/10.5281/ZENODO.3944786.

Anderson, J. R., L. M. Reder and H. A. Simon. „Situated Learning and Education“. *Educational Researcher* 25, no. 4 (May 1996): 5-11. https://doi.org/10.2307/1176775.

Charters, E. “The Use of Think-aloud Methods in Qualitative Research. An Introduction to Think-aloud Methods.” *Brock Education* 12, no. 2 (2003): 68-82. https://doi.org/10.26522/brocked.v12i2.38.

Foroushani, S. “Misconceptions in Engineering Thermodynamics: A Review.” *International Journal of Mechanical Engineering Education* 47, no. 3 (July 2019): 195–209. https://doi.org/10.1177/0306419018754396.

JSXGraph. “Dynamic Mathematics with JavaScript v1.8.0.” Accessed April 4, 2024. https://jsxgraph.org/wp/. 2024.

Mayring, P. *Qualitative Inhaltsanalyse: Grundlagen und Techniken.* Weinheim/ Basel: Beltz, 2015.

Lindsey, B. A., P. R. L. Heron, and P. S. Shaffer. „Student Understanding of Energy: Difficulties Related to Systems“. *American Journal of Physics* 80, no. 2 (2012): 154–63. https://doi.org/10.1119/1.3660661.

Middendorf, J. and L. Shopkow. *Overcoming Student Learning Bottlenecks. Decode the Critical Thinking of Your Discipline*. New York/ London: Routledge, 2018.

Riegler, P. “Decoding the Disciplines – A Roundtrip from Novice to Expert back to Novice.” *Didaktik-Nachrichten* (July 2020): 4-8.

STACK. “STACK - Online assessment.” V4.5.0. Accessed April 4, 2024. https://stack-assessment.org/, 2024.

Waite, J. L. and P. Curzon, W. Marsh, S. Sentance, A. Hadwen-Bennett. “Abstraction in action: K-5 teachers’ uses of levels of abstraction, particularly the design level, in teaching programming.” *International Journal of Computer Science Education in Schools*, no. 2(1) (2018): 14–40. https://doi.org/10.21585/ijcses.v2i1.23

Wiemer, M. and A. C. Kenneweg. “Threshold Concepts: Übergänge zu disziplinären Denkweisen und transformative Lernprozesse in der Fachlehre verstehen und begleiten.” *Neues Handbuch Hochschullehre*, no. 100 (2021): 43-66.

Wild, K.-P. “Individuelle Lernstrategien von Studierenden. Konsequenzen für die Hochschuldidaktik und die Hochschullehre.” *Beiträge zur Lehrerbildung* 23, no. 2 (2005): 191-206.

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Challenge-Based Learning in Practice: Redesign and Evaluation of an Interdisciplinary Minor

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Conference Key Areas: *Curriculum development and emerging curriculum models in engineering, Teaching technical knowledge in and across engineering disciplines, Building the capacity and strengthening the educational competences of engineering educators*
Keywords: *Challenge-Based Learning, Interdisciplinary Education, Higher Education, Student-driven learning*

ABSTRACT

Challenge-Based Learning (CBL) is revolutionizing education by placing authentic challenges at the forefront of student learning, while enabling interdisciplinary education, as it allows students to define a challenge, based on their disciplinary competencies and interests. In this paper through the presentation of the redesign of the minor From Idea to Prototype, we aim to offer an example of the practical implementation of CBL within an existing interdisciplinary context, and help educators disentangle complex concepts related to the application of CBL. Key takeaways from this study are that CBL is a very good fit with interdisciplinary education, a low number of students is favourable for the initial application of CBL, and educators should pay close attention to managing the challenge providers to successfully apply CBL. Our findings suggest that CBL not only benefits students and educators but also creates value for challenge providers. Furthermore, it helps educators expand their professional networks and is in line with the concept of entrepreneurial education. However, it needs to be clear that the initial investment may need a significant effort before it starts paying off, and continuous evaluation and reflection is necessary. Future work will investigate the long-term value of CBL within the presented context.

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1 INTRODUCTION

1.1 Challenge-Based Learning and Interdisciplinary Education

It is evident that students in higher education need, next to discipline-focused courses, also courses that focus on the development of 21st century skills (Beers 2011). This way students can use disciplinary knowledge for more than one thing (i.e. programming can help students structure their ideas better), if those connections are made explicit. CBL is gaining traction as a pedagogical approach within higher engineering education since it was first introduced in 2011 (Leijon et al. 2022; Doulougeri, van den Beemt, et al. 2022). Partly so, due to its ability to foster the development of 21st century skills, such as critical thinking, communication, and creativity (Vilalta-Perdomo, Mapfaira, and Michel-Villarreal 2022; Doulougeri, Bombaerts, et al. 2022). It combines the pros of both problem-based learning (PBL) and project-based learning (PjBL) while enabling students to define their own challenge from general problems or themes provided by industrial or research stakeholders, therefore promoting self-driven learning (Kohn Rådberg et al. 2020). It additionally cultivates creativity and communication by facilitating collaboration between students and external stakeholders towards solving complex problems (Mayer, Ellinger, and Simon 2022). As authentic challenges are inherently multifaceted, CBL is especially useful for interdisciplinary contexts (Malmqvist, Kohn Rådberg, and Lundqvist 2015; Petrová 2020).

1.2 Minor From Idea to Prototype

This practice paper focuses on the redesign of the 15 ECTS (420 hours of workload) Minor From Idea to Prototype, for which the author is the coordinator. This minor is part of the larger Science 2 Society minor package (30 EC). Over a period of 10 weeks, participating students are divided into 8 groups of 6-7 students each and immerse themselves in the state-of-the-art science behind a challenge provided by an external company or research department. Such challenges span from robots that can be controlled with eye-tracking to help people with only eye movement communicate, smart lights that help you communicate non-verbally with your grandparents, monitoring and managing work stress, to capacity building in developing countries through serious gaming. Concurrently, students are exposed to various scientific disciplines and aided in developing relevant skills through basic lectures, mini-lectures, and interactive workshops. All groups progress from a general idea to one or more scientifically and practically grounded prototypes for the challenge at hand. As we welcome students from other universities nationally and internationally, as well as from all programs within the University of Twente, student teams boast diverse disciplinary backgrounds (both engineering and non-engineering) and nationalities. The minor is an elective module that becomes available to the students in the beginning of the 3rd year of their undergraduate studies.

1.3 Objective of this paper

In this paper a comprehensive way of implementing CBL in higher engineering education is presented, by guiding the reader through the redesign of a university minor. This will be presented through the methodology followed for redesigning the minor, the evaluation from students, colleagues, and educational experts, as well as the presentation of improvements based on that evaluation. For a more detailed explanation of the redesign of the minor, you can refer to this work (Nizamis 2021).

2 METHODOLOGY

2.1 Redesign Methodology

As the minor is affiliated with various university departments and individuals, it boasts a diverse ecosystem of tutors and experts, that need to be considered in the redesign. The redesign process, was based on the concept of constructive alignment (Biggs 1996), a principle essential for effective education design as it facilitates effective learning (Smith 2008). This process was assisted using Bloom's Taxonomy (Bloom and Krathwohl 1956) to categorize intended learning outcomes (ILOs) by complexity levels and select verbs that compose clearer ILOs. The focus on crafting specific and measurable ILOs aims to enhance their effectiveness and facilitate comprehension for students. Additionally, outdated or irrelevant ILOs were removed to maintain relevance (for the ILOs see Fig. 3). Consequently, we ensured that teaching, learning activities, and assessments directly correspond to the ILOs (Fig.1). The 1st iteration was the first attempt in redesigning the minor after it was originally designed by its previous coordinator (which was not the author). This attempt helped into getting insights, and feedback from students, colleagues, and challenge providers, in order to again redesign the next year (2nd iteration).

2.2 Redesign – 1st Iteration

ILOs: The constructive alignment was supported by creating *alignment tables*

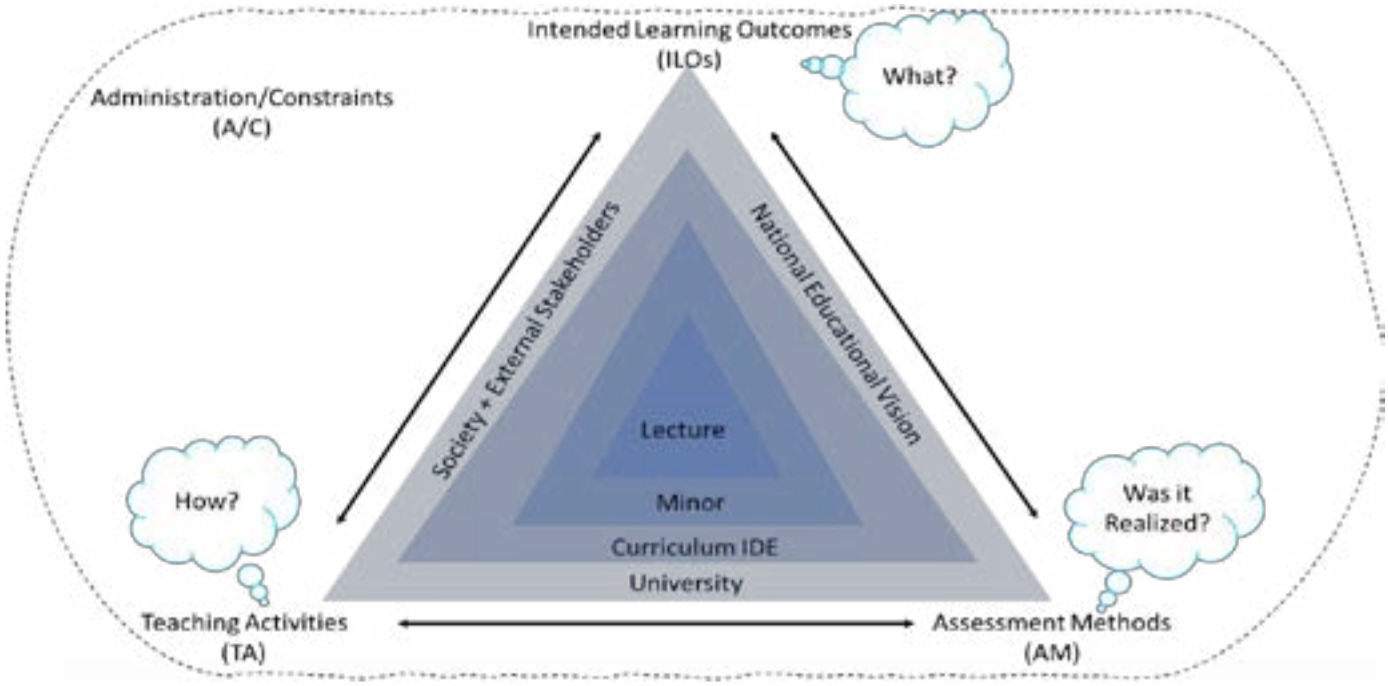

Fig.1 is an illustration of the principle of constructive alignment. The constructive alignment triangle can zoom out to more abstract ILOs (goals of the University, ILOs of the encompassing programme curriculum) and zoom in to a specific minor/module or even down to course/lecture level. All the aligned elements operate within constraints imposed by the context (time/capacity, university, resources, etc.

between ILOs, teaching activities, and assessment methods (See Fig. 3). These tables were used to make sure we cover sufficiently the ILOs.

Formative Assessment			Summative Assessment			
Motivation Letter (1)	Assignment Proposal (1,2)	Midterm Presentation (2,3)	Report (60%) (1,2,3,4a)	Individual Reflection (10%) (1, 4b)	Final Presentation (30%) (1,3)	
					Peer Assessment (10%)	Expert Assessment (20%)

Fig.2 This table is shared with the students in the minor manual. The weight of each of the summative assignments is given to enhance transparency. Each form of assessment is linked to the ILOs in line with constructive alignment (see numbers in brackets and Fig. 3).

Teaching Activities (TA): The introduction of CBL, catering to students from various programs and disciplines across applied and social sciences, necessitated the introduction of *workshops on CBL, and Stakeholder Analysis*, enhancing students' interactive experiences. By allowing students to define challenges based on their expertise and interests, CBL facilitates collaboration in addressing authentic, multidisciplinary challenges. Previously, student groups were assigned to challenges based on preference, and in cases of overlapping interests, a first come-first serve process was followed. This approach often left groups dissatisfied with their assigned cases, and in the worst-case scenario, resulted in lower quality results due to a lack of relevant disciplines. Therefore, we introduced an intermediate step requiring a *motivation letter*. This ensures that groups receiving their first choice do so based on merit rather than chance or timing.

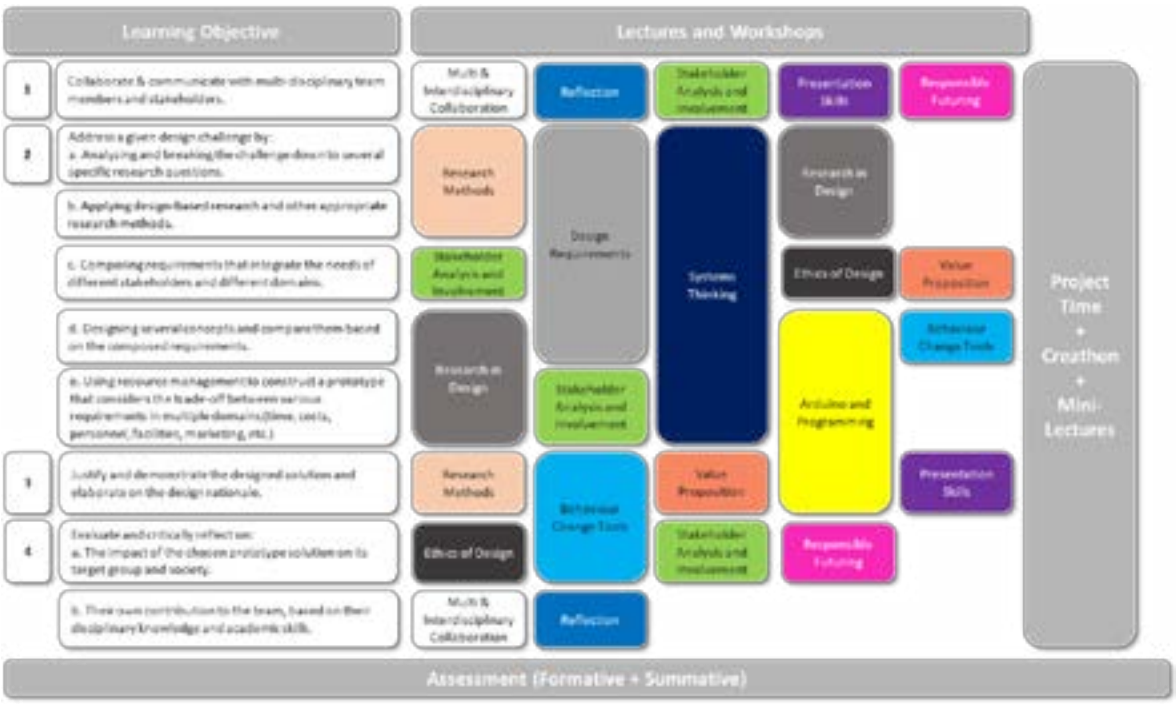

Fig.3 Alignment between the ILOs and the lectures and workshops of the minor based on discussions with the teachers. Some activities are presented more than once, as they contribute to more than one ILOs (i.e. presentation skills).

Assessment Methods (AM): Additionally, we created *detailed rubrics* that not only helped students align with assessors' expectations but also facilitated a better assessment procedure, ensuring consistency, transparency, and fairness in grading, particularly when multiple assessors were involved per assignment (Atkinson and Lim 2013). Lastly, we introduced a combination of *formative and summative assessments* to ensure students receive proper feedback (Fig. 2).

Each ILO is supported by teaching activities (lectures/workshops as seen in Figure 3), that aim to support the student in reaching those objectives. One such example is "Presentation Skills". This activity contributes towards 2 ILOs (ILO 1 and ILO 3), and that is why it appears twice. This activity is implemented right after the midterm presentation of the students, and includes a workshop on visual storytelling and the construction of impactful slideshows. This way the students try on their own in the midterm and subsequently rectify potential mistakes during this workshop. After the workshop, the lecturer provides office hours to every student group once a week until the final presentation. Consequently, each ILO is assessed by one or more types of formative and summative assessment (Fig.2 and Fig.4). The percentages of the summative assessment are motivated by the amount of ILOs assessed. Fig. 2, shows clearly that ILO 4b is only assessed by an Individual Reflection, bringing also forward the challenges of individual assessment in group work. This challenges was partially addressed in the 2nd design iteration (Section 3.2). Students are individually assessed for ILOs 1 and 4b as part of the Individual Reflection. ILOs 2, 3, and 4a, are assessed as group work. However, each students needs to have a passing score in all components to receive a final grade.

*Administration/Constraint*s (A/C): However, to maintain the element of authentic external challenges and keep the student groups between 6 students per group (as close as our capacity allows to the desired number of 4 students per group according to (Brickell et al. 1994; Chou and Chang 2018)), it was important to limit the number of students to a maximum of 48-50 per year. The final change implemented involves *changing process tutors* from student assistants to PhD students and assistant professors. This transition ensures that the process is overseen by more experienced tutors, enhancing the quality of monitoring and support provided to students, as well as safeguarding the CBL process.

Table 1 presents the types of evaluations performed, and the results and actions taken to address the feedback. The changes of the 1st iteration were evaluated with the use of evaluation surveys for the students (both by the coordination team (internal) and the university (central)), as well as by asking feedback from all the involved educators (teachers and tutors), to see how the changes resonate with them, and identify areas where we need to improve/adapt. Additionally, the minor was evaluated as to how it implements interdisciplinary education by an educational expert (results published in (Uthrapathi-Shakila et al. 2021) (external evaluation). To interpret feedback accurately, we examined the overlap between various evaluations and compiled a document outlining areas needing improvement. Subsequently, we collaborated with educational experts to propose realistic solutions and actions, considering time and logistics constraints.

3 RESULTS

3.1 Feedback

Table 1. The results from all stakeholders together with the planned actions by the coordinator.

Stakeholder	Feedback (Tops/Tips)	Actions
Students **(Internal Evaluation)** 	✓ The minor is well organized. ✓ Coordinator is very responsive and attentive. ✓ Good support to the group work by the coordinator - Make sure that challenge provider realizes the internationalization component. - Too many students lacking technical skills that are needed for the challenges.	➢ Include at least one student that speaks the local language. ➢ Promote actively the minor in technical programmes to attract more technical students and screen the challenges more thoroughly.
Students **(Central University Evaluation)** 	✓ The module was intellectually stimulating for me. ✓ As a whole, I learned a lot in the module. ✓ I have learned a lot from doing the project. ✓ The teaching methods enabled me to learn successfully. - In general, I did not have enough prior knowledge to successfully do the module. - The coherence between the module parts was not clear to me. - The number of feedback moments was sufficient.	➢ Have a balanced ratio between technical and non-technical students. ➢ Meet with all the teachers to align to the ILOs and assessment (Fig. 3). ➢ Create more feedback instances for the students and implement a double peer review.
Teaching Staff 	✓ Open issues were resolved quickly. ✓ Course information was clear. ✓ Great Organization. - Good to have a clear overview of grading tasks prior to the minor. - Help with the use of Canvas (The Learning Management System used by the University). - Unclear how the students use our lectures/workshops in their outcomes.	➢ Recruit tutors every year stating the amount of time expected to be invested. ➢ Be present on demand in a lecture when a teacher requires support. ➢ Since this was also a concern of the students we have decided to meet with all teachers and discuss the common thread of all courses and how they related to the ILOs and the assessment (Fig. 3).
External Evaluation (Uthrapathi-Shakila et al. 2021) 	✓ Both staff and students see the benefits of interdisciplinarity. ✓ Working on a real challenge from a provider is highly motivating. ✓ Students learn to appreciate approaches from other disciplines. - Staff team cohesion. - Minimal structure for guidance (for the process and group work) and interaction. - Support and clarity of expectations for staff to balance guidance and freedom for the students. - Recruitment and involvement of challenge providers. - Resources and content support.	➢ Introduce bi-weekly meetings, to introduce the minor, discuss progress, and address issues timely, by forming a teaching community. ➢ Manage our relationships with the challenge providers (as they can be too dominant or too absent) more explicitly and highlight to them our expectations. ➢ Create targeted activities with a clear contribution to the assessment of the students and a CBL creathon to showcase CBL in one day. ➢ Create a series of things described above (rubric exercise, peer review,

	- Lack of alignment between objectives, activities (challenge topic) and assessment.	better alignment between courses/workshops and ILOs, etc.).

3.2 Redesign – 2nd Iteration

The suggestions of the multi-stakeholder evaluation were implemented in the final structure of the minor, and grouped based on Fig.1 (ILOs, TA, AM, and A/C).

1. Aligning all the teachers, and subsequently illustrating the contributions of all teaching activities to the ILOs (as shown in Fig. 4, below). (ILOs)
2. The implementation of a one-day CBL Creathon in the beginning of the minor. (TA)
3. A double instance of peer review was introduced using Buddycheck[2]. One 3 weeks after the start of the minor, prior to the midterm and one at the end. The students are asked to reflect on this on their individual reflection essay. (AM)
4. Due to the introduction of the peer review moments, and in order to emphasize more individual assessment, we increased the percentage of the individual reflection for the final grade (Fig. 4).(AM)
5. Explicit communication with challenge providers, by creating a challenge recruitment word template. This helps align the expectations of all stakeholders. (A/C)
6. Support the tutors and teachers in order to create a teaching community, that in turn can support novice tutors. Tutors undergo training in CBL, in addition to receiving tutor guidelines based on past experiences. (A/C)

Formative Assessment				Summative Assessment			
Motivation Letter (1)	Assignment Proposal (1,2)	Peer Review (x2) (1,4b)	Midterm Presentation (2,3)	Report (50%) (1,2,3,4a)	Individual Reflection (20%) (1, 4b)	Final Presentation (30%) (1,3)	
						Peer Assessment (10%)	Expert Assessment (20%)

Fig.4 The new assessment structure of the minor after the evaluation. The addition of the peer review was aiming to enhance the assessment of ILO 4b that was under-represented in the previous iteration (see Fig. 2), and increase the contribution of the individual reflection to the final grade by asking the students to reflect on teamwork, based on their peer review evidence.

4 Discussion and Conclusion

A key factor for the implementation of CBL within the interdisciplinary minor From Idea to Prototype is the opportunity for students to define their own challenge. This way no matter their composition, groups can fit the challenge to their own capacity and interests. Previous research in this context has shown that CBL unlocks the potential for interdisciplinary learning (Uthrapathi-Shakila et al. 2021). Students have claimed to gain respect for other disciplines, better understanding, and the ability to integrate their work (Huutoniemi et al. 2010). However, this requires proper support

[2] https://www.buddycheck.io/

is given to all involved stakeholders, to make ensure cohesion and proper guidance of the students (Uthrapathi-Shakila et al. 2021).

Another key takeaway is the implementation of a whole day CBL Creathon in the beginning of the minor. This serves multiple objectives, as it gives both students and tutors a taste of CBL in one day, by including external challenge providers to give the opportunity to the students to experience working with them. And additionally, it demonstrates in one day what is expected by the students in the minor and let them practice without consequences. Lastly, this creathon can help manage stakeholders that do not want to have a longer commitment and give them a test to CBL in order to build a solid network for the future.

As more courses incorporate CBL in their curricula, challenge provider saturation may become an issue, therefore a stong network of interested stakeholders may prove valuable for CBL practicioners. Recruiting challenges is maybe one of the most important and time consuming parts for CBL practicioners. Our recommendation is that beside their own network practicioners can look for help in recruiting challenges externally, in local bussiness incubators, NPOs, and even companies that connect companies with teachers.

Last, but not least, providing enough information, attention, and training to the CBL tutors is very important (Uthrapathi-Shakila et al. 2021). This can be achieved by building a strong tutor community that can become independent over time, and able to incorporate and assist new tutors over time. However, we recommend that someone should have a specific pool of tutors, to maintain knowledge and experience, and ensure quality does not deop over time.

5 LIMITATIONS AND FUTURE WORK

Student numbers are rising, and despite the presented example being limited in the number of students, it may soon be necessary to accommodate larger numbers. This can be enabled by convincing external providers to take care of the supervision of more groups. Another way would be for universities to employ people that can provide connections to the industry and enable proper matchmaking between the industry and and academia. This will have multiple benefits for external providers that need to be explicit (access to young talent, innovative solutions, etc.)(Mayer, Ellinger, and Simon 2022). In the longterm future, it would be interesting to explore how AI can play a role in assisting CBL practice and help teachers deal with larger student numbers (Zhang and Aslan 2021). Additionally, rigorous methodologies such as SASER (Spiral Approach for SE Research) ((Bonnema, Pereira Pessoa, and Nizamis 2022; Pessoa and Nizamis 2023)), that claim to effectively bridge academia and industry, should be tested in a CBL context. Such approaches can facilitate challenge provider satisfaction and manage expectations in shorter cycles (that are desired by industry, and recently also implemented in agile academic programs). Lastly, in the future, we would like to observe and evaluate the longterm impact of the implemented changes by gathering data over the years to see which of the implemented changes work better and what are their strengths and weaknesses.

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REFERENCES

Atkinson, Doug, and Siew Leng Lim. 2013. “Improving Assessment Processes in Higher Education: Student and Teacher Perceptions of the Effectiveness of a Rubric Embedded in a LMS.” *Australasian Journal of Educational Technology*. http://www.blackboard.com/.

Beers, Sue Z. 2011. “21st Century Skills: Preparing Students for THEIR Future.” *STEM*.

Biggs, John. 1996. “Enhancing Teaching through Constructive Alignment.” Vol. 32. Kluwer Academic Publishers.

Bloom, Benjamin S, and David R Krathwohl. 1956. “Taxonomy of Educational Objectives: The Classification of Educational Goals.” In *Handbook I: Cognitive Domain.*

Bonnema, G Maarten, Marcus V Pereira Pessoa, and Kostas Nizamis. 2022. “Spiral Approach for SE Research (SASER)-Mating Research to Practice.” In *Complex System Design and Management 2022 (CSD&M)*.

Brickell, James L, L T Col, David B Porter, Michael F Reynolds Capt, and Richard D Cosgrove. 1994. “Assigning Students to Groups for Engineering Design Projects: A Comparison of Five Methods.”

Chou, Pao Nan, and Chi Cheng Chang. 2018. “Small or Large? The Effect of Group Size on Engineering Students’ Learning Satisfaction in Project Design Courses.” *Eurasia Journal of Mathematics, Science and Technology Education* 14 (10): 1–9. https://doi.org/10.29333/ejmste/93400.

Doulougeri, Karolina, Antoine van den Beemt, Jan D Vermunt, Michael Bots, and Gunter Bombaerts. 2022. “Challenge-Based Learning in Engineering Education: Toward Mapping the Landscape and Guiding Educational Practice.” In *The Emerald Handbook of Challenge Based Learning*, edited by Eliseo Vilalta-Perdomo, Jorge Membrillo-Hernández, Rosario Michel-Villarreal, Geeta Lakshmi, and Mariajulia Martínez-Acosta, 35–68. Emerald Publishing Limited. https://doi.org/10.1108/978-1-80117-490-920221003.

Doulougeri, Karolina, Gunter Bombaerts, Diana Martin, Adam Watkins, Michael Bots, and Jan D. Vermunt. 2022. “Exploring the Factors Influencing Students’ Experience with Challenge-Based Learning: A Case Study.” *IEEE Global Engineering Education Conference, EDUCON* 2022-March:981–88. https://doi.org/10.1109/EDUCON52537.2022.9766574.

Huutoniemi, Katri, Julie Thompson Klein, Henrik Bruun, and Janne Hukkinen. 2010. “Analyzing Interdisciplinarity: Typology and Indicators.” *Research Policy* 39 (1): 79–88. https://doi.org/10.1016/J.RESPOL.2009.09.011.

Kohn Rådberg, Kamilla, Ulrika Lundqvist, Johan Malmqvist, and Oskar Hagvall Svensson. 2020. “From CDIO to Challenge-Based Learning Experiences–Expanding Student Learning as Well as Societal Impact?” *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2018.1441265.

Leijon, Marie, Petri Gudmundsson, Patricia Staaf, and Cecilia Christersson. 2022. “Challenge Based Learning in Higher Education– A Systematic Literature Review.” *Innovations in Education and Teaching International* 59 (5): 609–18. https://doi.org/10.1080/14703297.2021.1892503.

Malmqvist, Johan, Kamilla Kohn Rådberg, and Ulrika Lundqvist. 2015. “COMPARATIVE ANALYSIS OF CHALLENGE-BASED LEARNING EXPERIENCES.” *P.R. China*. www.grandchallenges.com.

Mayer, Gesa, Dorothea Ellinger, and Siska Simon. 2022. “Involving External Partners in CBL: Reflections on Roles, Benefits, and Problems.” In *The Emerald Handbook of Challenge Based Learning*, 325–44. Emerald Publishing Limited. https://doi.org/10.1108/978-1-80117-490-920221014.

Nizamis, Kostas. 2021. “Redesign of the High-Tech Human Touch Minor From Idea to Prototype.” https://research.utwente.nl/en/publications/redesign-of-the-high-tech-human-touch-minor-from-idea-to-prototyp.

Pessoa, M. V.Pereira, and Kostas Nizamis. 2023. “Using a Spiral Approach to Facilitate Engineering Research and Education Embedded in Real Industry Settings.” In *SEFI 2023 - 51st Annual Conference of the European Society for Engineering Education: Engineering Education for Sustainability, Proceedings*, 3223–30. European Society for Engineering Education (SEFI). https://doi.org/10.21427/RM0J-A759.

Petrová, Nikola. 2020. “Challenges of Interdisciplinary Engineering Education : A Case Study for the Module Discrete Structures and Efficient Algorithms.” http://essay.utwente.nl/83941/.

Smith, Calvin. 2008. “Design-Focused Evaluation.” *Assessment and Evaluation in Higher Education*. https://doi.org/10.1080/02602930701772762.

Uthrapathi-Shakila, Niveditha, Kostas Nizamis, Cindy L. Poortman, and Jan van der Veen. 2021. “Interdisciplinary Challenge-Based Learning: Science To Society.” In *SEFI 49th Annual Conference Blended Learning in Engineering Education: Challenging, Enlightening, and Lasting?*, 1491–99. https://www.sefi.be/wp-content/uploads/2021/12/SEFI49th-Proceedings-final.pdf.

Vilalta-Perdomo, Eliseo, Herbert Mapfaira, and Rosario Michel-Villarreal. 2022. “Embedding 21st-Century Skills Through Challenge-Based Learning. Delivering Operations Management to Undergraduate Students.” *The Emerald Handbook of Challenge Based Learning*, August, 199–225. https://doi.org/10.1108/978-1-80117-490-920221009.

Zhang, Ke, and Ayse Begum Aslan. 2021. “AI Technologies for Education: Recent Research & Future Directions.” *Computers and Education: Artificial Intelligence*. Elsevier B.V. https://doi.org/10.1016/j.caeai.2021.100025.

DESIGN AN ENGINEER. A FUN-DAMENTAL LEARNING EXPERIENCE AND RESEARCH ACTIVITY.

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ABSTRACT

In an era where social and environmental responsibility are paramount, engineering education faces the crucial challenge of integrating these values into the core identity of its graduates. This paper discusses an innovative workshop that has been designed by the Rethinking Engineering Education in Ireland (REEdI) project to address this challenge by engaging students in a process that is both a fundamental learning experience for undergraduate engineering students and a method for collecting qualitative data on emerging engineering identities. Through group interactions, presentations, and reflections, the novel *Design an Engineer* workshop serves as a research instrument for exploring the themes that arise when students are tasked with envisioning the engineer needed to tackle current and future challenges. This study contributes to the broader discourse on the enhancement of engineering education by responding to calls for expanded frameworks of engineering role identity to better understand its development in the face of evolving professional landscapes.

1 INTRODUCTION

Higher education must rise to the challenge of developing curriculum that ensures both social and environmental responsibility is core to the identity of engineering graduates. This paper introduces the *Design an Engineer* (DAE) workshop. This is a novel concept that seeks to serve a dual purpose, as both a fundamental learning

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experience for engineering students, and as a (focus group) research instrument for gathering qualitative data through facilitating group interactions, presentations, and participant reflections.

As the engineering profession continues to evolve, so too must our approach to fostering the next generation's engineering identities. Rodrigues et al., (2018) call for scholarship in this area to focus on expanding forms of engineering role identity (ERI) frameworks and to facilitate a greater understanding of ERI development. Such frameworks are essential for comprehending the nuances of professional identity formation among engineering students, particularly in relation to their roles as future engineers, faced with complex societal and environmental dilemmas. This study is a component in a larger body of research that aims to address that call. The specific aim of this study is to explore the following question.

What themes emerge when a group of undergraduate students, from a mixed range of disciplines, are asked to design an engineer as the kind of person we need to solve the engineering challenges of now and the future?

This inquiry is not only about identifying the skills and knowledge that future engineers should possess but also about understanding how students perceive the role of an engineer, in society. By employing a workshop format that encourages active participation, collaborative design, and reflective practice, this study aims to uncover themes pertaining to underlying values, ethics, and responsibilities that participants associate with the engineering profession. We propose that the workshop holds the potential to serve a dual purpose. Firstly, as a pedagogical tool based on the principles of social constructivism, it enhances learning and ERI formation. Secondly, the workshop serves as a research instrument in the form of a focus group, that allows the researcher to gather insights into the evolving conceptualisation of what it means to be an engineer.

1.1 Defining Engineering role identity

Engineering role identity (ERI) encompasses the values, attributes, and core competencies that individuals associate with being an engineer. ERI plays a pivotal role in shaping the aspirations and motivations of individuals pursuing engineering careers (Patrick et al., 2018; Goodwin and Kirn, 2020). ERI is an individual's self-concept within the broader societal and professional context of engineering. It impacts both self-perception and interactions within professional communities (Rodrigues et al., 2018; Klaassen, et al., 2019).

1.2 Engineering role identity and social responsibility

ERI has been traditionally centred around technical proficiency and problem-solving skills (Niles et al., 2020), more recently it is undergoing a transformative expansion to include social responsibility as a core component (Crosthwaite, 2021). This shift is driven by the increasing recognition that engineering decisions have profound impacts on society and the environment. Consequently, engineering education must evolve to prepare students to navigate the ethical dilemmas and societal implications of their work (Niles et al., 2020). By asking participants to envision the engineer of the future, the DAE workshop serves as a crucible for exploring how these expanded responsibilities can be integrated into the ERI. The expansion of ERI to include social responsibility reflects an acknowledgment of the broader impacts engineering decisions have on society and the environment. This broader conceptualisation necessitates a curriculum that equips students not just with technical knowledge but with a moral compass to navigate the ethical dilemmas inherent in engineering practice (Rodrigues et al., 2018; Niles et al., 2020).

2 METHODOLGOY

2.1 Workshop format - Design an Engineer (DAE)

The DAE workshop is designed to consist of a series of interactive activities and discussion points. These activities were intentionally sequenced to facilitate active engagement and to scaffold participants in documenting their shared understanding and vision of an engineer. The pedagogical approach includes a brain-dump, mind-map, group discussion, presentation, and reflection. The selection of these activities was informed by constructivist and social constructivist principles (Von Glasersfeld, 1989). The workshop design allows for the incorporation of a central theme (figure 1) and discussion of topics related to ERI, such as values, attributes, stereotypes, and societal impact.

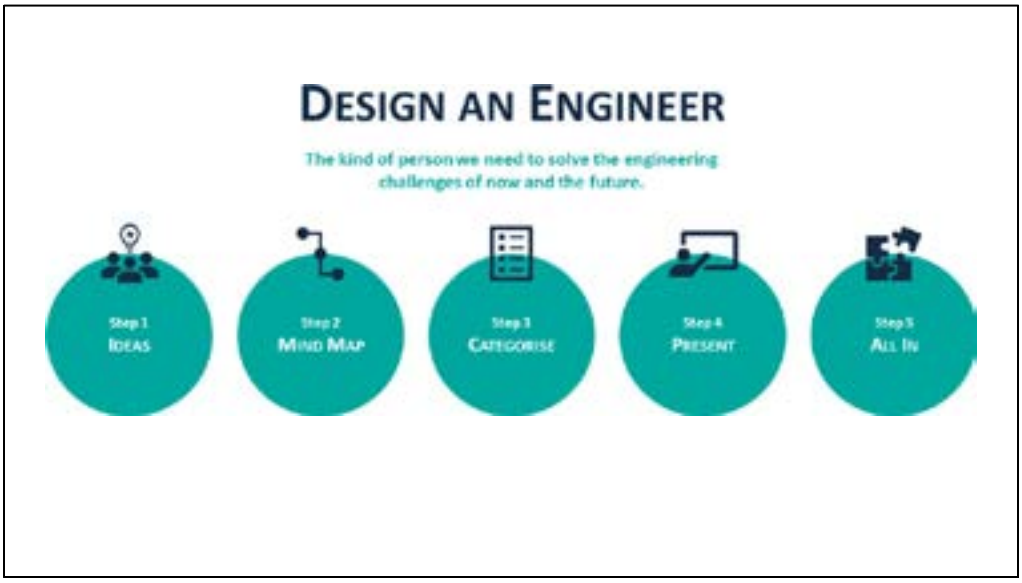

Figure 1 Overview of DAE workshop with theme and steps.

2.2 Adaptability and learning outcome

The DAE workshop is a 1.5-hour in-person activity for up to 25 participants, incorporating brain-dumping, mind mapping, categorisation, group presentations, and reflection (see figure 1). This format ensures active engagement and meaningful interaction, we propose it is adaptable for various educational and research contexts to explore professional identity in various disciplines. The workshop's simplicity allows for easy implementation, providing a versatile tool for educators to foster a deeper understanding of professional roles. Upon completing the workshop, participants will be able to identify and articulate the essential qualities, skills, and values of a modern engineer, demonstrating enhanced understanding of engineering role identity and its relevance to societal and environmental responsibilities.

2.3 Data collection

As a research instrument the DAE workshop generates qualitative data at each of the five steps outlined in figure 1. In addition, a reflection activity at the end of the workshop also yields qualitative data. Table 1 presents an overview of the data collection at each step of the workshop.

Table 1 Description of workshop steps and data collection method

Step	Name	Description	Data collection
1	Ideas	Participants are encouraged to "brain-dump" their initial thoughts on the qualities and characteristics required for engineers.	Activity artefact
2	Mind map	Through the creation of mind maps, participants visually organise and categorise their ideas, adding depth and detail. This step offers insights into how participants conceptualise the integration of various skills and ethical considerations.	Activity artefacts
3	Categorise	This step involves grouping similar ideas, which helps in identifying common themes and priorities among participants. It provides quantitative data on consensus areas and qualitative data on the reasoning behind these categorisations.	Activity artefacts
4	Presentation	Groups orally present their design of an engineer, offering an overview of their collective vision. This stage yields qualitative data through narratives that explain the integration of skills, experiences, and values envisioned for engineers.	Transcripts of recordings made during this step offers direct, verbatim insights.
5	All In	The consolidation of ideas from all groups into a single vision allows for the identification of universally valued traits and skills. This provides both qualitative insights into shared values and quantitative data on the most frequently mentioned attributes.	Activity artefacts
6	Reflection and Feedback	Participants reflect on their learning and changes in perception, providing qualitative feedback on the workshop's impact.	Activity artefacts

As outlined above each of DAE workshop steps generates data that can be analysed to understand the group's current conceptualisation of an engineer. The data collection method and management plan for this study has received approval from the university's human research ethics committee.

2.4 Participants

This study strategically leveraged the *Ingenium University Junior Winter School* as our participant selection pool. This decision was underpinned by the school's educational initiative to congregate students (n=50) from ten university members of the *Ingenium* alliance, to engage in innovative and creative learning approaches to enhance their educational experience. The setting fostered an interdisciplinary and multicultural collaboration, and the generation of innovative ideas within a narrative space that encouraged learning by way of social constructivism.

Opting to leverage this setting, allowed us to access a richly diverse participant pool without the logistical and ethical complexities of setting up a separate study. The research goal of exploring how undergraduate students from a mixed range of disciplines conceptualise an engineer as the kind of person we need to solve the engineering challenges of now and the future, was aligned with the participant selection approach. As per the conditions of the university's human research ethics policy each participant provided informed consent.

2.5 Data analysis

The data from steps 1, 2 and 3 (see table 1) of the workshop was analysed using thematic analysis, as described by Braun and Clarke (2006). This process removed duplications, organised the coded data in a structured way, allowed for the identification of themes within data and served to interpret various aspects of the research topic. It is important to note that the thematic analysis was conducted solely by the first author, which may affect the robustness of the findings. Recognising this limitation, this paper is submitted as a practice paper rather than a research study. The DAE workshop represents an innovative approach, and this submission seeks to explore new territory within engineering education. The aim is to gather initial insights and solicit feedback from the engineering education community to refine and improve the methodology.

3 RESULTS

Table 2 presents the core of our thematic analysis, directly addressing our research question: "What themes emerge when a group of undergraduate students, from a mixed range of disciplines, are asked to design an engineer as the kind of person we need to solve the engineering challenges of now and the future?" This question guided our inquiry into generating the initial codes on the attributes, skills, and values that students perceive as essential for the future engineer. Table 2 organises the initial codes extracted from the data generated during steps 1 and 2 of the DAE workshop (figure 1) data into broader themes, reflecting the diverse and comprehensive vision of engineering identity that students hold.

Table 2 Initial codes and themes extrapolated form data generated in steps 1 and 2 of DAE workshop.

Initial codes	Theme
• Problem solving • Innovative • Thinking outside the box • Addressing challenges creatively • Mental flexibility • Visionary	Creative problem solving

• Awareness of environmental impact • Long-term thinking • Responsible • Think of long-term impact of projects • Sustainable mind-set • Inclusive mindset • Mindful • Empathy • Integrity	Sustainability and Ethical Responsibility
• Willing to learn and improve • Persistent • Determined and goal focused • Self-awareness • Continuous learning • Discipline • Persistence in the face of adversity • Ambitious • Adaptable • Open minded • Enthusiastic	Growth and Resilience Mindset
• Team player • Change management • Social skills • Leadership • Composure • Relatable • Planning skills	Leadership and interpersonal excellence
• Technically capable • Proficient in maths and science • Highly educated • Solve technical problems • Detailed orientated • Accuracy • Logical	Technical Proficiency

3.1 Preliminary analysis of results

The thematic analysis reveals a multifaceted vision of the future engineer, encompassing Creative Problem Solving, Sustainability and Ethical Responsibility, Growth and Resilience Mindset, Leadership and Interpersonal Excellence, and Technical Proficiency. These themes collectively underscore the necessity for a holistic engineering education that goes beyond traditional technical training to include innovation, ethical stewardship, and social responsibility. Creative Problem Solving and Technical Proficiency highlight the essential balance between innovative thinking and foundational technical skills, suggesting an evolving pedagogical focus that fosters both inventive solutions and rigorous scientific understanding.

Sustainability and Ethical Responsibility, along with Growth and Resilience Mindset, reflect an emerging paradigm where engineers are seen not just as problem solvers but as responsible stewards of the planet, equipped with the resilience and adaptability to learn and grow in the face of challenges. This shift towards embedding ethical considerations and sustainability into the core of engineering identity aligns with global sustainability goals and the pressing need for ethical decision-making in engineering practices (Boshoff et al., 2013). This is consistent with Boshoff et al. (2013) and Niles et al. (2020) who advocate for educational frameworks that incorporate macro-ethics and societal responsibility, ensuring that future engineers are not only technically proficient but also socially conscious and ethically grounded.

The Leadership and Interpersonal Excellence theme emphasises the critical role of communication, teamwork, and leadership skills, advocating for an education system that prepares students to lead with empathy and integrity in a collaborative professional environment. This aligns with the conclusions drawn by Rottmann and Kendall (2022) in their exploration of engineering leadership education. Notably, they argue that educators must produce engineers who are not only technically competent but also capable of leading with empathy and integrity, addressing both professional and societal challenges effectively.

3.2 Summary of findings

The themes that emerged from the DAE workshop outline a comprehensive framework for engineering education. Such a framework can prepare students to meet the challenges of the future with a well-rounded set of skills and values. By integrating these themes into curriculum development and pedagogical strategies, engineering educators can cultivate a new generation of engineers poised to tackle global challenges with innovative solutions, ethical foresight, and effective leadership (Lavi and Marti, 2023; Rottmann and Kendall, 2022; Niles et al., 2020; Boshoff et al., 2013). The insights gathered from the DAE workshop underscore the importance of innovative educational practices to foster a diverse set of competencies, highlighting the role of pioneering pedagogical tools in shaping the future of engineering identity and practice.

3.3 Limitations

We recognise this study’s limitations in its approach to data collection and the workshop's design scope. Understanding these limitations is key to contextualising the study's findings and identifying areas for future research.

The DAE workshop is centred around group activities and discussions. This approach may limit the depth of qualitative data collected. This structure can result in varying levels of contribution among participants, potentially overshadowing less-dominant perspectives. Additionally, the once-off nature of a workshop cannot fully capture the evolving and complex nature of students' engineering identities. Methods allowing for more detailed individual analysis or longitudinal tracking could yield richer insights into the development of ERI over time.

Placing the emphasis on envisioning the engineer of the future with a focus on social responsibility provides valuable insights. However, it potentially narrows the scope of discussion, sidelining other vital elements such as technical skills and the impact of technological advancements. Expanding the thematic range of the workshop to include these aspects, could offer a more holistic perspective on ERI.

These limitations underscore the importance of adopting a multifaceted approach to research in engineering education. By addressing these areas, future studies can enhance the depth of data collection and expand the conceptual scope of the DAE workshop, thereby offering more nuanced insights into the complexities of ERI.

3.4 Future research

In addition to the addressing the research question, this study served to validate the DAE workshop as both a fundamental learning experience and research activity. This was a necessary step in advance of a larger research project which will focus on exploring similarities and or differences in how undergraduate engineer students and professional engineers conceptualise ERI. In addition, several other avenues for future research using the DAE workshop concept and format have been identified.

I. Conducting a longitudinal study to gain a deeper understanding of the evolution of ERI. This would involve capturing data to track the perceptions of the same individuals at different points in time. Exploring how ERI evolves as student engineers become professionals and advance in their careers and take on leadership roles within organisations. This may provide insights into the long- term impact of ERI on career progression and persistence.

II. Another possibility is to extend the scope of the research question(s) to examine cultural and global perspectives. This may uncover variations in ERI influenced by cultural norms, societal expectations, and education systems. Comparative studies may reveal culturally specific perspectives of an engineer. Investigating how factors such as gender, race, ethnicity, and socioeconomic background intersect with ERI would offer a more nuanced understanding of the experiences and perceptions of underrepresented groups in engineering.

III. Finally, future research could explore the impact of educational interventions such as mentorship programs, and workplaces in shaping students' perceptions of the engineer. Evaluating the impact of these interventions on ERI development has the potential for improving engineering education and practice.

4 SUMMARY

By focusing on understanding how participants conceptualise an engineer the DAE workshop serves as both a learning experience and a research instrument. This study’s initial findings validate that the DAE workshop has the potential to facilitate groups in documenting a broad and nuanced vision on an engineer. It is hypothesised that participating in the DAE workshop is a catalyst in the development of ERI, for engineering students. However, further research is required to measure and evaluate its effectiveness for this purpose.

As an innovative research instrument, the workshop contributes to the field of engineering educational research by providing a format for the generation and collection of data that reveals a nuanced understanding of how a group conceptualises an engineer. In addition, to contributing to the academic discourse on engineering education research the study offers a practical solution that enhances the curriculum by bridging the gap between technical competence and ERI development.

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REFERENCES

Boshoff, N., Jacobs, C., and Le Roux, A. "Editors’ Overview: Perspectives on Teaching Social Responsibility to Students in Science and Engineering". Science and Engineering Ethics, 19(4), (2013): 1301-1312.

Braun, Virginia and Victoria Clarke. "Using Thematic Analysis in Psychology." *Qualitative Research in Psychology* 3, no. 2 (2006): 77-101.

Crosthwaite, C. *“Engineering Futures 2035: Engineering Education Programs, Priorities & Pedagogies.” Australian Council of Engineering Deans (ACED)* (2021).

Godwin, Allison, and Adam Kirn. "Identity-Based Motivation: Connections Between First-Year Students' Engineering Role Identities and Future-Time Perspectives." *Journal of Engineering Education*, 109, no. 3, (2020): 362-383. doi:10.1002/jee.20324

Klaassen, R., Van Dijk, M., Hoope, R., and Kamp, A. “Engineer of the Future: envisioning higher engineering education in 2035”. (2019) Delft: TU Delft Open.

Lavi, Rea, and Deniz Marti. "A Proposed Case-Based Learning Framework for Fostering Undergraduate Engineering Students’ Creative and Critical Thinking." Journal of Science Education and Technology 32, no. 3 (2023): 898-911. https://doi.org/10.1007/s10956-022-10017-w.

Niles, Skye, Santina Contreras, Shawhin Roudbari, Jessica Kaminsky, and Jill Lindsey Harrison. "Resisting and Assisting Engagement with Public Welfare in Engineering Education." Journal of Engineering Education (Washington, D.C.) 109, no. 3 (2020): 491-507.

Patrick, Anita D., Maura Borrego, and Alexis N. Prybutok. "Predicting Persistence in Engineering through an Engineering Identity Scale." *International Journal of Engineering Education* 34, no. 2A (2018): 351-363.

Rodrigues, Sarah L., Charles Lu, and Morgan Bartlett. "Engineering Identity Development: A Review of Higher Education Literature." *International Journal of Education in Mathematics, Science and Technology* 6, no. 3 (2018): 254-265.

Rottmann, Cindy, and Meagan R. Kendall. "Looking to the Future: Four Key Purposes of Engineering Leadership Education." New Directions for Student Leadership 2022, no. 173 (2022): 149-155. https://doi.org/10.1002/yd.20486.

Von Glasersfeld, Ernst. "Cognition, Construction of Knowledge, and Teaching." *Synthese* 80, no. 1 (1989): 121-140.

Engineering Education for a Sustainable Future: Integrating Social and Environmental Transversal Competencies

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ABSTRACT

Inclusive design in engineering is essential to enhance accessibility. Ireland's national Deposit Return Scheme (DRS) exemplifies the consequences of excluding inclusive design, as return machines are primarily designed for standing users, making them inaccessible to wheelchair users. Additionally, cramped spaces and narrow aisles can further hinder manoeuvrability, underscoring the need for inclusive design principles to ensure equal participation in recycling efforts.

This paper focuses on the development of a Socio-Environmental Framework that integrates transversal competencies to foster sustainable and inclusive designs in

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engineering education. Transversal competencies, encompassing skills, values, and attitudes essential for comprehensive development and adaptability, are vital for advancing inclusive design. These competencies, which include communication, empathy, lifelong learning, and teamwork, are supported by frameworks such as LifeComp and GreenComp developed by the EU. LifeComp focuses on personal, social, and learning-to-learn competencies, while GreenComp emphasizes sustainability competencies.

By evaluating a professional development module for Level 7 engineering students, this study assesses the curriculum's effectiveness in preparing future engineers to create inclusive and sustainable solutions. Emphasizing empathy, critical thinking, and adaptability, the framework guides engineers to meet societal, ethical, and environmental responsibilities.

1 INTRODUCTION

Engineering education must embrace transversal competencies to address the complex challenges of a sustainable future. Inclusive design in engineering ensures accessibility for all individuals. The shortcomings of Ireland's national Deposit Return Scheme (DRS), where return machines are primarily designed for standing users and thus inaccessible to wheelchair users, highlight the consequences of neglecting inclusive design.

Transversal competencies, as synthesised by Cruz (Cruz, Saunders-Smits and Groen 2020), are defined by Care and Luo (Care and Luo 2016) as ‘skills, values, and attitudes required for learners’ holistic development and adaptability,’ are crucial for promoting inclusive design. These competencies are also known as employability skills (Markes 2006), generic skills (Bennett, Dunne and Carré 2000), key competencies (Organisation for Economic Co-Operation Development 2005), non-technical skills (Knobbs and Grayson 2012), non-traditional skills (Crawley, et al. 2007), professional skills (Shuman, Besterfield-Sacre and McGourty 2005), soft skills (Whitmore and Fry 1974), transferable skills (Kemp and Seagraves 1995), and twenty-first-century skills (National Research Council 2013).

Transversal competencies such as communication, empathy, lifelong learning, and teamwork are vital for promoting inclusive and sustainable engineering practices. This paper presents a Socio-Environmental Framework, based on the European frameworks, LifeComp (Sala, et al. 2020)and GreenComp (Bianchi, Pisiotis and Cabrera 2022), to enhance these competencies in engineering education. By evaluating a professional development module for Level 7 engineering students, this study examines the curriculum's effectiveness in preparing future engineers to create inclusive and sustainable futures. Emphasising empathy, critical thinking, and adaptability, the framework guides engineers to meet societal, ethical, and environmental responsibilities.

2 METHODOLOGY

2.1 Case Study Analysis: Ireland's Deposit Return Scheme (DRS)

The need for the Socio-Environmental Framework arose from analysing Ireland's national Deposit Return Scheme (DRS), an initiative to boost recycling rates for drink containers. The assessment, based on Jutta Treviranus'(2018) inclusive design principles, highlighted significant accessibility challenges, particularly for wheelchair users. Issues such as the height of return machines revealed that the DRS did not adequately meet the needs of diverse users. These findings underscore the necessity of incorporating social aspects into environmental contexts to create more inclusive and sustainable solutions.

2.2 Framework Development

Following the insights gained from the DRS case study, the Socio-Environmental Framework was developed by integrating competencies from two established European frameworks: LifeComp and GreenComp and applying Jutta Treviranus' inclusive design framework as a lens of inquiry.

Initially, a comprehensive literature review identified relevant transversal competencies from LifeComp and GreenComp applicable to engineering education. LifeComp focuses on personal, social, and learning-to-learn skills like self-regulation, empathy, and critical thinking, emphasising the social aspects. GreenComp emphasises sustainability competencies, including embodying sustainability values, embracing complexity, envisioning sustainable futures, and acting for sustainability, highlighting the environmental aspects.

The next step involved synthesising the framework. A framework was developed, combining the identified competencies from LifeComp and GreenComp. These competencies were organised into categories: Personal (P), Social (S), and Learning to Learn (L) from LifeComp, and Sustainability Values (1), Complexity in Sustainability (2), Sustainable Futures (3), and Acting for Sustainability (4) from GreenComp. The LifeComp competencies form the horizontal categories, while the GreenComp competencies form the vertical categories.

2.3 Module Assessment

Using the newly developed Socio-Environmental Framework, the Professional Development & Employability module for Level 7 engineering students was reviewed. This assessment aimed to evaluate how effectively the module prepares students to apply transversal competencies in real-world scenarios. The module's components, including the Personal Development Plan, CV Crafting and Optimisation, Teamwork Poster, and Reflective Essay, were analysed to determine their effectiveness in fostering key transversal competencies such as communication, empathy, lifelong learning, and teamwork. This assessment aimed to ensure that the curriculum equips students with the skills needed to address societal, ethical, and environmental challenges in their future careers.

2.4 Data Collection and Analysis

Data collection involved a qualitative method, specifically content analysis of students' submissions. Each curriculum component—Personal Development Plan (PDP), CV Crafting and Optimisation, Teamwork Poster, and Reflective Essay—was systematically mapped to the categories and competencies outlined in the Socio-Environmental Framework.

The coding scheme was developed based on the competencies identified in the Socio-Environmental Framework. These competencies are divided into three main categories: Personal (P), Social (S), and Learning to Learn (L) from LifeComp, which form the horizontal categories. The vertical categories are formed by the GreenComp competencies: Sustainability Values (1), Complexity in Sustainability (2), Sustainable Futures (3), and Acting for Sustainability (4).

To apply this coding scheme, relevant documents, including students' PDPs, CVs, Teamwork Posters, and Reflective Essays, were reviewed. Using qualitative data analysis, each piece of text that reflected a competency was tagged with the corresponding code. For example, a paragraph discussing self-regulation and adaptability in the PDP would be coded under the personal category. Thematic analysis was then conducted to identify recurring themes and patterns.

Each component was assessed for alignment with the framework using a color-coded system: red for little to no alignment, orange for some alignment, and green for strong alignment. This approach provided insights into how effectively the module components fostered transversal competencies.

3 Case Study: The Need for Inclusive Design in Engineering Solutions

The complexity of modern engineering solutions often reveals a critical gap between technical feasibility and user accessibility. Engineers play a crucial role in sustainability efforts, exemplified by Ireland's implementation of a national Deposit Return Scheme (DRS) aimed at boosting recycling rates for drinks containers. This initiative, aligned with the EU's Single Use Plastics Directive (European Parliament and the Council of the European Union 2019), under which, “Ireland must ensure the separate collection of 77% of plastic beverage bottles placed on the market by 2025, rising to 90% in 2029” (Department of the Environment 2022).

Ensuring these systems are accessible to all users, including those with disabilities, is challenging. The design of reverse vending machines, integral to the DRS, has come under scrutiny for not being universally accessible. Issues have been raised regarding their usability for wheelchair users and individuals with visual impairments, as some machines lack Braille instructions and rely on touch screens, which can be a barrier to access for some. This oversight not only restricts certain individuals from participating in recycling efforts but also inadvertently imposes additional costs on those unable to use the infrastructure. Ireland's national Deposit Return Scheme (DRS) exemplifies the consequences of excluding inclusive design, as return machines are primarily designed for standing users, making them inaccessible to wheelchair users. Underscoring the need for inclusive design principles to ensure equal participation in recycling efforts.

In the preamble of the Convention on the Rights of Persons with Disabilities (CRPD), section (e) states that disability arises from the interaction between individuals with impairments and “*environmental barriers*”, which obstruct their full and effective participation on an equal basis with others. This perspective is officially recognised by the United Nations, underlining the global commitment to understanding and addressing disability within the framework of human rights and societal inclusion (United Nations 2006). This concept is frequently described as the social model of disability, individuals are all different and it is not this difference that is disabling but rather the environments or designs that limit access. Acknowledging the diversity and evolving nature of human capabilities, underlines the imperative for environments and designs to ensure that accessibility keeps pace with our changing needs. The phrase "*Nothing about Us, Without Us*" (United Nations 2004), which became notable within the disability rights movement, emphasises the necessity of including those it concerns in the design process, highlighting that their participation in design is essential.

This scenario underscores a fundamental challenge: while technical solutions can address specific problems, their design and implementation must consider and include the diverse needs of users to truly be effective. This situation illustrates that engineers, despite their expertise and technical knowledge, cannot work in isolation. Collaborative efforts that include policymakers, community representatives, and inclusion of "*edge users*" (Treviranus 2018) are essential to ensure that engineering solutions are both effective and accessible. The case of Ireland's DRS serves as a reminder of the importance of inclusive design in engineering projects, emphasising that true sustainability encompasses not only environmental benefits but also equitable access for all members of society. *"Designing for inclusion starts with recognising exclusion"* (Holmes 2018).

To embrace inclusive design, engineers need a wide range of transversal skills such as collaboration, communication, and critical thinking. Key competencies from GreenComp, like valuing sustainability and supporting fairness, along with LifeComp skills such as empathy and effective communication, are essential for integrating diverse perspectives, especially those of users with disabilities.

This case study highlights the necessity for a socio-environmental framework in engineering, promoting solutions that are both inclusive and sustainable. Incorporating this framework into engineering education is crucial to equip future engineers with the needed transversal competencies. This preparation ensures they can meet society's diverse needs, making technological advancements accessible and beneficial to all, including marginalised groups.

4 SOCIO-ENVIRONMENTAL TRANSVERSAL COMPETENCE FRAMEWORK

LifeComp (2020) and GreenComp (2022), developed by the European Commission's Joint Research Centre (JRC), emphasise personal, social, and environmental competencies to guide policy formulation. Drawing insights from these frameworks, a new socio-environmental framework, detailed in Table 1, was created and applied to assess the Professional Development & Employability engineering module. This assessment aims to determine the module's alignment with social and environmental objectives.

Table 1 Socio-Environmental Framework

Category	**Personal (P)**	**Social (S)**	**Learning to Learn (L)**
Sustainability Values (1)	Self-regulation, Flexibility, Wellbeing Valuing Sustainability, Supporting Fairness, Promoting Nature (P1)	Empathy, Communication, Collaboration Valuing Sustainability, Supporting Fairness, Promoting Nature (S1)	Growth Mindset, Critical Thinking, Managing Learning, Valuing Sustainability, Supporting Fairness, Promoting Nature (L1)

Complexity in Sustainability (2)	Self-regulation, Flexibility, Wellbeing Systems Thinking, Critical Analysis, Problem Framing (P2)	Empathy, Communication, Collaboration Systems Thinking, Critical Analysis, Problem Framing (S2)	Growth Mindset, Critical Thinking, Managing Learning, Systems Thinking, Critical Analysis, Problem Framing (L2)
Sustainable Futures (3)	Self-regulation, Flexibility, Wellbeing Futures Literacy, Adaptability, Exploratory Thinking (P3)	Empathy, Communication, Collaboration Futures Literacy, Adaptability, Exploratory Thinking (S3)	Growth Mindset, Critical Thinking, Managing Learning, Futures Literacy, Adaptability, Exploratory Thinking (L3)
Acting for Sustainability (4)	Self-regulation, Flexibility, Wellbeing Policy Advocacy, Community Collaboration, Active Engagement (P4)	Empathy, Communication, Collaboration Policy Advocacy, Community Collaboration, Active Engagement (S4)	Growth Mindset, Critical Thinking, Managing Learning, Policy Advocacy, Community Collaboration, Active Engagement (L4)

5 THE PROFESSIONAL DEVELOPMENT & EMPLOYABILITY MODULE

The Level 7 Professional Development & Employability module for engineering students, delivered to online adult learners, was assessed using the Socio-Environmental Framework. Applying an inclusive design lens of inquiry, this evaluation considered the unique needs of these learners, who may be considered "edge users" compared to traditional campus students. It examined how well the module prepares these students to apply transversal competencies in real-world scenarios.

5.1 Personal Development Plan: Aligning Goals with Societal Needs

The Personal Development Plan (PDP) facilitates students' self-assessment, goal setting, skill development, networking, and continuous reflection. It emphasises self-discovery and strategic career planning, aligning personal growth with societal and environmental responsibilities. For a detailed assessment, see Table 2, which uses color-coded percentages: red for little to no alignment, orange for some alignment, and green for strong alignment.

Table 2 PDP Assessment against Table 1

Category	**Personal (P)**	**Social (S)**	**Learning to Learn (L)**

Sustainability Values (1)	90% self-regulation, sustainability, skill development, networking plan,, adaptability, well-being, continuous growth.	80% Networking: connection, understanding, sustainability, fairness, conservation, collaboration, best practices. Continuous Reflection and Adjustment: empathy, environment, communication, collaboration, sustainability focus.	95% Self-Assessment and Goal Setting: growth mindset, learning goals, challenges, proactive, overcoming obstacles, critical thinking. Continuous Reflection and Adjustment: learning management, strategy adjustments, learning objectives, embracing new ideas.
Complexity in Sustainability (2)	90% Self-Assessment and Goal Setting: systems thinking, critical analysis, improvement, sustainability challenges. Skill Development: problem framing ability.	80% Skill Development: complex systems understanding, sustainability, critical analysis, problem framing, social settings. Networking: diverse perspectives, sustainability challenges, systems thinking, social contexts.	90% Skill Development: systems thinking, critical analysis, problem understanding, solution framing. Self-Assessment: strengths and weaknesses identification, systems thinking, critical analysis, focused improvement.
Sustainable Futures (3)	90% Strategic Career Planning: futures literacy, anticipation, shaping opportunities, sustainability challenges. Networking, Continuous Reflection, and Adjustment: adaptability, exploratory thinking, navigating uncertainty, innovative solutions.	90% Continuous Reflection and Adjustment: futures literacy, open-mindedness, future scenarios, social dynamics, sustainability. Strategic Career Planning: adaptability, exploratory thinking, societal needs, sustainability challenges.	90% Strategic Career Planning, Continuous Reflection: futures literacy, anticipation, adaptability, exploratory thinking, uncertainties. Skill Development: future trends engagement, challenges, futures thinking capacity.
Acting for Sustainability (4)	60% Self-Discovery, Strategic Career Planning: policy advocacy, community collaboration, active engagement, sustainability action preparation	55% Networking, Skill Development: policy advocacy, community collaboration, active engagement, sustainability. Continuous Reflection and Adjustment: evaluation, advocacy, collaboration effectiveness, responsiveness.	60% Networking: influencers, decision-makers, peers, advocacy, collaboration, policymaking, community projects. Self-Assessment and Goal Setting: interests, skills, advocacy, engagement, development, action.

This analysis of the PDP illustrates how it aligns with the Socio-Environmental Framework, emphasising self-regulation, empathy, systems thinking, and sustainability. However, it also identified gaps in community collaboration and policy advocacy.

5.2 Summary of Other Module Components

The remaining components were also assessed, and the results are summarised below:

CV Crafting: This component aligns self-awareness and career planning with job market demands. Assessment showed strong alignment in self-reflection (85%), and continuous improvement (95%), but moderate alignment in ethical orientation (70%), social engagement (70%) and community advocacy (50%). This highlights the need for more focus on social impact and policy advocacy in CV preparation.

Teamwork Poster on "Walk the Walk in Ethics": This project focuses on wellness activities and ethical case studies. Evaluation showed high alignment with ethical practice (95%), collaboration (80%), and reflective learning (95%), and alignment in adaptability (80%) and future-oriented teamwork (80%). The project excels in ethical considerations and teamwork.

Reflective Essay: This component explores the student's learning journey, focusing on sustainability, self-awareness, and empathy. The assessment showed strong alignment in self-awareness (95%), ethical values (95%), and critical thinking (90%), but moderate alignment in civic engagement (55%) and policy influence (55%). This suggests the reflective essay supports growth but could better integrate community engagement and advocacy.

6. RESULTS: ADVANCING SOCIAL AND SUSTAINABLE ENGINEERING EDUCATION

This paper developed a Socio-Environmental Framework to evaluate and support inclusive design in engineering education, grounded in LifeComp (2020) and GreenComp (2022). The need for this framework emerged from a review of Ireland's Deposit Return Scheme (DRS) using inclusive design principles. The DRS highlighted significant accessibility challenges, particularly for wheelchair users, underscoring the necessity of integrating social aspects into environmental contexts. The Socio-Environmental Framework places a strong emphasis on transversal competencies, such as critical thinking, problem-solving, and adaptability. This approach ensures that engineering students are equipped to tackle complex socio-environmental issues and design inclusive solutions that address both social and environmental needs effectively.

Applying this framework to the Professional Development & Employability module for Level 7 engineering students revealed various strengths. The module showed strong alignment with competencies such as self-regulation, empathy, systems thinking, and sustainability. Students demonstrated self-awareness through personal development plans and reflective essays, a commitment to continuous improvement via CV crafting and teamwork projects, and a deep understanding of ethical values through ethics-focused assignments.

However, the evaluation also identified gaps in community collaboration and policy advocacy, underscoring the need for students' development to align more closely with societal and environmental responsibilities. While the module effectively fosters individual skills and values, it should place more emphasis on teaching students how to collaborate with communities and advocate for policies that support sustainability.

To address these gaps, future enhancements should focus on embedding social impact and policy advocacy more deeply into the curriculum. Future research could explore applying this framework to technical modules and integrating accreditation criteria from Engineers Ireland to align more closely with professional standards. Conducting empirical research to gather data on the framework's impact on student outcomes, including surveys, interviews, and focus groups, is crucial. Embracing transversal competencies is essential for promoting inclusive and sustainable engineering practices, ensuring engineers meet societal, ethical, and environmental responsibilities.

REFERENCES

Bennett, Neville , Elisabeth Dunne, and Clive Carré. 2000. *Skills Development in Higher Education and Employment.* Buckingham, United Kingdom: The Society for Research into Higher Education and Open University Press.

Bianchi, Guia , Ulrike Pisiotis, and Marcelino Cabrera. 2022. *GreenComp The European sustainability competence framework.* Luxembourg: Publications Office of the European Union,. doi:doi:10.2760/13286.

Care , Esther , and Rebekah Luo. 2016. "Assessment of Transversal Competencies: Policy and Practice in the Asia-Pacific Region." In *United Nations Educational, Scientific and Cultural Organization*, 307 to 366. Paris France: UNESCO.

Crawley, Edward F, Johan Malmqvist, Sören Östlund, and Doris R Brodeur. 2007. *Rethinking Engineering Education: The CDIO Approach.* New York, NY: Springer.

Cruz, Mariana Leandro , Gillian N Saunders-Smits, and Pim Groen. 2020. "Evaluation of competency methods in engineering education: a systematic review." *European Journal of Engineering Education* 729-757. doi:10.1080/03043797.2019.1671810.

Department of the Environment, Climate and Communication. 2022. *Minister Smyth launches Ireland's Deposit Return Scheme.* Accessed 03 20, 2024. https://www.gov.ie/en/press-release/b3f2f-minister-smyth-launches-irelands-deposit-return-scheme/.

Engineers Ireland. 2021. *Accreditation Criteria.* Engineers Ireland. https://www.engineersireland.ie/LinkClick.aspx?fileticket=Mz3SCCk_uRg%3D&portalid=0&resourceView=1.

European Parliament and the Council of the European Union. 2019. *Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment.* Brussels: Official Journal of the European Union, 1–19. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019L0904.

Holmes, Kat. 2018. *Mismatch How Inclusion Shapes Design.* MIT Press; Illustrated edition.

Kemp, Iam J, and Liz Seagraves. 1995. "Transferable Skills—Can Higher Education Deliver?" *Studies in Higher Education* 20 (3): 315-328.

Knobbs, Clive G., and David J Grayson. 2012. "An Approach to Developing Independent Learning and non-Technical Skills Amongst Final Year Mining Engineering Students." *European Journal of Engineering Education* 37 (3): 307-320.

Markes, Imren . 2006. "A Review of Literature on Employability Skill Needs in Engineering." *European Journal of Engineering Education* 31 (6): 637-650.

National Research Council. 2013. *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century.* Washington, DC: National Academies Press.

OECD. 2024. "Education and Innovation Practice Community (EPIC)."

Organisation for Economic Co-Operation Development. 2005. *The Definition and Selection of Key Competencies: Executive Summary.* Paris, France: OECD.

Re-Turn. 2022. *Minister Smyth launches Ireland’s Deposit Return Scheme.* Accessed 03 20, 2024. https://re-turn.ie/minister-smyth-launches-irelands-deposit-return-scheme/.

Rittel , H. W. J. , and M. M. Webber. 1973. "Dilemmas in a general theory of planning." *Policy Sci.* 4 (2): pp. 155–169. doi:10.1007/BF01405730.

Sala, Arianna, Yves Punie, Vladimir Garkov, and Marcelino Cabrera. 2020. *LifeComp: The European Framework for Personal, Social and Learning to Learn Key Competence.* Luxembourg: EUR 30246 EN, Publications Office of the European Union. doi:doi:10.2760/302967.

Shuman, Larry J, Mary Besterfield-Sacre, and Jack McGourty. 2005. "The ABET 'Professional Skills'—Can They be Taught? Can They be Assessed?" *Journal of Engineering Education* 94 (1): 41-55.

Treviranus, Jutta. 2018. *The three dimensions of inclusive design: A design framework for a digitally transformed and complexly connected society.* PhD thesis, University College Dublin. http://openresearch.ocadu.ca/id/eprint/2745/.

Treviranus, Jutta. n.d. *The three dimensions of inclusive design: A design framework for a digitally transformed and complexly connected society.* PhD thesis, University College Dublin. http://openresearch.ocadu.ca/id/eprint/2745/.

United Nations. 2006. *Convention on the Rights of Persons with Disabilities, Preamble (e).* New York: United Nations. https://www.ohchr.org/en/instruments-mechanisms/instruments/convention-rights-persons-disabilities.

—. 2004. *International Day of Persons with Disabilities (IDPD), 3 December 2004.* Accessed 03 20, 2024. https://www.un.org/esa/socdev/enable/iddp2004.htm#:~:text=The%20motto%20%E2%80%9CNothing%20About%20Us,and%20with%20persons%20with%20disabilities.

Whitmore, Paul G, and John P Fry. 1974. *Soft Skills: Definition, Behavioral Model Analysis, Training Procedures.* Alexandria, VA: Ft. Belvoir Defense Technical Information Center, Human Resources Research Organization.

World Commission on Environment and Development. 1987. *Our Common Future.* Oxford: Oxford University Press, 41.

Sharing collaborative classroom experiences: in groups vs in team

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Keywords*: collaborative work; collaborative learning; teaching and learning experiences; work in groups, teamwork.*

ABSTRACT

Teachers are increasingly encouraged to teach more attractive, dynamic and contemporary classes. In this sense, the teacher must seek to transform education based on the construction of experiences, with previously defined objectives and strategies that meet the needs and interests of the class and that allow them to participate in the construction of their knowledge, based on real situations and experienced by the group. This paper shares a diversity of collaborative teaching-learning experiences (CTLE) carried out in groups and teams, with the aim of a qualitative investigation to explore the impact of the subjects' contents on students' perceptions, as well as obtaining feedback from students on the group/team experience. The CTLEs were very enriching: (1) for teachers as education professionals because they allowed a reflection on the difficulties experienced by students in learning mathematics; (2) for students because the results show that students were involved in building their knowledge, solving problems and communicating their resolution both in groups and as a team, enabling the

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development of the expected skills, which can contribute to improving the success of the curricular units.

1 INTRODUCTION

A high number of students in higher education have many difficulties in mathematics subjects because they require abstract concepts, the manipulation of symbols and signs, and the resolution of problems with a sequence of engaged steps (Muhammad and Angraini, 2023; Wang, et al. 2023). However, these concepts are fundamental to engineering studies and applications. The difficulty in learning mathematics content due to the students' lack of motivation, the absence of habits and working methods, and the difficulties they have in achieving the curriculum objectives, leads to abandonment of classes in these subjects and failure in higher education. Failure in the Mathematics subjects appears constantly associated with academic failure. This problem is not new, it has persisted over time, which is why the need to reflect on it and search for practices to implement to reverse the situation is justified. International studies and the results obtained by Portuguese students in national exams in this subject increase the visibility of this problem that worries educators, teachers, parents, students, and society in general.

Continuous collaboration is an essential part of learning and working in the 21st century (Millis 2023). There are many CTLEs of collaborative work in the classroom, including (Lailiyah et al. 2021), (Supriyadi and Kuncoro 2023) and (Gumiero, and Pazuch 2024). Collaborative practical classes improve the teaching of higher-level mathematics by providing engaging learning tools (Darmayanti 2023) and allowing students to increase the skills they acquire from these collaborative teaching-learning experiences (CTLE) (Du et al. 2013). There is a vast number of experiences described in the literature on collaborative learning of mathematics regarding the way of monitoring learning (Isohätälä et al, 2020, Nungu et al., 2023) and developing skills (Warsah, et al., 2021, Lewis et al., 2024) and evaluation (Darmayanti, 2023; Boud, and Margaret, 2023). Collaborative experiences can be applied using classroom work groups or teamwork (Wullschleger et al. 2023). In groups, tasks are distributed among all participants, each student is responsible for planning the tasks assigned to them and respecting deadlines. Members can share and respect opinions. On the other hand, in a team everyone works for a single purpose, exchanging knowledge and experiences to facilitate work optimization (Coers et al. 2009). One of the most notable differences is the way the experience is evaluated, as in a group, it is possible to evaluate each member of the group individually, which cannot happen in a team, as the work will depend on the joint performance of each member (Paulus et al. 2014).

This paper aims to share a set of CTLEs in mathematics for first-year engineering students. The objective of these CTLEs is to provide students with the necessary mathematical skills in a more motivating way, in addition to providing them with a wide range of soft skills that are equally necessary for the inclusion of future engineers in the job market. This qualitative study arose from the desire to better understand student and teacher perceptions of groups and team CTLE in classroom environments. Focused on groups and team learning based on CTLE proposed by teachers in different curricular units during a semester of classes or for one week. The use of questionnaires and direct observation allowed researchers to obtain answers about students' perceptions and provide valuable information necessary for the successful integration of group or team experiences into mathematics learning for engineers.

This document is organized as follows: after the introduction to the topic, in section 2 the materials and methods used in this study, in section 3 the parameters observed during the experiments carried out are presented, in section 5 the results according to performance and skills technological information of students, direct observation in the classroom and student opinion; in the last section (6) conclusions are presented.

2 MATERIALS AND METHODS

The CTLEs described in this paper refer to collaborative teaching and learning, applied in different formats: collaborative team experiences (CTE) and collaborative groups experiences (CGE) (Fig. 1). CTE involve all students working in the same environment, on the other hand, CGE involve students working in groups of elements, with several groups existing in the classroom. In each of the formats, the teacher participates as an observer, guiding student learning and providing all the support necessary for its completion.

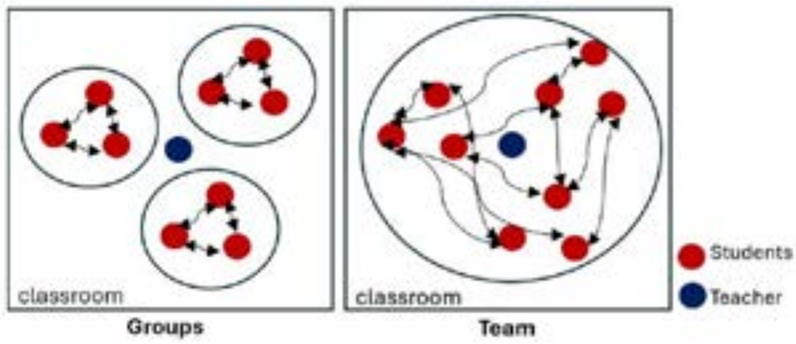

Fig. 1. Collaborative groups experiences (CGE) (left) and collaborative team experiences (CTE) (right)

2.1 Collaborative team experiences

In these experiments, different platforms for collaborative learning were used, such as Jamboard, Padlet, and Miro. These platforms allow joint access (students and teachers at the same time) to a mural, where exercises or work carried out by students are available. Students can write directly on the mural, or upload different formats of technologies, such as files, videos, images, apps, etc. On these platforms, students are invited to solve different exercises with different content and share them with their colleagues (Fig. 2). The teacher is responsible for monitoring, helping, and providing timely feedback on posts. To improve interaction between students and the exchange of knowledge, the teacher also gives students the opportunity to correct their colleagues' exercises or work, providing peer feedback. The mural is shared during classes and outside, as group learning and as support for independent and community study.

Fig. 2. Padlet (left) and Miro (right) mural.

2.2 Collaborative group experiences

In these CGE, teachers encourage collaborative projects in groups during classes and outside of classes, with the help of mathematical technologies such as GeoGebra and MATLAB. Students are encouraged to solve a given experience, made up of a set of tasks defined in a script, in groups using mathematical tools. The objective of the experience is for the student to be able to apply the syllabus contents in a motivating way. In Fig. 3 an experiment for the student to calculate the volume of liquid inside a container may be observed. The students must photograph their object, upload the photography to GeoGebra, and model the three-dimensional object and the liquid it contains, being able to control the amount of liquid inside the container. Then they must calculate the volume of the liquid when the container is full. In this experience, the syllabus contents covered are the construction of interpolating polynomials and the calculation of areas, curve lengths, and volumes using integrals. To captivate the student, objects can be introduced into reality through GeoGebra's augmented reality.

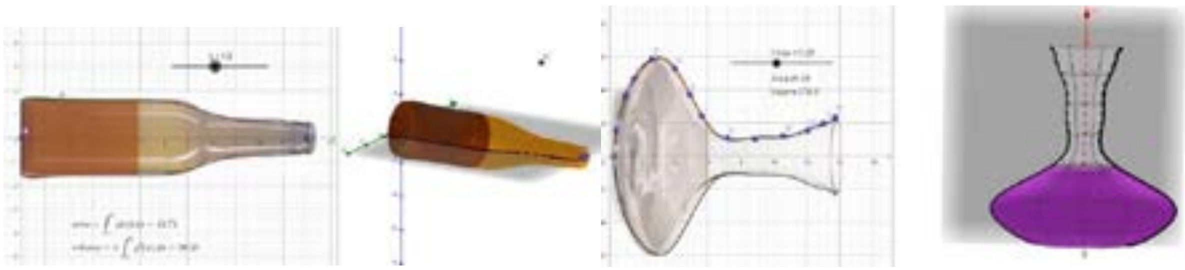

Fig. 3. Volume of liquid inside a container (bottle and decanter).

A second experience, also using GeoGebra, consisted of the story lived by each group of students entitled “An adventure on treasure island” (Fig. 4. left). Each group of pirates find the treasure island and intend to divide the area of this island between each other to search for the treasure. They must fortify the island with a net along its entire length to defend themselves from the other pirates that attack the island. To build this fortification it is necessary to take materials from the mainland into the island through a secret underwater tunnel. The entire story reflects the contents curriculum of Calculus I. Students, following the script, apply their knowledge and obtain solutions to the tasks proposed.

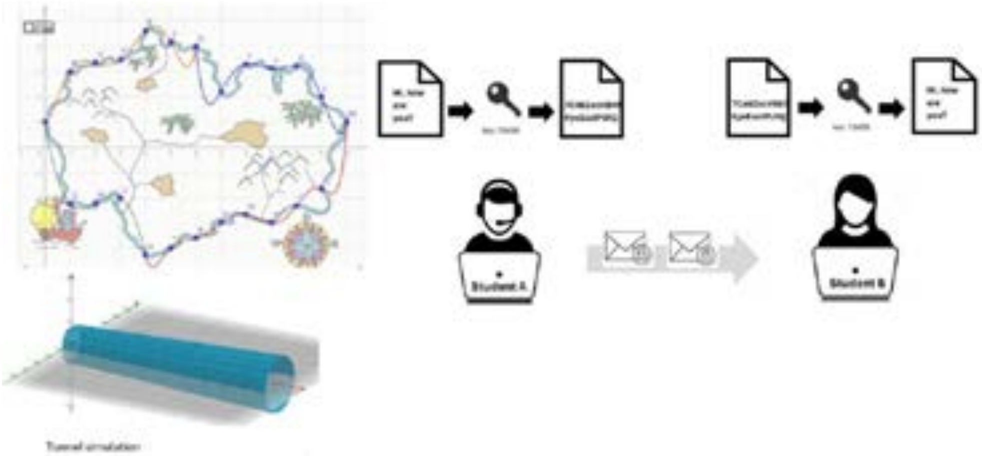

Fig. 4. An adventure on treasure island (left): island map and tunnel simulation; encode and decode messages (right)

Another experiment, using MATLAB, consists of encoding and decoding secret codes, using matrix calculation (Fig. 4 right). The students are led to become secret agents and to encode or decode messages between themselves and the teacher. In the end, after everyone discovers the messages, they play "secret group" and put a message in code for another group to decode and associate a group with that message. In this experience, the syllabus covered is specific to a theme.

2.3 Collaborative team and group experiences

Conjugating both CTE and CGE we proposed a challenge to our students that we believed would foster their holistic development, observe Fig. 5.

Fig. 5 Service Learning to a local NPO

Integrating Service Learning into curricular units has emerged as a powerful tool and this is particularly pertinent in the case of Statistical Methods, where the fusion of academic rigour with community engagement can yield profound benefits for both students and society. By its nature, the subject demands analytical thinking, problem-solving skills, and a deep understanding of data interpretation – all of which are invaluable in addressing real-world challenges. Through Service Learning, students not only acquire theoretical knowledge but also apply it in practical settings, thereby bridging the gap between classroom learning and real-life scenarios. Central to this approach is the formation of cohesive teams within the classroom. Through strategic division of tasks, students learn the importance of collaboration and effective communication. As they work together towards a common goal, they develop a deeper appreciation for the diverse skill sets each team member brings to the table. Moreover, the collaborative environment nurtures a sense of community and shared responsibility, essential qualities for success in both academic and professional paths. Students were challenged to serve a local Non-Profit-Organization (NPO) by building the necessary questionnaires, collecting, and analysing data, elaborating reports, and presenting them to the NPO's President. By engaging in projects that directly serve the needs of local organizations or underserved populations, students gain firsthand experience in using their mathematical knowledge for the benefit of others. Whether it's conducting surveys to assess community needs or analysing data to inform policy decisions, students witness the tangible effects of their work, instilling a sense of purpose and civic responsibility. The integration of service learning into any curriculum represents a symbiotic relationship—one where academic learning enriches community service, and vice versa. As students engage with real-world problems, they not only deepen their understanding of mathematical concepts but also become active agents of positive change. By nurturing a culture of students-teacher-society involvement, we not only enrich educational experiences but also cultivate a generation of empowered individuals committed to serving the greater good.

3 INTERVENTION AND OBSERVED PARAMETERS

The experiments were carried out either in classroom or outside and could be accessed or completed outside the classroom. Some of the experiments were carried out over 1 week (4 hours) and others over the semester. Classes were taught in mathematics laboratories, with computers, internet, and the necessary technologies. The teacher, as an observer, made the necessary notes on the students' participation, both individually and collectively. His role consisted of guiding students, when necessary, and observing the behaviour of the class, the functioning of the groups and the elements within the group. The activities involved in the CTE were saved on the collaborative platforms, while the activities involved CGE were saved in the reports and submitted in the Moodle or by e-mail. Assessment is done individually, and the exercises or reports were analysed by the teachers and feedback was given to each student. At the end of the experiments, satisfaction questionnaires were given to all students, to collect student feedback on the experiments they had just carried out.

4 RESULTS

4.1 Student performance

When analysing the grades obtained both in the assessment exercises and the scripts submitted, it was found that the quality was quite good, the number of positive grades was higher than in previous years, and most students acquired the mathematical skills that were intended. In the CTE, some students dropped out throughout the semester, as continuous study and constant participation on the part of the students were required. In CGE, this aspect was not visible, because in this case, the requirement was made for just one week.

4.2 Students' ability to use technology

Students currently have higher technological skills and digital proficiency. The major difficulties experienced in carrying out the experiments were: understanding the requested, having knowledge of the content involved, and the use of some mathematical software. Therefore, at first, some students felt lost and did not know what they should do. After the first contact and the ever-present help of the teacher, these difficulties disappeared, and the students felt capable and enthusiastic about their own knowledge and how they were able to apply it in solving the tasks asked.

4.3 Direct observation of teachers

At the beginning of each experience, the teacher supports all groups/teams and students, either guiding them because they sometimes feel lost, helping them because they cannot identify the content they should apply, or encouraging them because they show little willpower. But then, the classroom environment changes completely, students become autonomous in solving tasks, complement each other in groups, and know what they should do and what content to apply. They want to be the first to achieve success and to obtain the best classification.

4.4 Student opinion

To obtain the students' opinions about the experiments carried out, a questionnaire was given. Table 1 presents the Yes/No answers (in percentage) obtained in the questionnaire of one of the CGE. In the Fig. 6 the students' answers to another experience with CTE may be observed.

Table 1. Example of the answers obtained in the questionnaire from one of the CGE.

Questions	**“Yes”**	**“No”**
Was my contribution valuable to the group during the experience?	100%	0%
Am I confident in what I've learned about syllabus?	100%	0%
Did I enjoy carrying out this innovative experience?	100%	0%
Did I enjoy carrying out the experience on Padlet?	100%	0%
Can this experience contribute to the development of academic and professional skills?	94%	6%
Do I like innovative learning experiences in the classroom?	100%	0%
Do I consider that the teacher’s guidance was important in overcoming doubts when carrying out the experience?	100%	0%

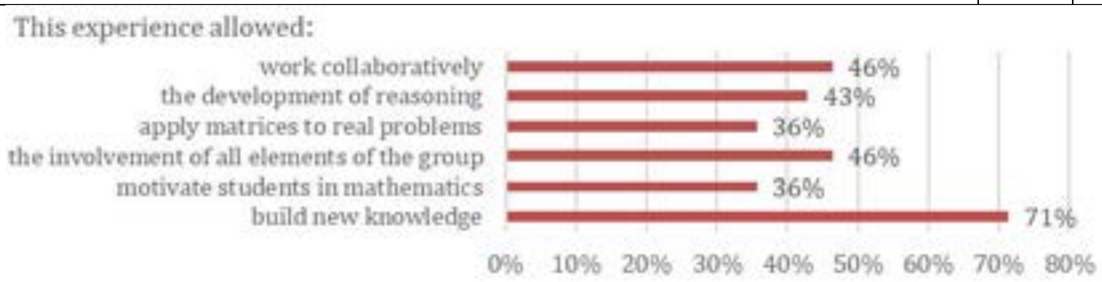

Fig. 6. Student answers in a CTE.

5 CONCLUSIONS

As Pereira and Silva (2018) state, teachers are increasingly encouraged to teach more attractive, dynamic, and contemporary classes. The diversity of experiences and strategies applied allow classes that motivate students in their learning, and thus promote student success. In this sense, it is necessary that the teacher developed experiences, with previously defined objectives and strategies that allow students to build their knowledge, based on real situations experienced by the group. Teachers who use groups and teams in the classroom should continue to use these qualitative research methods to explore the impact of the syllabus on student perceptions, as well as obtain student feedback on the group/team experience. This way, teachers better understand students' needs and can incorporate this information into developing new collaborative experiences. Furthermore, should be incorporated, group and team experiences into teaching (Barr et al. 2005, Astin and Astin 2000) because it plays an important role in developing the leadership skills needed and desired by employers and today's society. The experiences shared here are quite diverse, in relation to the courses, curricular units, syllabus, and teachers. They were very enriching for teachers as educational professionals because they allowed a reflection on the difficulties experienced by students in learning mathematics and encouraged the teachers to question themselves about the experiences they should provide to students, to support them in their learning. The results show that the experiences involved students in the construction of their learning, making it possible to solve problems and communicate the respective resolution both in groups and as a team. They also suggest a successful use of these experiences in the construction of mathematical knowledge, being a strategy to consider improving students' motivation for mathematics and enabling the development of the expected skills, which can contribute to improving the success on the curricular units.

REFERENCES

Astin, A.W., and Astin, H.S. Leadership reconsidered: Engaging higher education in social change. Battle Creek, MI: W. K. Kellogg Foundation (2000).

Barr, T.F., Dixon, A.L., and Gassenheimer, J.B. “Exploring the “lone wolf” phenomenon in student teams.” *Journal of Marketing Education*, 27(1) (2005), 81-90.

Boud, David, and Margaret Bearman. "The assessment challenge of social and collaborative learning in higher education." Educational Philosophy and Theory 56.5 (2024): 459-468.

Coers, N., Lorensen, M., and Anderson, J.C. “Case study: Student perceptions of groups & teams in leadership education.” Journal of Leadership Education, 8(1) (2009), 93-110.

Darmayanti, R. (2023). ”Lecturer vs. Practitioner: How is collaborative class assessment for math learning?” Delta-Phi: Jurnal Pendidikan Matematika, 1(1) (2023), 58-64.

Du, Xu, et al. "A multimodal analysis of college students’ collaborative problem solving in virtual experimentation activities: a perspective of cognitive load."Journal of Computing in Higher Education, 35(2) (2023), 272-295.

Gumiero, B. S., and V. Pazuch. "Digital technologies and mathematics teaching: An analysis of teacher professional knowledge."Pedagogical Research, 9(2) (2024).

Isohätälä, Jaana, Piia Näykki, and Sanna Järvelä. "Cognitive and socio-emotional interaction in collaborative learning: Exploring fluctuations in students' participation." Scandinavian Journal of Educational Research 64.6 (2020): 831-851.

Lailiyah, M., Setiyaningsih, L. A., Wediyantoro, P. L., and Yustisia, K. K. "Assessing an effective collaboration in higher education: A study of students' experiences and challenges on group collaboration.", EnJourMe (English Journal of Merdeka): Culture, Language, and Teaching of English, 6(2) (2021), 152-162.

Lewis, Anna Lena, Lilian Julia Trechsel, and Anne Barbara Zimmermann. "Monitoring the integration of Sustainable Development into higher education teaching: a collaborative learning approach." Nachhaltige Lehre-Nachhaltige Bildungsinstitution Hochschule 4 (2024): 61.

Millis, B. (Ed.). Cooperative learning in higher education: Across the disciplines, across the academy. Taylor & Francis. 2023.

Muhammad, I., and Angraini, L.M. "Research On Students' Mathematical Ability In Learning Mathematics In The Last Decade: A Bibliometric Review." JOHME: Journal of Holistic Mathematics Education, 7(1) (2023), 108-122.

Nungu, Leonard, Evode Mukama, and Ezechiel Nsabayezu. "Online collaborative learning and cognitive presence in mathematics and science education. Case study of university of Rwanda, college of education." Education and Information Technologies 28.9 (2023): 10865-10884.

Paulus, P.B., Larey, T.S., and Dzindolet, M.T. (2014). Creativity in groups and teams. In Groups at work. Psychology Press. 333-352

Pereira, Z.T.G., and Silva, D.Q. (2018). "Metodologia Ativa: Sala de Aula Invertida e suas Práticas na Educação Básica. "Revista Iberoamericana sobre Calidad, Eficacia y Cambio en Educación - REICE,16(4), 63-78.

Supriyadi, E., and Kuncoro K.S. "Exploring the future of mathematics teaching: Insight with ChatGPT." Union: Jurnal Limia Pendidikan Matematika 11(2) (2023), 305-316.

Wang, G., Du, H. and Liu, Y. " Case study on improving high school students with learning difficulties in mathematics. "Journal of mathematics Education, 2 (2) (2023), 122-123.

Warsah, Idi, et al. "The impact of collaborative learning on learners' critical thinking skills." International Journal of Instruction 14.2 (2021): 443-460.

Wullschleger, A., Vörös, A., Rechsteiner, B., Rickenbacher, A., and Merki, K.M. "Improving teaching, teamwork, and school organization: Collaboration networks in school teams." Teaching and Teacher Education, volume 121 (2023), 103909.

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Informing the Design of 10-Minute Videos for Vector Calculus Instruction: A Rapid Review

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Keywords: *Vector calculus, instructional design, 10-minute video, constructivism, cognitive load theory*

ABSTRACT

This rapid literature review explores the design and use of instructional videos for teaching vector calculus in engineering education. Drawing on constructivism, cognitive load theory, and multimedia learning theory, the review identifies key design principles and effective strategies for developing 10-minute videos tailored to the needs of engineering students. The review highlights the importance of clear explanations, visual aids, and interactive elements in enhancing student learning and engagement. The findings suggest that well-designed instructional videos hold the potential to improve student understanding and performance in vector calculus. The implications of this research are significant for educators and instructional designers seeking to enhance student learning outcomes in engineering education.

1 INTRODUCTION

1.1 Vector Calculus

Vector calculus plays a pivotal role in engineering education, serving as a foundational element to further studies in various engineering disciplines. However,

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mastering vector calculus concepts can be challenging for students, often leading to a diminished understanding of fundamental principles, high failure rates, and even dropout. To address these challenges, educators have explored various instructional interventions, including the use of short videos, to enhance student comprehension of complex concepts in vector calculus. This project aims to develop more effective 10-minute instructional videos to cover key concepts, address misconceptions, and provide hints for mastering the course material.

Reporting on the first phase, this paper draws on theories like constructivism and cognitive load theory and a rapid review of literature from the past 10 years to present a framework to guide the design and use of videos to enhance student learning outcomes and engagement in vector calculus.

1.2 Educational Theories

Constructivism, cognitive load theory, and multimedia learning theory are not only foundational to this research but also directly applicable to the design and implementation of instructional videos for vector calculus instruction in engineering education. Constructivism's emphasis on active learning (Christie and de Graaff 2015) aligns with the goal of creating videos that engage students and encourage them to construct their understanding of vector calculus concepts. By presenting information in a way that prompts students to actively think and problem-solve, videos can facilitate deeper learning and comprehension.

Cognitive load theory (Sweller 1988; Sweller 2020) provides valuable ideas on how teaching design can be optimized to reduce cognitive load and improve learning. By designing videos to reduce the extraneous cognitive load, such as by presenting information clearly and avoiding unnecessary complexity, students can more effectively process and retain material.

Multimedia learning theory (Mayer, 1997) emphasises using multiple channels, such as auditory and visual. By incorporating animations, diagrams, and other visual aids, videos can cater to different learning styles and enhance students' understanding of abstract concepts in vector calculus. For instructional videos, Mayer et al. (2020) advise drawing graphics on the board while lecturing, shifting eye gaze between the audience and the board while lecturing, prompting to engage in summarizing or explaining the material, filming from a first-person perspective, and adding subtitles to a narrated video that contains speech in the learner's second language. They warn that people do not learn better from a multimedia lesson when interesting but extraneous video is added.

2 METHODOLOGY

2.1 Introduction

This paper reports on the first of three phases in a research project.

- Phase 1: Rapid literature review to provide an overview of existing literature on the design and use of 10-minute videos for vector calculus instruction.
- Phase 2: Develop pilot videos to cover various concepts in vector calculus, using the best practices extracted from the literature review.

- Phase 3: Iteratively develop videos based on analysis of student feedback and student performance in vector calculus following video use.

A rapid rather than systematic literature review was chosen as our aim was to develop a narrative summary of studies on instructional videos relevant to learning vector calculus. As a team of two researchers with assistance from a librarian, we felt our aims would be reached with a rapid review limited of peer-reviewed studies published from 2020. Our review followed the steps for conducting rapid reviews of educational research by Cirkony et al. (2022).

2.2 Research Question

The research question addressed in the rapid literature review is:

> *How can insights gained from literature since 2020 inform the design and use of concise 10-minute videos to improve engineering students' understanding and performance in vector calculus?*

2.3 Data Collection and Analysis

Prior to undertaking the review, the following protocol was drafted.

1. Inclusion Criteria: Peer-reviewed articles, conference papers, theses and reports published since 2020, relevant to instructional videos for vector calculus in engineering education. Results were not limited by language.
2. Exclusion Criteria: Non-peer-reviewed sources (to prioritise high-quality studies), articles not related to instructional videos suitable for vector calculus, and studies published before 2020.
3. Search Strategy: Use education-related databases: EbscoHost (40 databases), Engineering Village (2 databases), Scopus and Web of Science. Use the search string verified by a librarian: (“instructional videos” OR “video production” OR “making videos” OR “made videos”) AND (“mathematical sciences” OR “mathematics” OR “math”) AND undergrad* AND (“higher education” OR university OR college).
4. Screening Process: Screen titles and abstracts independently with ‘blind on’ on the app Rayyan (Ouzzani et al. 2016) to identify articles as included maybe and excluded. Both authors negotiate to reach consensus on included and excluded studies based on abstracts and titles, and full texts if necessary.
5. Data Extraction: Both authors tabulate key findings from each individual text to identify students’ preferences, and advice on video design and production.
6. Analysis: Led by the first author and verified by the second author. Summarise themes from all studies into a framework for video design and use based on the synthesized literature.

Bias was limited by using independent, blind reviewing by both authors of all results before meeting to reach consensus reaching on conflicts to decide on included results.

2.4 Further probing

Following reviewer suggestions, we were curious to see if more novel findings emerged if we changed the search. We broadened the search terms from a focus on mathematics to include STEM disciplines as they are likely to be similar needs in terms of reliance on definitions, examples with calculations, and they are often based on hierarchical knowledge systems. Addressing the fact that video production methods have advanced due to the rapid change in technology over the past decade, we narrowed the time span to focus on the years from 2020 to 2024. Guided by these two adjustments, we embarked on an additional search to augment the findings of our initial search.

3 RESULTS

3.1 Overview of Literature

The rapid literature review revealed several key findings regarding the design and use of videos for vector calculus instruction. Studies consistently reported that well-designed videos can improve student understanding and performance in vector calculus. Effective videos were found to incorporate clear explanations, visual aids, and interactive elements. Additionally, the review identified a need for videos to address common misconceptions and provide practice exercises to enhance student learning. Overall, the findings of the literature review support the use of tutorial videos as a valuable instructional tool in engineering education.

The additional search revealed more results than anticipated. We continued our focus of looking for guidelines to produce effective videos. However, instead we found many studies about the impact of using videos for learning in STEM and extracted video production advice based on positive experiences and perceptions of different uses of videos.

3.2 Emerging Themes

To create an effective mapping between the theoretical frameworks (constructivism, cognitive load theory, and multimedia learning theory) and the design suggestions from Seethaler et al. (2020) and other authors, we align each design suggestion with the principles of the respective theories.

Seethaler et al.'s three-part framework considers (1) context and sequencing, (2) cognitive supports, and (3) affective considerations, and serves as the primary design source due to its comprehensive and well-established nature. However, to enhance and expand upon this framework, additional categories and suggestions from other authors are incorporated. These additions are justified by their relevance and ability to provide a more nuanced understanding of effective instructional video design for vector calculus. By integrating these supplementary categories, the review aims to offer a more thorough set of guidelines for designing instructional videos, enriching Seethaler's framework with insights from a broader range of scholarly work.

CONTENT AND SEQUENCING

***Concepts*:**

- *Constructivism*: Seethaler et al. (2020) aligns with the idea that learning is an active process where learners construct their understanding. Clarifying concepts and linking them to prior knowledge supports this process. De Lima and da Cunha (2023) suggested that student-produced videos promote collaborative education. Fotiyeva and Shockley (2015) uses videos to address problems and concepts that typically cannot be resolved independently by students. Weinberg et al. (2022) asserts that pre-knowledge was needed for student engagement in video tasks.

- *Cognitive Load Theory*: Seethaler et al. (2020) ensures that concepts are presented in a way that minimizes cognitive load, allowing learners to process information more effectively.
- *Multimedia Learning Theory*: Seethaler et al. (2020) supports the use of visuals and animations to enhance understanding of abstract concepts. Barry et al. (2019) found that short videos (5-7 min) were preferred by students, while Rodemer et al. (2021, 2022) highlighted the importance of aligning audio with video to aid understanding. Johnston (2017) emphasized the convenience and flexibility of video learning.

Logic:

- *Constructivism*: Seethaler et al. (2020) emphasizes the importance of logical progression in learning where each concept builds on previous ones, while Johnston (2017) mentioned the mix of learning modes which caters for diverse learning styles and provides varied opportunities for learners to construct their understanding.
- *Cognitive Load Theory*: Seethaler et al. (2020) suggest logical sequencing reduces extraneous cognitive load, making it easier for learners to follow and understand the content. Rodemer et al. (2021, 2022) emphasised the use of signalling to guide learners through the content logically.
- *Multimedia Learning Theory:* Barry et al. (2019) found that short videos save time.

Story:

- *Constructivism*: Seethaler et al. (2020) supports the use of narratives or stories to engage learners and provide context for learning, making the content more meaningful while Barry et al. (2019) found that watching videos at one's own pace was beneficial. De Lima and da Cunha (2023) suggested creating "learning scenarios" to encourage questioning and communication.
- *Multimedia learning theory*: Seethaler et al. (2020) says that the relevance and motivation is enhanced by presenting content in a narrative format.

L*anguage*:

- *Constructivism*: Seethaler et al. (2020) encourages the use of language that is accessible and meaningful to learners, aligning with the idea of building on prior knowledge.
- *Cognitive Load Theory*: Seethaler et al. (2020) emphasises the importance of clear and concise language to reduce cognitive load. Rodemer et al. (2021, 2022) confirm the importance of clear, concise language.
- *Multimedia Learning Theory*: Johnston (2017) mentioned that videos offer better quality than lecture capture. Chand and Deshmukh (2019) say there is

a shortage of local language videos suggesting students make translation videos as part of community service.

COGNITIVE SUPPORTS

***Visualisations*:**

- *Constructivism:* Barry et al. (2019) found that 45% of students prefer watching videos while learning maths, while Lui and Elms (2019) highlighted the use of animations and illustrations for better understanding.
- *Cognitive Load Theory*: Seethaler et al. (2020) says that well-designed visuals can reduce cognitive load by providing additional support for understanding.
- *Multimedia Learning Theory*: Seethaler et al. (2020) advocates for the use of visuals to complement verbal information, as they can enhance learning and aid in understanding complex concepts. Abbasian and Sieben (2016) advise that a PC with pen-tablet and Camtasia video editor produce better quality videos than a tablet and Doceri software. However, they add that an instructor's time may be better spent making a viewing list of high-quality existing videos.

***Signals*:**

- *Constructivism*: Rodemer et al. (2021, 2022) emphasised the use of highlighting and other visual cues to aid understanding.
- *Multimedia Learning Theory*: Seethaler et al. (2020) supports the use of cues and signals to guide learners' attention and help them navigate the content. Rodemer et al. (2021, 2022) emphasized the use of signalling to guide learners through the content logically.
- *Cognitive Load Theory*: Seethaler et al. (2020) say effective use of signals can reduce extraneous cognitive load by directing learners' focus to relevant information.

***Synchronization*:**

- *Constructivism*: Chand and Deshmukh (2019) list the most common reasons for low-quality videos: inappropriateness for the target audience, problems in comprehensibility, inadequate use of visuals and technical glitches.
- *Multimedia Learning Theory*: Seethaler et al. (2020) emphasises the importance of synchronizing visuals and narration to enhance learning and reduce cognitive load. Johnston (2017) mentioned the synchronization of learning modes, and Barry et al. (2019) highlighted the convenience of watching videos at any time and place.

***Segmentation*:**

- *Cognitive Load Theory, Constructivism*: Seethaler et al. (2020) supports the idea of breaking down complex information into smaller segments to reduce cognitive load and aid in understanding.
- *Multimedia Learning Theory, Constructivism*: Barry et al. (2019) found that short videos are preferred, while Rodemer et al. (2021, 2022) suggested segmenting content to aid in information processing. Henley (2015) maintains

the use of visual aids and examples in videos made it easier to grasp concepts, adding that If videos are too long, students lose focus and get bored. Henley's (2015) advice includes: keep the time to watch video comparable to the time to read the same content; minimize extraneous words and images, highlight key pieces of information, have text captioning as closed captioning so that it can be turned off, have words and images presented at the same time and near each other on the screen, have the videos broken up into smaller pieces, summarize what will be covered in the video, have the text presented in a conversational style, and have the audio done in a human voice.

***Streamlining*:**

- *Cognitive Load Theory*: Seethaler et al. (2020) advocates for presenting information in a streamlined manner to avoid overloading learners with unnecessary distractions or conflicting information.

AFFECTIVE CONSIDERATIONS

***Relevance*:**

- *Constructivism*: Seethaler et al. (2020) Emphasises the importance of relevance and meaningfulness in learning. Making the content relevant to learners' experiences and interests can enhance engagement and learning outcomes.
- *Multimedia Learning Theory*: Johnston (2017) mentioned that videos offer a mix of learning modes, and de Lima and da Cunha (2023) suggest creating "learning scenarios" to enhance relevance. Chand and Deshmukh (2019) say that the most common reasons for low-quality videos are: inappropriateness for the target audience, problems in comprehensibility, inadequate use of visuals and technical glitches.

***Rapport*:**

- *Constructivism*: Seethaler et al. (2020) support the idea of creating a supportive and respectful learning environment. Depicting characters or interactions that model respectful and helpful behaviour can enhance the learning experience.

  Multimedia Learning Theory, Constructivism: De Lima and da Cunha (2023) suggested creating "learning scenarios" to empower students, while Barry et al. (2019) highlighted the convenience of watching videos at any time and place. Weinberg et al. (2022) reported that videos were designed to take the place of class discussions where actors portrayed calculus students attempting to solve problems and demonstrated various ways of thinking- this was scripted.

***Accessibility*:**

- *Multimedia Learning Theory*: Seethaler et al. (2020) advocates for designing materials that are accessible to all learners, including those with disabilities. Following universal design principles ensures that the content is accessible to a wide range of learners.

- *Multimedia Learning Theory, Constructivism*: Barry et al. (2019) emphasized the convenience and flexibility of video learning, while Lui and Elms (2019) highlighted the use of animations and illustrations for better understanding. Chen and Ho (2021) say that for low cognitive load videos, students used captions more than if the load was high. Captions were used less for videos with high cognitive load. Chen and Ho (2021) add that when content is more difficult, use graphics rather than captions.

By mapping each design suggestion to the relevant theoretical framework, we can demonstrate how the instructional design principles align with established theories of learning, enhancing the credibility and effectiveness of our framework.

These themes collectively illustrate the importance of designing video learning materials that are engaging, accessible, and cognitively supportive to optimise learning outcomes for diverse learners. These themes were extracted from the thematic analysis of the literature on design and implementation of video-based learning materials:

1) **Design Features:** Highlight the importance of video quality, synchronisation of visuals and narration, and segmentation of content to aid in information processing and reduce cognitive load.
    a) ***Video Quality*:** Ensure that videos are clear, well-produced, and visually engaging to maintain student attention and facilitate understanding of complex vector calculus concepts.
    b) ***Synchronization of Visuals and Narration*:** Align visual representations of vector operations, diagrams, and graphs with verbal explanations to enhance comprehension and reinforce learning.
    c) ***Segmentation of Content*:** Break down vector calculus topics into smaller, manageable segments, allowing students to digest information more easily and reducing cognitive load.
2) **Affective Considerations:** Stress the relevance and meaningfulness of content to enhance engagement and learning outcomes. Emphasise the importance of creating a supportive and respectful learning environment.
    a) **Relevance and Meaningfulness:** Demonstrate the practical applications of vector calculus in engineering, physics, and other fields to illustrate the real-world significance of the concepts being taught.
    b) **Supportive Learning Environment:** Foster a positive and encouraging atmosphere in which students feel comfortable asking questions, making mistakes, and actively participating in their learning process.
3) ***Student Involvement*:** Involving students in the creation of videos, such as through student-produced videos or translation projects, can promote collaborative education and enhance learning experiences.
    a) ***Creation of Videos*:** Encourage students to create their own instructional videos explaining vector calculus concepts. This promotes deeper understanding through the process of teaching others and allows for a variety of perspectives and approaches to be shared.
4) **Accessibility:** Focus on designing materials that are accessible to all learners, including those with disabilities, and following universal design principles to ensure inclusivity.

a) ***Universal Design*:** Design videos with accessibility features such as closed captioning, transcripts, and audio descriptions to ensure that all students, including those with disabilities, can access and benefit from the instructional content.

By incorporating these principles into your teaching of vector calculus, you can create a more engaging, inclusive, and effective learning experience for your students.

4 RESULTS OF THE FURTHER PROBING

Our extended search revealed several novel ideas that can significantly enhance the effectiveness of instructional videos for teaching Vector Calculus. One key insight is the active involvement of students in the video-making process. Research shows that when students create their own videos, their motivation and participation increase, leading to a deeper understanding of the subject matter (Vasilehenko, 2020). This active engagement allows students to take ownership of their learning, making the process more meaningful and reinforcing their comprehension through teaching others. Additionally, multilevel collaboration between undergraduate and postgraduate students during video production fosters diverse insights, which helps clarify concepts and ensure the reliability of the content (Peres & Hoffman, 2020; Box et al., 2024). Such collaborations not only enhance the quality of the educational material but also provide mentorship opportunities, enriching the learning experience for both groups.

Other research highlights the benefits of videos created by former students, which help embrace a sense of lost community and provide a fresh perspective that resonates with new students (Kong et al., 2022). This approach not only fosters a sense of belonging but also offers relatable content that enhances the learning experience. Videos made by peers or recent graduates can bridge the gap between instructors and students, making complex topics more accessible and understandable.

Moreover, incorporating these videos into collaborative platforms facilitates discussion, creates a feedback loop, and promotes collaborative learning with peers (Mutch-Jones et al., 2021; Adhami & Taghizadeh, 2024). Collaborative platforms such as discussion boards or group chats integrated with video content enable students to engage in meaningful dialogue, ask questions, and receive timely feedback, thereby deepening their understanding. Embedding interactive questions within the videos keeps students actively engaged and allows them to assess their comprehension in real-time (Petillion & McNeil, 2020). Tailoring the content to the learner's level and addressing specific needs further enhances engagement and understanding (Barnes et al., 2023; Larson et al., 2021; Rai et al., 2020; Yi et al., 2024).

Reflective activities, such as questions and prompts throughout the video, encourage students to think deeply about the concepts taught (Lasheen et al., 2024). These activities promote metacognitive skills, helping students to become more aware of their own learning processes and to develop critical thinking skills. Using real-world scenarios to show how vector calculus is applied in various fields can make the material more relatable and engaging. This contextualization not only enhances interest but also demonstrates the practical value of the subject matter, thereby motivating students to learn.

Finally, including mechanisms for feedback and evaluation within the videos ensures continuous improvement and relevance of the instructional content. Regular feedback from students allows instructors to refine their videos, address any misconceptions, and ensure that the content remains up-to-date and effective (Clark & Mayer, 2016). This iterative process of evaluation and improvement helps maintain high-quality educational resources that meet the evolving needs of students.

By incorporating these strategies, instructional videos for vector calculus can become powerful tools that not only convey information but also engage students, foster collaboration, and enhance learning outcomes.

5 SUMMARY

The review findings, guided by constructivism, cognitive load theory, and multimedia learning theory, offer insights into designing effective videos for teaching vector calculus. Educators can use these principles to create engaging videos that improve student learning outcomes in engineering education. It sets the stage for developing pilot videos in the next research phase.

REFERENCES

Note: Included citations from the rapid review are indicated with a star and numbered 1 to 28.

Abbasian, R. O., and J. T. Sieben. "Creating Math Videos: Comparing Platforms and Software". *PRIMUS* 26, no. 2 (7 February 2016): 168–77. https://doi.org/10.1080/10511970.2015.1047916.

Adhami, N. and Taghizadeh, M. (2022) "Integrating inquiry-based learning and computer supported collaborative learning into flipped classroom: Effects on academic writing performance and perceptions of students of railway engineering", *Computer Assisted Language Learning*, 37(3), pp. 521–557. doi:10.1080/09588221.2022.2046107.

Barnes, A.F., McCoy, A.P. and Warnick, Q. (2023) "Developing supplemental instructional videos for Construction Management Education", *Buildings*, 13(10), p. 2466. doi:10.3390/buildings13102466.

Barry, A. L., A. S. Gay, M. L. Pelkey, K. Rothrock, and M. Mnayer. "Students Tell Us the Best Way to Learn Mathematics in High School". *Issues in the Undergraduate Mathematics Preparation of School Teachers* 2, no. July 2019 (n.d.): 1–13. https://files.eric.ed.gov/fulltext/EJ1223005.pdf.

Box, M., Gallardo-Williams, M. and Paye, C. "Students as creators of instructional videos: Best practices and lessons learned", *Journal of College Science Teaching*, 53(1), pp. 31–36. (2024). doi:10.1080/0047231x.2023.2292406.

Chand, V. S., and K. S. Deshmukh. "Addressing the Undergraduate Internship Challenge in Developing Countries: A "Learning-by-Doing" Project-Based Online

Internship Model". *Education + Training* 61, no. 9 (3 October 2019): 064–77. https://doi.org/10.1108/ET-12-2018-0254.

Chen, Yi-Ting, and Ming-Chou Ho. "Eye Movement Patterns Differ While Watching Captioned Videos of Second Language vs. Mathematics Lessons". *Learning and Individual Differences* 93 (January 2022): 102106. https://doi.org/10.1016/j.lindif.2021.102106.

Christie, M., and E. De Graaff. "The philosophical and pedagogical underpinnings of Active Learning in Engineering Education." *European Journal of Engineering Education* 42, no. 1 (2017): 5-16.http://dx.doi.org/10.1080/03043797.2016.1254160.

Cirkony, C., M. Rickinson, L. Walsh, J. Gleeson, M. Salisbury, and B. Cutler. "Reflections on conducting rapid reviews of educational research." *Educational Research* 64, no. 4 (2022): 371-390. https://doi.org/10.1080/00131881.2022.2120514.

de Lima, L. F., and M. F. da Cunha. "For a Mathematics Education beyond Reproduction Producing Videos to Reflect on Social Issues". *Prometeica - Revista de Filosofía y Ciencias*, no. 27 (27 July 2023): 432–42. https://doi.org/10.34024/prometeica.2023.27.15328.

Fotiyeva, I., and E. T. Shockley. "Using Traditional LMS for Mathematics Instruction - Lessons Learned from Instructor-Made Videos." In *Proceedings of the 7th International Conference on Computer Supported Education*, 338–42. Lisbon, Portugal: SCITEPRESS - Science and Technology Publications, 2015. https://doi.org/10.5220/0005495603380342.

Henley, E. "Engaging College Students in Online Remedial Mathematics Courses with Video Instruction". Doctoral thesis, Walden University, 2015. http://ezproxy.uct.ac.za/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2016-99010-511&site=ehost-live.

Johnston, B. M. "Implementing a Flipped Classroom Approach in a University Numerical Methods Mathematics Course". *International Journal of Mathematical Education in Science and Technology* 48, no. 4 (19 May 2017): 485–98. https://doi.org/10.1080/0020739X.2016.1259516.

Kay, R., and R. Ruttenberg-Rozen. "Exploring the Creation of Instructional Videos to Improve the Quality of Mathematical Explanations for Pre-Service Teachers". *International Journal of E-Learning & Distance Education* 35, no. 1 (2020): 1–22. https://files.eric.ed.gov/fulltext/EJ1278499.pdf.

Kumta, S., Kong, S. and Vardar Ulu, D. *Made for students, by students: Integrating former-student-directed videos into a de-densified biochemistry laboratory* [Preprint]. (2021). doi:10.1021/scimeetings.1c00310.

Larson, B., A Bohler, J. and Krishnamoorthy, A. "Innovative pedagogical strategies of streaming, just-in-time teaching, and scaffolding: A case study of using videos to add business analytics instruction across a Curriculum", *Journal of Information Technology Education: Innovations in Practice*, 20, pp. 001–019. (2021). doi:10.28945/4694.

Lasheen, N.N., Fawzy, M.M. and Ibrahim, M.B. “The use of instructional videos to compensate for flexible physiology learning during the pandemic of COVID 19”, *BMC Medical Education*, 24(1). doi:10.1186/s12909-023-04924-8.

Liu, C., and P. Elms. “Animating Student Engagement: The Impacts of Cartoon Instructional Videos on Learning Experience”. *Research in Learning Technology* 27 (1 April 2019): 2124. https://doi.org/10.25304/rlt.v27.2124.

Mayer, R. E., L. Fiorella, and A. Stull. "Five Ways to Increase the Effectiveness of Instructional Video." *Educational Technology Research and Development* 68, no. 3 (2020): 837-852. https://doi.org/10.1007/s11423-020-09749-6.

Mayer, R. E. "Multimedia learning: Are we asking the right questions?" *Educational Psychologist* 32, no. 1 (1997): 1-19. https://doi.org/10.1207/s15326985ep3201_1.

Mshayisa, V. V., and M. Basitere. “Flipped Laboratory Classes: Student Performance and Perceptions in Undergraduate Food Science and Technology”. *Journal of Food Science Education* 20, no. 4 (October 2021): 208–20. https://doi.org/10.1111/1541-4329.12235.

Mutch-Jones, K. *et al.* (2020) “Professional science education videos improve *Biochemistry and Molecular Biology Education*, 49(1), pp. 151–159. (2024). doi:10.1002/bmb.21415.

Ouzzani, M., H. Hammady, Z. Fedorowicz, and A. Elmagarmid. "Rayyan—a web and mobile app for systematic reviews." *Systematic Reviews* 5 (2016): 1-10. https://doi.org/10.1186/s13643-016-0384-4.

Peres, M.V. *et al.* “Articulated video production between teachers and training teachers as a proposal for the teaching of modern and contemporary physics”, *Acta Scientiae*, 22(6). (2020). doi:10.17648/acta.scientiae.6051.

Petillion, R.J. and McNeil, W.S. “Johnstone’s Triangle as a pedagogical framework for flipped-class instructional videos in introductory chemistry”, *Journal of Chemical Education*, 97(6), pp. 1536–1542. (2020). doi:10.1021/acs.jchemed.9b01105.

Rai, B. *et al.* “Engaging science and engineering students in computing education through learner-created videos and physical computing tools (2020).

Rodemer, M., J. Eckhard, N. Graulich, and S. Bernholt. “Connecting Explanations to Representations: Benefits of Highlighting Techniques in Tutorial Videos on Students’ Learning in Organic Chemistry”. *International Journal of Science Education* 43, no. 17 (22 November 2021): 2707–28. https://doi.org/10.1080/09500693.2021.1985743.

Rodemer, M., M. A. Lindner, J. Eckhard, N. Graulich, and S. Bernholt. "Dynamic Signals in Instructional Videos Support Students to Navigate through Complex Representations: An Eye-tracking Study". *Applied Cognitive Psychology* 36, no. 4 (July 2022): 852–63. https://doi.org/10.1002/acp.3973.

Salas-Rueda, R. "Analysis of Facebook in the Teaching-Learning Process about Mathematics through Data Science". *Canadian Journal of Learning and Technology* 47, no. 2 (1 January 2021): 731565622. https://cjlt.ca/index.php/cjlt/article/view/27895.

Seethaler, S., A. J. Burgasser, T. J. Bussey, J. Eggers, S. M. Lo, J. M. Rabin, L. Stevens, and H. Weizman. “A Research-Based Checklist for Development and

Critique of STEM Instructional Videos". *Journal of College Science Teaching* 50, no. 1 (September 2020): 21–27. https://doi.org/10.1080/0047231X.2020.12290671.

Sweller, J. "Cognitive Load during Problem Solving: Effects on Learning". *Cognitive Science* 12, no. 2 (April 1988): 257–85. https://doi.org/10.1207/s15516709cog1202_4.

Sweller, J. "Cognitive Load Theory and Educational Technology". *Educational Technology Research and Development* 68, no. 1 (February 2020): 1–16. https://doi.org/10.1007/s11423-019-09701-3.

Vasilchenko, A. *et al.* "Engaging science and engineering students in computing education through learner-created videos and Physical Computing Tools", *Proceedings of the 4th Conference on Computing Education Practice 2020* [Preprint]. doi:10.1145/3372356.3372372. *27 Weinberg, A., D. L. Corey, M. Tallman, S. R. Jones, and J. Martin. "Observing Intellectual Need and Its Relationship with Undergraduate Students' Learning of Calculus". *International Journal of Research in Undergraduate Mathematics Education*, 3 September 2022. https://doi.org/10.1007/s40753-022-00192-x.

Zhang, Y. *et al.* "How does drawing influence the effectiveness of oral self-explanation versus instructional explanation in video learning?", *British Journal of Educational Technology*, 55(3), pp. 1189–1208. (2023).doi:10.1111/bjet.13423.

Enhancing Professional and Engineering Skills via Practical Design Projects for First-Year Electrical and Electronic Engineering Students

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Keywords: Engineering education, Professional competencies, Practical design project, Skill development, Student perceptions

ABSTRACT

This study examines the development and utilization of professional and engineering skills among first-year Electrical and Electronic Engineering students during a practical design project. Spanning five weeks, students engage in project work and reflect on their skill utilization through weekly surveys. Key skills include Science and Mathematics (SM), Engineering Analysis (EA), Design and Innovation (DI), Widening Engineering Context (WEC), and Professional Competencies (PC). Results reveal distinct trends in skill utilization, with some skills peaking at certain stages while others demonstrate consistent usage. Towards the project's conclusion, there is a shift towards greater utilization of professional competencies, underscoring their significance. Box plots offer insights into variations in student responses within each skill category. The findings highlight the importance of integrating professional skills development within engineering curricula, offering insights for curriculum development efforts. This study contributes to the discourse on engineering education reform, emphasizing the need for a holistic approach to skill development to meet the demands of the engineering landscape.

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1 INTRODUCTION

The preparedness of engineering graduates for the job market is a crucial concern, underscored by numerous organizations and researchers who emphasize the necessity of a well-rounded skill set that extends beyond technical proficiency. In today's dynamic industrial environment, these interpersonal and professional skills are indispensable for engineers operating within a global and interdisciplinary context.

1.1 Background

The readiness of engineering graduates for the workforce has been a subject of ongoing debate, with various organizations and researchers highlighting the need for a comprehensive set of skills beyond technical knowledge (Deters et al., 2018, 2024; Munir, 2022, 2019; Al-Sharif et al., 2019). Employers increasingly seek graduates who possess not only strong technical acumen but also effective communication, teamwork, problem-solving, and leadership skills (Moir, 2018; Bennet, 2017). These "soft" or professional skills are essential for engineers working in today's global, interdisciplinary, and rapidly evolving industrial landscape (Deters et al., 2018, 2024; Munir, 2022, 2019).

Despite the growing recognition of the importance of professional skills, integrating them into engineering curricula remains a challenge. There is often resistance from faculty and students, with concerns that emphasizing soft skills may come at the expense of technical proficiency (Deters et al., 2018, 2024; Munir, 2022, 2019). However, research suggests that the integration of professional skills within engineering education can enhance graduates' employability and career success (Al-Sharif et al., 2019; Bennet, 2017).

In response to these challenges, many engineering departments have begun to explore innovative approaches to incorporate professional skills development into their programs. One such approach involves integrating soft skills training within design projects and modules, which are core components of engineering curricula (Al-Sharif et al., 2019; Bennet, 2017). By embedding professional skill development within authentic engineering tasks, students can contextualize and apply these skills in real-world scenarios, thereby enhancing their effectiveness and transferability (Al-Sharif et al., 2019; Bennet, 2017).

The Department of Electrical and Electronic Engineering at our institution undertook a comprehensive curriculum review in 2019 to address these issues. As part of this review, a decision was made to explicitly incorporate professional skills development into end-of-year design projects for first and second-year students. The rationale behind this decision was twofold: to underscore the importance of professional skills in engineering practice and to provide students with tangible examples to enhance their professional portfolios.

We are conducting a longitudinal study which aims to investigate student perceptions of their engineering and professional skills development as they progress through summer term design projects in their first and second years of the degree. By examining students' attitudes, experiences, and self-perceptions, this study seeks to gain insights into the effectiveness of integrating professional skills development within engineering education. The findings from this study can inform future curriculum development efforts and contribute to the ongoing discourse on engineering education reform.

This paper presents findings from the first-year design project conducted in May and June of 2023. Data from the second-year project will be collected in the upcoming summer term and will be included in a subsequent paper, which will feature detailed qualitative and quantitative analysis. For now, this paper focuses solely on data from the first-year project.

1.2 Comparative Analysis with Similar Educational Initiatives

To underscore the unique contributions of our practical design project, we conducted a comparative analysis with similar educational initiatives at different universities and in varying countries. This comparative approach enriches our understanding of the project's relative effectiveness and distinctiveness within the educational landscape.

For instance, a study by Smith et al. (2021) explored a similar project-based learning approach in mechanical engineering programs across several European universities. They found that while projects varied in scope and emphasis, the integration of professional skills alongside technical competencies consistently enhanced student employability and readiness for industry. Our study builds upon this foundation by focusing specifically on Electrical and Electronic Engineering, thereby providing a nuanced perspective on skill development within this discipline.

Furthermore, contrasting our findings with those of programs in Asia, such as the study by Li and Wang (2020) on innovative design projects in Chinese engineering education, reveals cultural and contextual differences in skill acquisition and project outcomes. Despite these variations, the overarching importance of integrating professional skills development remains a common thread across diverse educational contexts.

This comparative analysis not only validates the efficacy of our approach but also highlights its adaptability and potential for broader application within global engineering education frameworks.

1.3 Engineering and Professional Skills

The definitions of engineering and professional skills utilized in this study are aligned with the criteria outlined for the accreditation of degree programs by professional bodies. While the specific competencies may vary across different engineering disciplines, there exists a common understanding regarding desired graduate outcomes and student experiences.

In the United Kingdom, the criteria that graduates must satisfy to attain registration with the relevant professional institution are delineated within the UK Standard for Professional Engineering Competence and Commitment (UK-SPEC) (Engineering Council UK, 2023). These criteria are subsequently integrated into the Accreditation of Higher Education Programs (AHEP), which provides the framework, policies, regulations, and procedures for program accreditation. This study, therefore, adheres to AHEP 3, which serves as the current benchmark for accrediting degree programs. The five key areas specified in AHEP 3 (Engineering Council UK, 2020) are outlined in Table 1 below:

Table 1: AHEP3 areas of competence

No.	Competence Area
1	Science and mathematics

2	Engineering analysis
3	Design and innovation
4	The Engineer and society
5	Engineering practice

These domains of competence and commitment serve as the foundation for the ranking and reflection undertaken by students in this paper.

1.4 First-Year Project

At the conclusion of their first year, students embark on a group project wherein they design, construct, and test a practical application over the final six weeks of the summer term. In the academic year 2022-23, the first-year project took place from May 12th to June 20th, 2023.

The challenge presented to the first-year cohort was to create a self-driving rover capable of identifying different types of aliens based on their different electrical signals along a predefined course in the shortest possible time. Students were divided into groups of six and provided with a starter kit, as well as guidance and support from faculty members.

Each rover was equipped with a remote control interface accessible via a mobile phone app or laptop interface. Additionally, to detect various electrical signals emitted from sample rocks, each rover was outfitted with three distinct sensors:

- Radio sensor
- Infrared (IR) sensor
- Magnetic sensor

These sensors enabled the rovers to identify the types of aliens based on the detected signals. Throughout the project duration, students collaborated to design and implement the functionality of their rovers, integrating sensor data processing, control algorithms, and navigation strategies to accomplish the specified task. In addition, students received support through lectures and workshops covering the topics shown in Table 2.

Table 2: Supporting Activities for First-Year Design Project

Week	Date	Workshops and Lectures
1	May 19	- Problem-solving cycle - Design process - Introduction to ethics in engineering
2	May 26	- Teamwork - Project management - Introduction to academic writing - Product Design specifications

3	June 2	- Documentation and technical communication
4	June 9	- Formative feedback for report draft
5	June 16	- Report submission and project demo

In the final stage, students engaged in a competitive demonstration against each other. Figure 1 illustrates a snapshot from the demo, depicting two rovers alongside an alien.

2 METHODOLOGY

In this section, we outline the research design and methodology employed in our study to investigate the development of professional and engineering skills among first-year Electrical and Electronic Engineering students.

2.1 Study Design

This study adopts a longitudinal approach to explore students' perceptions regarding the utilization of their engineering and professional skills throughout the first-year design project. Weekly data collection via a questionnaire was implemented to gauge students' self-reported engagement with key skills. Notably, the same cohort will participate in a similar reflection

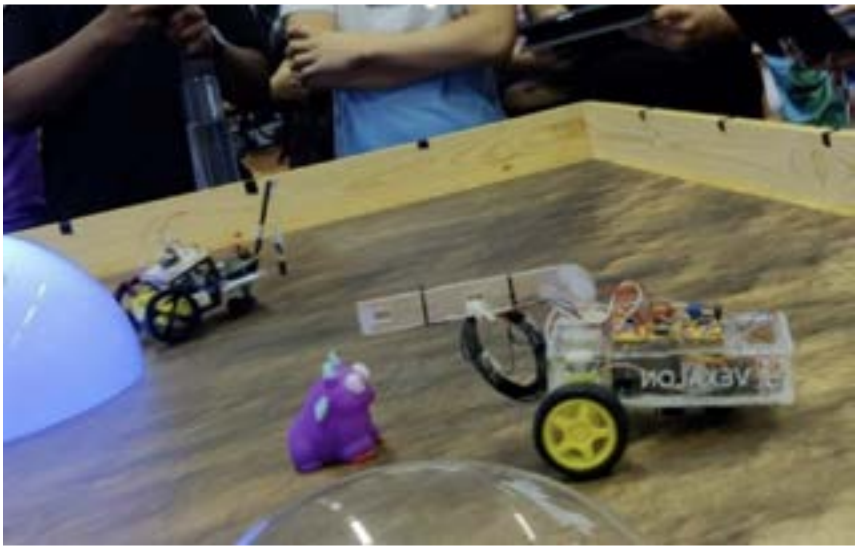


Figure 1: First year project demonstrations

exercise during their second-year project, thereby concluding the two-year longitudinal investigation. However, this paper focuses solely on presenting results from the first year.

Our longitudinal study aims to delve into students' evolving perceptions of their engineering and professional skills development across the first and second years of their degree program. By scrutinizing students' attitudes, experiences, and self-assessments, we aim to glean insights into the efficacy of integrating professional skills development within engineering education. The outcomes of this study have the potential to shape future curriculum enhancements and contribute to ongoing discussions on reforming engineering education.

2.2 Participants

Participants in this study were first-year students enrolled in the electrical and electronic engineering program during the academic year 2022-23. The cohort consisted of 180 students who were actively engaged in the design project.

2.3 Data Collection

Data were collected weekly through a questionnaire administered to participants. The questionnaire prompted students to reflect on the extent to which they utilized five key skills: Science and Mathematics (SM), Engineering Analysis (EA), Design and Innovation (DI), Widening Engineering Context (WEC), and Professional Competencies (PC). Students rated their utilization of each skill on a scale from ”Not at all (0%)” to ”Every day (100%)”. Additionally, qualitative comments were collected to capture students’ reflections on their experiences and expectations. The key skills and the rating scale are shown in Table 3. Additionally, qualitative comments were collected to capture students’ reflections on their experiences and expectations.

2.4 Data Analysis

Quantitative data from the weekly questionnaires were analyzed to assess trends in students’ perceived skill utilization over time. Descriptive statistics were used to summarize the frequency and distribution of skill utilization ratings. Qualitative comments were analyzed thematically to identify recurring themes and patterns in students’ reflections.

Table 3: Key Skills and Rating Scale

Skill	Rating Scale
Science and Mathematics (SM)	Not at all (0%), Somewhat (25%), Some of the time (50%), Most days (75%), Every day (100%)
Engineering Analysis (EA)	Not at all (0%), Somewhat (25%), Some of the time (50%), Most days (75%), Every day (100%)
Design and Innovation (DI)	Not at all (0%), Somewhat (25%), Some of the time (50%), Most days (75%), Every day (100%)
Widening Engineering Context (WEC)	Not at all (0%), Somewhat (25%), Some of the time (50%), Most days (75%), Every day (100%)
Professional Competencies (PC)	Not at all (0%), Somewhat (25%), Some of the time (50%), Most days (75%), Every day (100%)

2.5 Ethical Considerations

Ethical considerations were carefully addressed throughout the research process. Informed consent was obtained from all participants, and they were assured of the confidentiality and anonymity of their responses. Participation in the study was voluntary, and students were free to withdraw at any time without consequence. Data were securely stored and used solely for research purposes, adhering to principles of ethical conduct in research.

3 RASULTS AND ANALYSIS

The results can be broadly categorized into quantitative findings, derived from the numerical data collected through the weekly surveys, and qualitative insights obtained from the comments submitted by the students.

3.1 Quantitative Analysis

The number of first-year student who responded each week is given in the Table 4.

Table 4: Number of First-Year Student Responses

Date	Number of Responses
19 May (Week 1)	129
26 May (Week 2)	111
2 June (Week 3)	143
9 June (Week 4)	117
16 June (Week 5)	126

The survey results are depicted in Figure 2, providing a summary of the findings. Given the substantial participation of over a hundred students each week, the figure presents the averages of student responses across the five categories to elucidate general trends. Notably, discernible patterns emerge from the data.

There is a consistent upward trajectory in the utilization of skills such as Widening Engineering Context (WEC) and Professional Competencies (PC) as the project progresses over the fiveweek period. Interestingly, PC consistently surpasses WEC in terms of usage throughout the duration of the project. Conversely, the usage of Science and Mathematics (SM) shows a declining trend, which aligns with its higher significance at the project's inception.

Furthermore, the utilization of Engineering Analysis (EA) reaches its peak midway through the project before gradually declining below professional competencies towards the project's culmination. In fact, towards the project's conclusion, professional competencies emerge as the most frequently employed skill.

Additionally, Design and Innovation (DI) initially see a steady increase in usage but experience a decline towards the final deliverables, as students shift their focus towards the report and presentation of the completed project. These findings align precisely with the anticipated outcomes envisioned during the project's design phase.

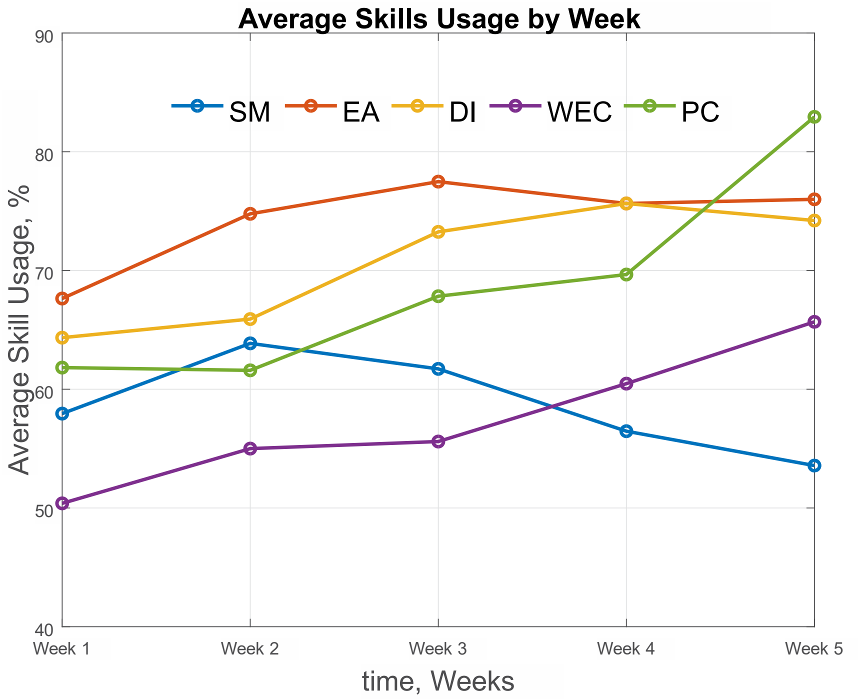


Figure 2: Utilization Trends of Key Skills Throughout the First-Year Design Project

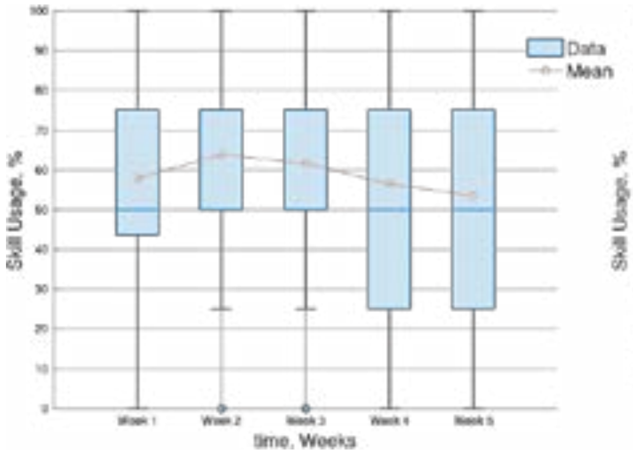
To provide a comprehensive view of the responses, box plots have been incorporated in Figures 3 to Figure 6 to illustrate student selections in four out of five categories. Box plots, also known as box-and-whisker plots, visually summarize the distribution of a dataset by displaying key statistical measures such as the median, quartiles, and outliers. They offer insights into the spread and central tendency of the data, allowing for a deeper understanding of the variability in student selections within each category. These plots complement the average values presented in the previous figures, offering a more detailed examination of the data distribution.

From Figure 3, it is apparent that not only does the student perception of the usage of Science and Mathematics (SM) decrease over the weeks, but there is also a noticeable increase in the disparity between students who perceive a greater need for SM towards the end of the project compared to the beginning. This is reflected in the larger interquartile range towards the end of the project, indicating a wider spread of responses. In contrast, at the start of the project, a smaller interquartile range suggests that most students chose similar responses.

Similarly, Figure 4 highlights that Engineering Analysis (EA) peaked in utilization during the middle of the project. Additionally, a smaller interquartile range indicates a consensus among students regarding the usage of EA during this period.

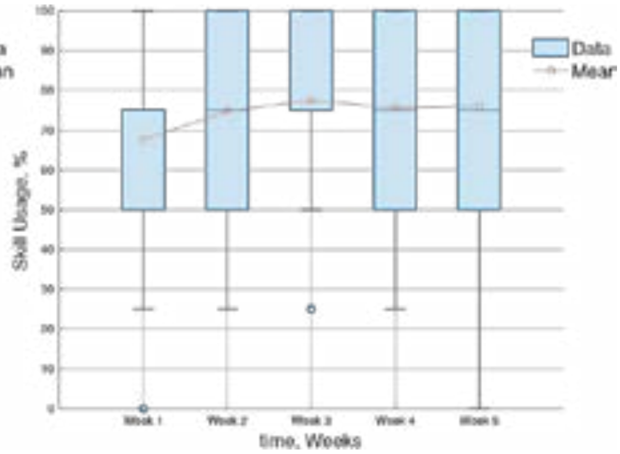
Similar observations can be made regarding the trends of Widening Engineering Context (WEC) and Professional Competencies (PC) from Figures 5 and 6, respectively. In both cases, the box plots depict trends over the course of the project, providing insights into the variations and consensus among student responses.

For WEC (Figure 5), there appears to be a gradual increase in utilization throughout the project, with a larger disparity between student perceptions as compared to other categories.



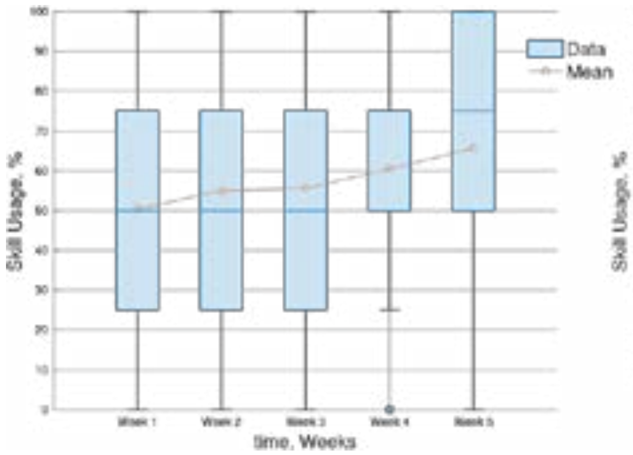
Science and Mathematics Usage by Week

Figure 3: Box Plots Illustrating SM



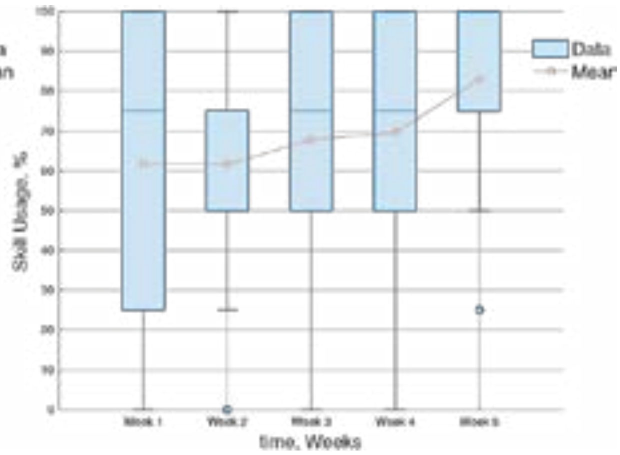
Engineering Analysis Usage by Week

Figure 4: Box Plots Illustrating EA



Wider Engineering Context Usage by Week

Figure 5: Box Plots Illustrating WEC



Professional Competences Usage by Week

Figure 6: Box Plots Illustrating PC

This is evidenced by the widening interquartile range, indicating a broader range of responses among students as the project progresses. This is however not true for Week 4.

Similarly, for PC (Figure 6), there is an increase in utilization of professional competencies throughout the project, with a smaller interquartile range at the end suggesting a consensus among students regarding their usage.

These trends, depicted by the box plots, provide valuable insights into the evolving perceptions and utilization of key skills among students throughout the first-year design project.

3.2 Qualitative Analysis

Upon performing a thematic analysis of the student comments, several key themes emerged regarding project management, lessons learned, and future applications.

3.2.1 Project Management

Students highlighted the significance of effective time management in project execution, stressing the need for better allocation of resources and schedules. Clear and consistent communication was identified as crucial for successful project coordination, enabling team members to stay aligned and address challenges proactively. Adequate planning and consideration of contingencies were deemed essential for project success, with students emphasizing the importance of anticipating and mitigating potential risks. Understanding others' tasks and roles within the team was recognized as vital for fostering collaboration and ensuring task completion. Additionally, students acknowledged the benefits of starting implementation earlier and allocating more time for testing to refine project deliverables and address any issues that may arise.

3.2.2 Lessons Learned and Future Applications

Students expressed a desire to invest more time in the initial planning phase of future projects, focusing on setting clear objectives, defining project scope, and establishing realistic timelines. They also recognized the importance of balancing personal development with meeting project deadlines, emphasizing the ultimate goal of team success. Furthermore, students valued both technical and non-technical skills, such as project management, teamwork, time management, and incremental idea development, underscoring the holistic nature of project success. Emphasis was placed on prioritizing effective team management, clear communication, task delegation, and fostering a collaborative environment in future projects. Additionally, students emphasized the need to verify technical strategies before implementation, assessing feasibility and potential challenges in advance to mitigate risks and ensure successful project outcomes.

4 DISCUSSION

Our project distinguishes itself from existing methods in several crucial aspects, thereby contributing to its innovation and potential impact on future educational practices. Central to its novelty is the intentional integration of professional and engineering skills development within a hands-on design project framework. Unlike conventional curricular approaches that primarily prioritize technical proficiency, our project emphasizes the holistic development of students' abilities to innovate, collaborate, and communicate effectively in real-world engineering scenarios.

Moreover, our approach incorporates interdisciplinary challenges, such as embedding ethical considerations into technical design decisions—an innovative facet that prepares students to navigate the multifaceted demands of modern engineering practice from an early stage in their academic journey.

The structured inclusion of workshops on project management, teamwork dynamics, and technical documentation further distinguishes our project. These workshops ensure that students not only acquire theoretical knowledge but also apply it in practical, team-based settings, thereby fostering deep engagement and retention of skills. This experiential learning paradigm is pivotal in preparing students for a seamless transition from academia to industry, aligning their educational experiences closely with real-world expectations.

While highlighting these innovative elements and their implications for educational reform, we recognize the importance of addressing potential criticisms and challenges alongside the benefits of integrating professional skills in engineering education. A notable concern is faculty resistance, rooted in traditional emphasis on technical training, which may conflict with the integration of soft skills development. This resistance often arises from concerns about curriculum saturation or the perceived dilution of core engineering competencies. Moreover, achieving a harmonious balance between technical rigor and soft skills training poses a significant challenge, given the densely packed nature of engineering curricula that leave limited room for additional modules without compromising depth in technical subjects.

To effectively address these criticisms, it is imperative to engage stakeholders in constructive dialogue aimed at refining curricular structures. This dialogue should emphasize the mutual benefits of blending technical expertise with essential professional skills, better equipping graduates to meet the diverse demands of contemporary engineering practice.

Furthermore, implementing adaptability in diverse educational and cultural contexts necessitates a thorough exploration of potential barriers and strategic solutions. Resource constraints and curricular rigidity are formidable challenges that can impede the integration of adaptability skills into engineering education. Strategies adopted by successful initiatives, such as flexible course designs, interdisciplinary collaborations, and industry partnerships, offer valuable insights into overcoming these barriers.

To enhance the discussion on impact, future studies could incorporate longitudinal assessments or follow-up surveys to track the long-term influence of acquired adaptability skills on student employability and career progression. This empirical approach would provide tangible evidence of the project's enduring effects on student professional development and industry readiness, thereby further substantiating its broader educational significance.

5 CONCLUSION

In conclusion, this study provides valuable insights into the development and utilization of professional and engineering skills among first-year Electrical and Electronic Engineering students during a practical design project. Our longitudinal investigation spanning five weeks reveals distinct trends in skill perception and application, with some skills peaking at specific stages while others maintain consistent usage. Notably, Science and Mathematics (SM) decline in utilization over time, while Professional Competencies (PC) emerge as predominant towards the project's culmination, underscoring their significance in the professional realm. Additionally, box plots offer nuanced insights into variations in student responses within each skill category, highlighting evolving perceptions and consensus among students.

Overall, our findings emphasize the importance of integrating professional skills development within engineering curricula to prepare students for the demands of the professional world. Future curriculum development efforts should encompass both technical proficiency and nontechnical competencies. This study contributes to the discourse on engineering education reform, advocating for a holistic approach to skill development that equips students with the competencies required to thrive in today's dynamic engineering landscape.

REFERENCES

Al-Sharif, L., O. Ouda, and S. Elattar (2019). Integrating soft skills in engineering education: Industry needs versus academic realities. *European Journal of Engineering Education 44*(3), 353–366.

Bennet, S. (2017). Integrating soft skills development into engineering education. *European Journal of Engineering Education 42*(6), 1086–1105.

Deters, C., S. Credle, and L. Hill (2018). Closing the gap: Professional skills development in the engineering curriculum. *Journal of Engineering Education 107*(4), 551–580.

Deters, J. R., M. C. Paretti, L. A. Perry, and R. Ott (2024). What does it mean to be "prepared for work"? Perceptions of new engineers. *Journal of Engineering Education 113*(1), 103– 123.

Engineering Council UK (2020). Accreditation of higher education programmes (AHEP). Technical report.

Engineering Council UK (2023). UK standard for professional engineering competence and commitment (UK-SPEC). Technical report.

Li, W. and L. Wang (2020). Innovative design projects in chinese engineering education. *International Journal of Engineering Education 25*(3), 300–315.

Moir, E. M. (2018). Employability skills for engineers. In E. M. Moir and B. G. Mauch (Eds.), *Engineering Communication From Principles to Practice*, pp. 205–222. CRC Press.

Munir, F. (2022). More than technical experts: Engineering professionals' perspectives on the role of soft skills in their practice. *Industry and Higher Education 36*(3), 294–305.

Munir, S. (2019). Soft skills in engineering education: Pedagogical strategies for innovation. *Journal of Professional Issues in Engineering Education and Practice 145*(3), 05019002.

Smith, J., E. Johnson, and D. Brown (2021). Project-based learning in mechanical engineering education: A comparative study. *Journal of Engineering Education 30*(4), 450–465.

RELUCTANCE DESPITE RECOGNITION: STUDENTS' PERCEPTIONS OF BENEFITS OF GROUP WORK

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ABSTRACT

As engineering educators pivot towards implementing evidence-based pedagogical strategies, group work - or collaborative work - is being increasingly used in undergraduate classrooms. In mathematics, collaboration is a crucial disciplinary practice. Participation in collaborative learning not only correlates with better academic performance and deeper conceptual knowledge but also leads students to adopt better learning strategies. Moreover, working in groups can improve students' intrinsic motivation and self-efficacy and lower mathematics anxiety. Despite the

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evidence, the implementation of group work in higher education mathematics courses has been slow, in part due to students' reluctance to engage in group work. This study describes the implementation of group work in a second-year university mathematics course taught in a flipped format, at an engineering university. We use quantitative and qualitative survey data from a student survey (N = 33) to analyse their perceptions of group work. We find that students are perceptive of the benefits of group work and especially value its affordances for access to feedback. Despite their positive experiences, we also find that students remain reluctant to group work being used more generally in other mathematics courses. We propose that even when students successfully participate in group work, they may not perceive the transferability of the skills they develop in the process. We suggest that teaching practices supporting those competencies and making them explicit may be necessary to improve student perceptions of group work beyond the classroom.

1 INTRODUCTION

Group work (or teamwork) is a pedagogical strategy involving students working in small teams toward a common goal. It has been implemented across a wide array of disciplines and levels of education. Group work is seen not only as a tool to improve disciplinary mastery (Kyndt et al. 2013; Laal and Ghodsi 2012; Apugliese and Lewis 2017), but as a way for students to acquire and master skills that are required by future employers (Craps et al. 2022; Robles 2012; Succi and Canovi 2020).

Working in groups can improve students' attitudes toward the discipline, the institution, and learning in general (Johnson et al. 2007). Students who participate in collaborative learning show higher motivation, including intrinsic and extrinsic motivation (Tran 2019; Slavin 2012), utility value (Volkov and Volkov 2015), and higher self-esteem (Johnson et al. 2007). Group work can also improve self-efficacy (Chiriac, Rosander, and Frykedal 2019), critical thinking skills (Gokhale 1995) and misconception remediation (Acar and Tarhan 2007). Moreover, group work can reduce self-efficacy gaps between women and men (Espinosa et al. 2019) and increase student perceptions of support (Johnson et al. 2007).

1.1 Group work in Mathematics.

Despite a prevalent social stereotype that mathematicians work in isolation, in a survey of 70 mathematics researchers Burton (1998) found that collaboration is perceived as an authentic disciplinary practice. Remarkably, all but three of the researchers reported regularly engaging in collaborative work. They noted that collaborating allowed them to generate more and better ideas which peers could critically evaluate and build on, to hold each other accountable in the face of deadlines, and to benefit from each other’s expertise. This suggests that collaboration is an important skill for mathematics students to acquire.

Moreover, in the context of education, the benefits of group work have been demonstrated across a range of outcomes. Students who work in small groups have better academic outcomes than those working individually (Springer et al. 1999; Smith et al. 2014), and with the acquisition of deeper knowledge (Koçak et al. 2009). These benefits could possibly be due to the need to organise knowledge well enough to provide explanations (Webb 1991), or because of increased self-efficacy, which is pivotal in mathematical problem-solving (Pajares and Miller 1994).

Collaboration in the mathematics classroom has contributed to students developing a sense of belonging (Rivera 2013) and lowering student anxiety (Lavasani and Khandan 2011). Moreover, the discussions involved in group learning make content more accessible to students (Webb and Farivar 1994).

1.2 Resistance to group work.

Despite the numerous and diverse benefits (both academic and otherwise), there is resistance from students to participate in group work, often based on fears of the free-rider effect (Shimazoe and Aldrich 2010; Latané et al. 1979) and worries about managing potential conflict. Instructors, too, resist implementation of group work due to the perceived higher load of managing group work (Gillies and Boyle 2010).

Group work is an active learning strategy, and the benefits of active learning have been well documented (Freeman et al. 2014) especially for non-traditional students (Theobald et al. 2020). However, studies have also shown that student buy-in to these active-learning strategies is related to their learning gains (Cavanagh et al. 2016; Hillyard et al. 2010; Reeves et al. 2023).

At our institution, there has been an increased focus on leveraging pedagogical strategies that have been shown to benefit non-traditional students and the development of transversal skills. The institution is implementing various initiatives, including increased intensity of group work. It is therefore important to understand the attitudes and opinions of our students concerning group work.

1.3 Research questions.

In the broader context of improving student learning outcomes, we aim to understand their perceptions about the affordances and constraints of group work in our institutional setting. To do this, we ask:

- What benefits do students perceive in relation to working in groups?
- What challenges do students face in relation to working in groups?

2 METHODOLOGY

2.1 Settings and participants

This study was conducted at a large, research-intensive Swiss engineering university. The students were enrolled in a second-year Bachelor’s course in abstract algebra for mathematics majors. The course begins with a thorough introduction to category theory and includes an exploration of group actions in various categories, the classification of finite abelian groups, and the Sylow theorems. The course is taught in flipped mode, so that the students have approximately one hour of video to watch each week, then attend a one-hour active learning session with the professor and a two-hour exercise session with the teaching assistants. Group work was mainly done during the exercise sessions, during which students were instructed to work in self-selected groups and solve assigned problem sets by applying course concepts. Working in groups was not mandatory, although it was highly encouraged at the beginning of the semester. Students did not receive instruction on how to work collaboratively but were expected to work in groups and consult with peers before reaching out to teaching assistants.

2.2 Data collection & analysis

Students enrolled in the course were asked about their experiences and perceptions of group work on the end-of-the-semester course evaluation survey which was anonymous at source[2]. The survey consisted of Likert-style questions (quantitative data), and three open-ended questions exploring their perceptions of group work (qualitative data). 35 students (37%) responded. The data was additionally filtered to remove two respondents who did not respond to the specific questions related to group work. Henceforth the word ‘students’ will be used to refer to these 33 respondents. Due to a small sample size, we used descriptive statistics to explore the quantitative data. The qualitative data was analysed for themes using the Qualitative Content Analysis methodology (Schreier 2014).

3 RESULTS

3.1 Most of the students worked in stable groups.

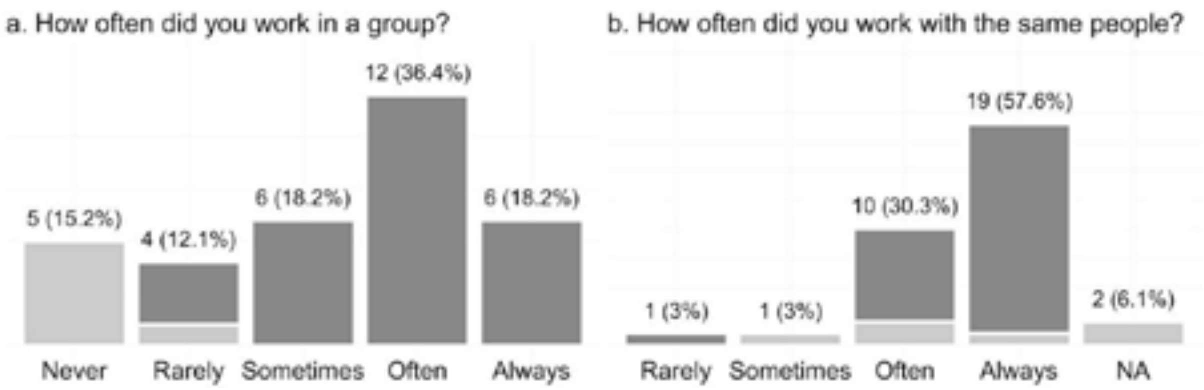

Fig. 1. Student participation in group work for students who claimed to take part in group work (dark grey, n=27) and students who did not (light grey, n = 6).

Most students (82%) reported participating in group work during the semester. Of these, 55% took part in group work often or always (Fig. 1a). Students were most likely to work in groups of five, but 41% of those working in groups worked in smaller groups. Group composition was stable during the semester, with two-thirds of the students who worked in groups always working with the same people (Fig. 1b).

3.2 Students had positive perceptions of group work.

Of the students who worked in groups, most (78%) stated that they liked to participate in group work in mathematics, with only three students stating the opposite (Fig. 2a). Similarly, 78% of them believe group work is a good idea (Fig. 2b); interestingly enough, three of the six students who did not participate in group work also believed so.

[2] Given the nature of the study design, it was exempt from a full review of the institutional ethics review board and was conducted in accordance with our institution’s guidelines.

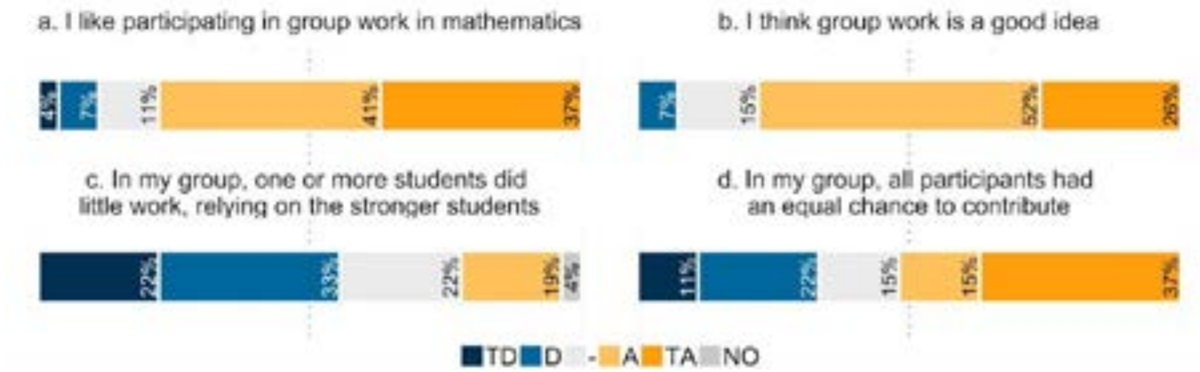

Fig. 2. Students who took part in group work had positive opinions about group work in general, and in the mathematics context in particular (n = 27). TD: Totally Disagree; D: Disagree; -: Neutral; A: Agree; TA: Totally Agree; NO: No Opinion.

Moreover, students did not perceive freeloading among their group mates, with only 19% of the students who participated in group work believing that some students in the group relied on the others to do the work (Fig. 3b). Still, just over half (51%) of the students who participated in group work believed all members in the group had an equal chance to contribute (Fig. 3a).

3.3 Students reported academic and non-academic benefits of working in groups.

Of the students who reported working in groups, 58% believed their groups solved problems efficiently (Fig. 3a), and 64% believed their group solved problems correctly (Fig. 3b). Additionally, almost half of the students felt like they learned the subject matter better when they took part in group work (Fig. 3c).

The large majority (82%) of students who participated in group work believed that group work improved their access to feedback, with only three students disagreeing with this statement (Fig. 3d). For example, students reported that "*Asking questions is very (sometimes too) easy*"[3] and that a positive aspect of group work was "*having to wait less time for help*"[3]. Several students stated that they appreciated the possibility of engaging with multiple viewpoints ("*It's also interesting to see how others think about a problem*"[3], "*having different ideas*"[3]).

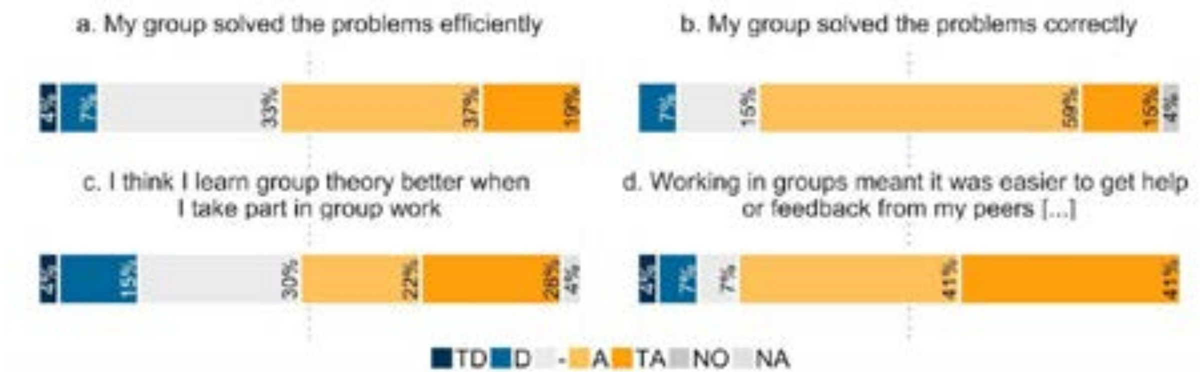

Fig. 3. Students who participated in group work had positive opinions about the academic benefits of working in groups (n = 27). TD: Totally Disagree; D: Disagree; - : Neutral; A: Agree; TA: Totally Agree; NO: No Opinion; NA: No Answer.

[3] Translated from the original French.

Some students also mentioned the affective benefits of group work ("*can take away the stress when you're struggling with certain things*"[3], "Less feeling stuck and demoralised"[3]), although they highlighted that these were due to the absence of a group-based graded component ("*the work is not graded, so there's no stress linked to the 'productivity' of group members*"[3]).

3.4 Students had some concerns about group work.

When prompted on what they disliked about group work, students expressed difficulties managing differences in the level of the team members and the pace at which the material was being covered ("*Feeling forced to progress through the exercises at the same pace as the others*"[3], "*The fact that there were disparities in level*"[3]). Some students also expressed concerns about whether the format of the problems they worked on was suitable for group work ("*The exercise series are too long for this work format*"[3]).

Finally, one student highlighted the importance of paying attention to student diversity in the class when planning group work: "*Care should also be taken with ASDs [Autism Spectrum Disorder], for whom group work can be more complicated and a greater source of stress, especially if there are graded reports*"[3].

3.5 Students do not perceive an increase in teamwork related skills.

Despite their positive opinions about group work and recognition of its academic and non-academic benefits, only slightly more than half the students who participated in group work (59%) said that they would choose to work with their group on a graded project the following semester. Additionally, less than half of them (44%) would prefer to have at least one course with a group work component.

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4 DISCUSSIONS AND CONCLUSIONS

Our goal with this study was to explore how students perceived group work in a second-year mathematics course. Our results show that students appreciate group work and claim to see its value in mathematics. This is in line with previous research both in and outside of mathematics, which has found that students perceive group work as helpful and enjoyable (Sofroniou and Poutos 2016) and that students participating in group work tend to view it in a positive light (Burdett 2003).

Our data shows that the main benefit perceived by students was that it allowed them to feel more supported in their learning. In fact, the two factors that stood out the most were their increased access to feedback and the fact that they could better evaluate their learning relative to their peers. The contribution of these two aspects to student well-being is not minimal. Receiving timely feedback in a low-stakes environment can improve student academic performance (Abdullah and Osman 2020) and has also been linked to reduced mathematics anxiety (Bjälkebring 2019).

Moreover, understanding their relative placement in the class can help students assess whether they are using appropriate learning strategies and make adjustments as needed. In combination, just these two aspects can significantly improve student experiences in the classroom. This is especially pertinent in classes where the teachers' time is a limited resource, such as in large classrooms with or in difficult courses, where students are likely to ask many questions and teaching assistants may be in high demand. In both these cases, using group work allows for questions and problems to be addressed by peers, thereby alleviating the demands of the teaching team.

The main shortcoming mentioned by students regarding group work was dealing with disparities between team members. Students reported struggling to work within the group at a level and pace suitable for everyone. This could be because in this course, students were allowed to work at their own pace, which meant that some students could be working on exercises that had been assigned weeks prior. Previous research has found that students may perceive such inequities as barriers to collaborative learning, which could undermine the value of group work (Eddy et al. 2015). This highlights the importance for instructors to recognize this issue and step in when necessary.

Additionally, it is worth noting that the tasks used in this class were initially designed for individual work akin to those that students use in their other mathematics courses, which means that students have a reference point for the pace at which they usually advance. It is possible that when their performance differs from their expectations, they interpret it as a waste of time, which they attribute to group work. Conceiving tasks for group work which benefit from multiple viewpoints and are designed to scaffold discussions can be a way to counter this student perception. Moreover, between member disparities need not be a hindrance to learning. In fact, Johnson and Johnson (1989) argued that the productive resolution of disagreements can itself make teamwork more effective, provided team members are taught how to resolve conflicts.

Even though most believed that they learned mathematics better because they participated in group work, students remain hesitant to adopt group work more widely. This could be because students attribute their success in group work to chance rather than to their development of group work skills. Furthermore, although students report being less anxious due to group work, several students note that this is contingent upon the absence of a graded component associated with teamwork. This indicates a lack of intrinsic value attributed to group work by students, who may view it merely as a different way of learning rather than as a skill in its own right. Moreover, students don't feel like they learn how to collaborate.

In combination, these two aspects mean that students do not perceive that the group work skills they acquired are transferable and are thus reluctant to engage in group work in wider scenarios. As with all transversal skills, students do not spontaneously develop the skills needed to collaborate effectively; as a result, it is essential to provide them with guidelines and feedback on what productive collaboration looks like. Research has shown that group work also works better when students receive coaching on how to work together (Shimazoe and Aldrich 2010), since such skills do not develop organically (Channon et al. 2017) and need explicit instruction and scaffolding (Kovacs et al. 2023; Picard et al. 2022; Isaac et al. 2023). Moreover, informing students of the value of group work can improve student perceptions regarding its value (Hillyard et al. 2010; Clinton and Kelly 2020).

That said, even when students recognise the value of collaboration in their careers, this may not translate into greater willingness to participate in group work. In this class, for example, the instructor highlighted the importance of collaboration in mathematics as a disciplinary practice. However, although students appreciated group work in this class, they didn't perceive it as a priority beyond the specific course context. Students know that group work can be useful for their careers but are hesitant to be assessed on their collaboration skills. However, they also prioritise studying the material that is directly linked to their assessments, which can lead them to neglect the development of collaboration skills. This creates a contradiction, where students don't value what is not evaluated, but are reluctant to be evaluated on something that they understand is valuable. The challenge is therefore to develop group work activities that provide students with tangible feedback to monitor and develop their group working skills even when they are not evaluated on these skills. Our recommendations are provided below.

4.1 Our recommendations:

- Encourage group work as it is an authentic disciplinary practice in mathematics.
- Design tasks that are suitable for group work
- Provide explicit and scaffolded instruction on the development of skills related to working in groups.
- When possible, train the teaching team to facilitate group work.

REFERENCES

Abdullah, A. H., and S. Osman. 2020. 'Effect of Peer Tutoring Strategy on Students Academic Performance in a Polytechnic Linear Algebra Classroom'. *Jour of Adv Research in Dynamical & Control Systems* 12 (3).

Acar, B., and L. Tarhan. 2007. 'Effect of Cooperative Learning Strategies on Students' Understanding of Concepts in Electrochemistry'. *International Journal of Science and Mathematics Education* 5 (2): 349–73. https://doi.org/10.1007/s10763-006-9046-7.

Apugliese, A., and S. E. Lewis. 2017. 'Impact of Instructional Decisions on the Effectiveness of Cooperative Learning in Chemistry through Meta-Analysis'. *Chemistry Education Research and Practice* 18 (1): 271–78. https://doi.org/10.1039/C6RP00195E.

Bjälkebring, P. 2019. 'Math Anxiety at the University: What Forms of Teaching and Learning Statistics in Higher Education Can Help Students With Math Anxiety?' *Frontiers in Education* 4 (April). https://doi.org/10.3389/feduc.2019.00030.

Burdett, J. 2003. 'Making Groups Work: University Students' Perceptions'. *International Education Journal* 4 (3): 177–91.

Burton, L. 1998. 'The Practices of Mathematicians: What Do They Tell Us About Coming to Know Mathematics?' *Educational Studies in Mathematics* 37 (2): 121–43. https://doi.org/10.1023/A:1003697329618.

Cavanagh, A. J., O. R. Aragón, X. Chen, B. A. Couch, M. F. Durham, A. Bobrownicki, D. I. Hanauer, and M. J. Graham. 2016. 'Student Buy-In to Active Learning in a College Science Course'. *CBE—Life Sciences Education* 15 (4): ar76. https://doi.org/10.1187/cbe.16-07-0212.

Channon, S. B., R. C. Davis, N. T. Goode, and S. A. May. 2017. 'What Makes a "Good Group"? Exploring the Characteristics and Performance of Undergraduate Student Groups'. *Advances in Health Sciences Education* 22 (1): 17–41. https://doi.org/10.1007/s10459-016-9680-y.

Chiriac, E. H., M. Rosander, and K. F. Frykedal. 2019. 'An Educational Intervention to Increase Efficacy and Interdependence in Group Work'. *Education Quarterly Reviews* 2 (2): 435–47. https://doi.org/10.31014/aior.1993.02.02.76.

Clinton, V., and A. E. Kelly. 2020. 'Student Attitudes toward Group Discussions'. *Active Learning in Higher Education* 21 (2): 154–64. https://doi.org/10.1177/1469787417740277.

Craps, S., M. Pinxten, H. Knipprath, and G. Langie. 2022. 'Different Roles, Different Demands. A Competency-Based Professional Roles Model for Early Career Engineers, Validated in Industry and Higher Education'. *European Journal of Engineering Education* 47 (1): 144–63. https://doi.org/10.1080/03043797.2021.1889468.

Eddy, S. L., S. E. Brownell, P. Thummaphan, M. Lan, and M. P. Wenderoth. 2015. 'Caution, Student Experience May Vary: Social Identities Impact a Student's Experience in Peer Discussions'. *CBE—Life Sciences Education* 14 (4): ar45. https://doi.org/10.1187/cbe.15-05-0108.

Espinosa, T., K. Miller, I. Araujo, and E. Mazur. 2019. 'Reducing the Gender Gap in Students' Physics Self-Efficacy in a Team- and Project-Based Introductory Physics Class'. *Physical Review Physics Education Research* 15 (1): 010132. https://doi.org/10.1103/PhysRevPhysEducRes.15.010132.

Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. 2014. 'Active Learning Increases Student Performance in Science, Engineering, and Mathematics'. *Proceedings of the National Academy of Sciences* 111 (23): 8410–15. https://doi.org/10.1073/pnas.1319030111.

Gillies, R. M., and M. Boyle. 2010. 'Teachers' Reflections on Cooperative Learning: Issues of Implementation'. *Teaching and Teacher Education* 26 (4): 933–40. https://doi.org/10.1016/j.tate.2009.10.034.

Gokhale, A. A. 1995. 'Collaborative Learning Enhances Critical Thinking'. *Journal of Technology Education* 7 (1). https://doi.org/10.21061/jte.v7i1.a.2.

Hillyard, C., D. Gillespie, and P. Littig. 2010. 'University Students' Attitudes about Learning in Small Groups after Frequent Participation'. *Active Learning in Higher Education* 11 (1): 9–20. https://doi.org/10.1177/1469787409355867.

Isaac, S., N. Petringa, Y. Jalali, R. Tormey, and J. Dehler Zufferey. 2023. 'Are Engineering Teachers Ready to Leverage the Power of Play to Teach Transversal Skills?' In *Proceedings of the SEFI 2023 Conference*. https://doi.org/10.21427/QP3D-B914.

Johnson, D. W., and R. T. Johnson. 1989. *Cooperation and Competition: Theory and Research*. Cooperation and Competition: Theory and Research. Edina, MN, US: Interaction Book Company.

Johnson, D. W., R. T. Johnson, and K. Smith. 2007. ‘The State of Cooperative Learning in Postsecondary and Professional Settings’. *Educational Psychology Review* 19 (1): 15–29. https://doi.org/10.1007/s10648-006-9038-8.

Koçak, Z. F., R. Bozan, and Ö. Işık. 2009. ‘The Importance of Group Work in Mathematics’. *Procedia - Social and Behavioral Sciences*, World Conference on Educational Sciences: New Trends and Issues in Educational Sciences, 1 (1): 2363–65. https://doi.org/10.1016/j.sbspro.2009.01.414.

Kovacs, H., T. Milosevic, and A. Niculescu. 2023. ‘Planned, Taught, Learnt: Analysis of Transversal Skills Through Curriculum Using Portfolio’. In *SEFI 2023 Proceedings*. https://doi.org/10.21427/R0JP-8277.

Kyndt, E., E. Raes, B. Lismont, F. Timmers, E. Cascallar, and F. Dochy. 2013. ‘A Meta-Analysis of the Effects of Face-to-Face Cooperative Learning. Do Recent Studies Falsify or Verify Earlier Findings?’ *Educational Research Review* 10 (December):133–49. https://doi.org/10.1016/j.edurev.2013.02.002.

Laal, M., and S. M. Ghodsi. 2012. ‘Benefits of Collaborative Learning’. *Procedia - Social and Behavioral Sciences*, World Conference on Learning, Teaching & Administration - 2011, 31 (January):486–90. https://doi.org/10.1016/j.sbspro.2011.12.091.

Latané, B., K. Williams, and S. Harkins. 1979. ‘Many Hands Make Light the Work: The Causes and Consequences of Social Loafing’. *Journal of Personality and Social Psychology* 37 (6): 822–32. https://doi.org/10.1037/0022-3514.37.6.822.

Lavasani, M. G., and F. Khandan. 2011. ‘The Effect of Cooperative Learning on Mathematics Anxiety and Help Seeking Behavior’. *Procedia - Social and Behavioral Sciences*, 3rd World Conference on Educational Sciences - 2011, 15 (January):271–76. https://doi.org/10.1016/j.sbspro.2011.03.085.

Pajares, F., and M. D. Miller. 1994. ‘Role of Self-Efficacy and Self-Concept Beliefs in Mathematical Problem Solving: A Path Analysis’. *Journal of Educational Psychology* 86 (2): 193–203. https://doi.org/10.1037/0022-0663.86.2.193.

Picard, C., C. Hardebolle, R. Tormey, and J. Schiffmann. 2022. ‘Which Professional Skills Do Students Learn in Engineering Team-Based Projects?’ *European Journal of Engineering Education* 47 (2): 314–32. https://doi.org/10.1080/03043797.2021.1920890.

Reeves, P. M., A. J. Cavanagh, M. Bauer, C. Wang, and M. J. Graham. 2023. ‘Cumulative Cross Course Exposure to Evidence-Based Teaching Is Related to Increases in STEM Student Buy-in and Intent to Persist’. *College Teaching* 71 (1): 66–74. https://doi.org/10.1080/87567555.2021.1991261.

Rivera, N. 2013. ‘Cooperative Learning in a Community College Setting: Developmental Coursework in Mathematics’. *ProQuest LLC*. Arizona State University. https://www.cpedinitiative.org/assets/resource-center/docs/rivera.pdf.

Robles, M. M. 2012. 'Executive Perceptions of the Top 10 Soft Skills Needed in Today's Workplace'. *Business Communication Quarterly* 75 (4): 453–65. https://doi.org/10.1177/1080569912460400.

Schreier, M. 2014. 'Qualitative Content Analysis'. In *The SAGE Handbook of Qualitative Data Analysis*, edited by Uwe Flick, 170–83. SAGE Publications, Inc. http://dx.doi.org/10.4135/9781446282243.n12.

Shimazoe, J., and H. A. 2010. 'Group Work Can Be Gratifying: Understanding & Overcoming Resistance to Cooperative Learning'. *College Teaching* 58 (2): 52–57. https://doi.org/10.1080/87567550903418594.

Slavin, R. E. 2012. 'Cooperative Learning and Achievement: Theory and Research'. In *Handbook of Psychology, Second Edition*, edited by I. Weiner, W.M. Reynolds, and G.E. Miller. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118133880.hop207008.

Smith, T. J., C. M. McKenna, and E. Hines. 2014. 'Association of Group Learning with Mathematics Achievement and Mathematics Attitude among Eighth-Grade Students in the US'. *Learning Environments Research* 17 (2): 229–41. https://doi.org/10.1007/s10984-013-9150-x.

Sofroniou, A., and K. Poutos. 2016. 'Investigating the Effectiveness of Group Work in Mathematics'. *Education Sciences* 6 (3): 30. https://doi.org/10.3390/educsci6030030.

Springer, L., M. E. Stanne, and S. S. Donovan. 1999. 'Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis'. *Review of Educational Research* 69 (1): 21–51. https://doi.org/10.3102/00346543069001021.

Succi, C., and M. Canovi. 2020. 'Soft Skills to Enhance Graduate Employability: Comparing Students and Employers' Perceptions'. *Studies in Higher Education* 45 (9): 1834–47. https://doi.org/10.1080/03075079.2019.1585420.

Theobald, E. J., M. J. Hill, E. Tran, S. A., E. N. Arroyo, S. Behling, N. Chambwe, et al. 2020. 'Active Learning Narrows Achievement Gaps for Underrepresented Students in Undergraduate Science, Technology, Engineering, and Math'. *Proceedings of the National Academy of Sciences* 117 (12): 6476–83. https://doi.org/10.1073/pnas.1916903117.

Tran, V. D. 2019. 'Does Cooperative Learning Increase Students' Motivation in Learning?' *International Journal of Higher Education* 8 (5): 12. https://doi.org/10.5430/ijhe.v8n5p12.

Volkov, A., and M. Volkov. 2015. 'Teamwork Benefits in Tertiary Education: Student Perceptions That Lead to Best Practice Assessment Design'. *Education + Training* 57 (3): 262–78. https://doi.org/10.1108/ET-02-2013-0025.

Webb, N. M. 1991. 'Task-Related Verbal Interaction and Mathematics Learning in Small Groups'. *Journal for Research in Mathematics Education* 22 (5): 366–89. https://doi.org/10.2307/749186.

Webb, N. M., and S. Farivar. 1994. 'Promoting Helping Behavior in Cooperative Small Groups in Middle School Mathematics'. *American Educational Research Journal* 31 (2): 369–95. https://doi.org/10.3102/00028312031002369.

EFFECTIVE DEVELOPMENT AND RECOGNITION OF TEACHING ASSISTANT PRACTICE: AN ALIGNED MODEL

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ABSTRACT

This practice paper presents an aligned model for the training and recognition of Graduate Teaching Assistants (GTAs) in the engineering teaching laboratories at a UK-based Russell Group university. The model comprises four key elements: reflective and critical feedback through peer teaching, technical and pedagogical training informed by practice, equality diversity and inclusion (ED&I) training, and community-building/mentorship. Specifically designed to meet the Professional Standards Framework (PSF) requirements, this model facilitates GTAs' achievement of Fellowship of the Higher Education Academy (FHEA). The training has significantly increased successful FHEA applications among GTAs, enhancing both their teaching efficacy and professional development. By detailing the development, implementation, and evaluation of this model, the paper provides actionable insights for institutions aiming to enhance their GTA programs, particularly in engineering

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education. These insights contribute to the broader discourse on effective training models and their impact on educational practices within engineering contexts.

1 INTRODUCTION

Graduate Teaching Assistants (GTAs) hold a critical position within higher education, particularly in disciplines like engineering where they often manage substantial teaching responsibilities in large classes. For instance, in the Multidisciplinary Engineering Education Department (MEE) at the University of Sheffield, where the model presented in this paper has been employed, GTAs play a vital role in facilitating laboratory sessions for groups of up to 80 students, alongside academic and technical staff. GTAs should therefore receive comprehensive training and development to ensure effective and inclusive teaching.

Numerous studies have explored GTA training and development programs, focusing on aspects such as program structure, self-perception, and efficacy measurement (Shum et al., 2020; Smith and Delgado, 2020; Bandura, 1977; Chiu and Corrigan, 2019). Notably, self-efficacy emerges as one of the crucial factors influencing GTA teaching quality, with scholars highlighting its significance in fostering effective teaching practices (Chiu and Corrigan, 2019, DeChenne et al. 2012). However, challenges persist in GTA development, including issues related to teacher identity, engagement, and role clarity. GTAs may struggle to perceive themselves as teachers, which becomes a barrier to embracing teaching responsibilities fully. Moreover, a lack of autonomy and unclear expectations can hinder their engagement and motivation. Mentorship emerges as a crucial component in addressing these challenges, providing guidance and support throughout the GTA's developmental journey.

GTAs occupy a unique position within academia, simultaneously serving as students, researchers, and teachers. This liminal space presents both opportunities and challenges, particularly concerning Equity, Diversity, and Inclusion (ED&I) in teaching. Research indicates that positive relationships between GTAs and students can mitigate inequalities in academic performance (Van Dusen and Nissen, 2020). GTAs, often reflecting diverse backgrounds, can serve as relatable mentors for students from various demographics, fostering inclusivity within educational settings. However, the blurred boundaries inherent in the GTA role can also pose challenges, particularly regarding confronting discrimination. A recent study in Switzerland concluded that whilst Engineering GTAs were overall quite confident in their readiness to take action, they rated the importance of addressing ED&I issues moderately higher than their ability to deliver them effectively (De Lima et al., 2024). They also point to research by Swim and Hyers in 1999 that shows a discrepancy between intention and action regarding prejudice. While most people believe they will intervene, less than half actually do so when faced with discriminatory behaviour (Swim and Hyers, 1999). Training interventions are thus crucial to empower GTAs in actively creating effective inclusive learning environments.

Existing literature offers valuable insights into GTA development programs and ED&I training; however, a gap exists in linking GTA progression with formal recognition pathways.

In the model presented in this paper, GTAs are encouraged to aspire to formal recognition from AdvanceHE, aiming for Fellowship of the Higher Education Academy (FHEA) over a structured two-year period. AdvanceHE, a leading organisation promoting excellence in higher education, offers professional recognition through its Professional Standards Framework (PSF). The PSF assesses individual competencies for university teaching against three key dimensions: 'Areas of Activity,' 'Core Knowledge,' and 'Professional Values.' (Advance HE, 2023).

Our model aligns closely with the PSF dimensions (but is widely transferable to other frameworks), forming the pathway for GTA development discussed in this paper. By integrating formal recognition pathways into GTA development, we aim to provide a clear progression structure for GTAs to attain FHEA recognition, enhancing the effectiveness of the GTA training program and GTA teaching practice as a result.

2 DEVELOPMENT ROADMAP FOR PROFESSIONAL RECOGNITION

Historically, GTAs had consistently felt unsure about both the value of and process of gaining formal recognition for their teaching ability (in this case, gaining FHEA recognition). GTAs were surveyed to find out about their incumbent understanding of FHEA and their perceived value of pursuing it - when asked what feels most unclear about the HEA recognition process, several answered "everything", others cited *the purpose, the process, what evidence is needed,* and *how to get started*.

Although central guidance around FHEA exists at the institution, an opportunity remained for tying this more tangibly to the GTA's specific teaching context.

GTAs were also asked how useful they would find having their training program mapped to the PSF. The average response was 4.1 / 5, giving a strong indication this would be valued, aligning with their earlier text-only answers.

This opportunity was addressed by creating a document mapping the GTA development experience to the FHEA requirements (the PSF) (Day and Di Benedetti, 2024). In conjunction, more structured support and mentoring were provided along with referring to competence development across the many training and team activities described in the following sections of this paper. The guidance document "FHEA Development Roadmap" was created which:

i. Describes the value of getting HEA recognition (incentives),

ii. Summarises the process of applying,

iii. Provides mapping to the PSF of the lab training/experience milestones,

iv. Provides guidance on compiling case studies for their FHEA application.

The mapping table presented by Day and Di Benedetti (2024) gives GTAs a clear progression route, which is discussed during individual training and mentoring sessions. This mapping table is essentially a step-by-step guide of the milestone activities a GTA will undertake, and how each relates explicitly to the PSF dimensions. The mapping helps GTAs form a narrative of their development journey and how their experience builds up towards applications for professional recognition. Elements of social learning theory are known to be of value in this context (Breau et al., 2020), so communities of learning are also encouraged within the team, with GTAs forming support groups while writing their applications.

Our model is thereby a combination of structured training and development elements, plus explicit mapping of those elements to the PSF (which GTAs can see in a concise document).

3 AREAS OF ACTIVITY AND CORE KNOWLEDGE

The ‘Areas of Activity’ section of the PSF groups together competencies relating to teaching design, delivery, student support, feedback, and assessment. Conversely, ‘Core Knowledge’ combines competencies related to the subject and pedagogical knowledge. To meet the requirements of FHEA, GTAs need to obtain sufficient competence in both. This is largely achieved through the specific training that is provided as part of their development plan.

3.1 Subject and Pedagogical Training

To support the development journey of GTAs a training methodology was devised to enhance their teaching skills while building sufficient knowledge of each teaching activity. This methodology, introduced by Di Benedetti et al. (2023) is summarised in an Open Educational Resource (Day and Di Benedetti, 2024); it relies on consistently alternating between training and teaching, interspersed with moments for self-reflection and feedback. This cycle is then repeated for all teaching activities delivered throughout the semester.

Before the academic year begins, a kick-off intro session and team-building exercise with all GTAs begin their journey. They are presented with role expectations, introduced to the HEA/PSF pathways, and work with their new colleagues on a pre-training exercise (Day and Di Benedetti, 2024).

As described in more detail in Di Benedetti et al. (2023), the training/teaching cycle (Fig. 1) starts with an Individual Training (IT) session, led by the academic and attended by a single GTA. This session supports the GTA’s activity-specific learning to reinforce their Core Knowledge of the subject. This would typically include a run-through of the lab activity, a revision of relevant background theories, and a discussion of the experimental results. In addition, pedagogical training is also offered as part of the IT to support the GTA development in the Areas of Activities, with particular emphasis on fostering a student-centred approach. Different pedagogical topics are covered, varying with the level of teaching experience of the GTA. Such topics, in line with the specific GTA skills prioritised by Tormey et al. (2019), include guidance on how to lead a teaching session (classroom management), a reflection on integrating theoretical frameworks such as Bloom's Taxonomy and constructive alignment into practical teaching contexts, and how to effectively use questioning strategies to assess students and provide constructive feedback. The duration of the IT session depends on the specific activity the GTA is being trained on, typically extending for one additional hour to account for the pedagogical training.

The Group Training (GT) session follows the IT. This is led by the same GTA trained during the IT but is now attended by other GTAs, while the academic is not present. The aim of this GT session is twofold. Peer teaching allows the lead GTA to practice before the in-service teaching, while the other GTAs learn the activity-specific content. As part of the GT, GTAs are also expected to collegially design a set of questions to assess students as well as to engage with self-reflection. For the lead

GTA, the latter involves self-assessment of their teaching, while for the other GTAs, it provides an opportunity to reflect on their learning and offer feedback to their peer (the lead GTA). The duration of the GT session also varies depending on the activity but is typically extended by 30 minutes to allow time for finalising the assessment questions and providing feedback.

Following the student teaching sessions, GTAs are encouraged to spend some time self-reflecting and using different lenses (i.e., self, students) to consider the effectiveness of their teaching.

The cycle is now ready to restart, with a different GTA receiving the IT for a new teaching activity. This cyclical nature where each GTA takes a turn in the leading role significantly aids community building across the wider team and responsibility levels in individuals.

Throughout the ITs and additional mentorship meetings, the leadership role of the academic is emphasised, providing deeper and more personalised support and encouragement for the GTAs. This, in turn, clarifies their current progress and greatly strengthens their sense of value individually and within the teaching team/community. In addition, the academic's absence during GT encourages GTAs' ownership of teaching sessions.

Finally, at the end of the academic year, all GTAs attend a workshop containing group exercises so GTAs can share their feedback/reflections and consolidate the team mentality.

4 PROFESSIONAL VALUES

To meet the requirements of FHEA, GTAs must demonstrate their integration of specific professional values throughout their practice. These include but are not limited to, V1: Respect individual learners and diverse groups of learners, V2: Promote engagement in learning and equity of opportunity for all to reach their potential, and V3: Use scholarship, research, or professional learning, or other evidence-informed approaches as a basis for effective practice (Advance HE, 2023). Inclusive education is essential for student retention and progress, therefore underpinning a sustainable pipeline of diverse and talented future engineers in both academia and industry.

The GTAs develop their professional practice in these ways through a combination of purpose-built training, community building, experience development, and mentorship.

4.1 ED&I training

Effective ED&I training becomes part of departmental culture through ongoing reflection and adjustments. It must address both the breadth of the topic and the nuance involved in both identifying and recognising the impact of often subtle discriminatory behaviours, whilst reinforcing the necessity for an ongoing commitment to the development of inclusive teaching practice through experience, reflection, and study. Based on these factors, a two-hour ED&I training was designed with a specific focus on the GTA teaching context. The two hours were divided between independent and group work. Follow-up reflective questions are shared with lead academics to use with GTAs working in their labs to continue their reflection and development of inclusive practice. Recommendations for support at the faculty level are also reported and implemented (Fig.2).

Teacher identity is a significant influence on the teaching approach and as discussed, can also impact how discriminatory behaviours based on different characteristics are recognised and addressed. As Lojdová et al. (2021) assert “Teacher identity is no longer acquired through professional standards but through teachers making sense of themselves and their teaching practice. Inclusive practice is brought into practice through teacher identity”. Identity awareness helps teachers bridge the gap between themselves and students with different backgrounds. Even when a teacher’s experience differs from students', that awareness can motivate them to compensate and be more vigilant about the issue (Drescher et al. 2023). The training was therefore designed around building GTA awareness of their identity to help them recognise their positionality and its commonalities and differences from their students.

A website of curated resources was designed (Plumb, 2024), giving the perspective of marginalised groups in STEM, grouped by different elements of GTA teaching practice such as facilitating group work, intervening and feedback. Resources include excerpts from pedagogic scholarship, short video clips and images to allow for quick engagement. It also includes local data on ED&I issues, from the faculties, university, and relevant student survey quotes from the Faculty of Engineering. Participants choose which resources they would like to explore independently. This approach offers participants a variety of “ways in” to the topics through engagement with a range of perspectives, prompting them to reflect on how their own identity impacts the way they teach and interact with students and the importance they place on incidents which stem from discrimination. They are also encouraged to think about the factors which affect their students’ approach and experience of education.

Fig. 1. Training & Teaching Activities Cycle

Fig. 2. ED&I Training Activities

Meaningful engagement with the material is elicited through a reflective exercise using a Google form where participants consider how identity and systemic barriers impact learning experiences and pedagogical approaches in their own context. This is followed by a workshop where participants discuss the ideas from the resources and their reflections with their peers. The workshop was designed in collaboration with colleagues from the English and Sociological Studies departments who have expertise in teaching sensitive topics to ensure that conversations were structured and facilitated in a way that ensured that participant views were respected even when challenged. Facilitators access the responses to the reflective tasks and if permission is given, leverage the information gathered to tailor discussion towards the topics of greatest collective interest or concern. Through these series of activities, participants are given opportunities to make sense of differing experiences and perspectives as well as to challenge their interpretations and those of others.

To further ensure that best practice is embedded, the ED&I training serves as a pipeline of inclusive practice feeding from GTA level upwards. Participants complete an action plan where they identify goals for making their practice more inclusive. Responses are made into a report and presented to the Faculty Director of Education so that relevant support can be put in place. Suggestions which have been implemented to date include clearer visibility and communication of reporting systems for GTAs to report instances of discrimination and bias.

5 RESULTS

5.1 Subject and Pedagogical Training

GTA teaching is assessed through multiple lenses, including instant student satisfaction ratings (Funnell, 2020), end-of-year student feedback, and well-established teaching observations conducted by both academics and students (Herrick and Shotts, in print). While student session satisfaction ratings provide valuable insights into students' engagement, independent teaching observations focus on GTA pedagogical skills.

The instant student satisfaction rating for the Lab in the past academic year averaged 4.5/5, closely aligning with the departmental average of 4.47/5. Both teaching observations and end-of-year feedback highlighted that GTAs acted autonomously and were instrumental in fostering critical thinking through questioning. Investing in GTA development significantly enhances their teaching skills, sense of responsibility, and identity as educators (Gardener and Jones, 2011), which in turn improves the quality of teaching they provide to students.

Observations also noted the need for a better balance in how and when GTAs engage with students. Future pedagogical training will focus on addressing this gap, ensuring continued improvement in GTA performance and student learning outcomes.

5.2 ED&I Training

Responses to the pre-workshop reflective task indicate how participants respond and interpret the materials. They also reveal misconceptions and questions before the second part of the training so there is time to respond to them. Participants often took the opportunity in the task to also give feedback on the resources they looked at with many of them saying that the materials had made them reflect differently on their approach and made them more aware and understanding of the perspectives and barriers faced by affected groups. The completed task is shared with the workshop facilitators who use the participants' ideas to structure the workshop discussions.

Participants also completed an action plan at the end of the workshop which evidences what they have taken from the session which is most valuable to them and outlines a specific commitment to introduce it to their teaching practice. These methods have proven useful in evaluating the effectiveness of the training as the written submissions evidence how participants interpret the content and how they intend to apply the ideas which have resulted from the activities.

5.3 Development Roadmap

The proposed training method combined with the development roadmap had a significant impact on GTAs achieving professional recognition. From an institutional equal opportunity document about PSF results, it was possible to infer that:

- Engineering historically had a disproportionately low number of FHEA applications compared to other faculties. However, in the past two years, this steadily increased with 9 (in 2022) and 12 (in 2023) applications to FHEA.
- Last year in Engineering, 50% of successful FHEA applications were by GTAs trained using the proposed training methodology.
- Finally, we have some direct feedback about the Development Roadmap; "*I found it very useful to help kickstart the process of filling out my "Statements and Supporting Examples" section and to give me an idea of potential case studies I could choose from my time as a GTA*".

6 SUMMARY

This practice paper presents a model for GTA development and recognition that is anchored in reflective peer teaching, technical, pedagogical, and ED&I training, as well as community-building/mentorship.

This model offers a practical framework that can be readily adopted by higher education institutions. By leveraging the structured training approach outlined by Di Benedetti et al. (2023) and by Plumb (2024) and the accompanying mapping tool (Day and Di Benedetti, 2024), institutions can establish highly effective GTA development programs with successful outcomes in attaining FHEA recognition.

Furthermore, because of the transferability of the principles it is anchored on, this model allows for adaptation to other professional recognition frameworks, ensuring its applicability across diverse institutional contexts. Implementing such a model promises substantial improvements in GTA teaching skills, ED&I practice, and professional recognition outcomes.

Future work will involve additional data analysis and broader adoption of the model within our Institution and partner ones. Specifically, our ED&I training will be further developed to include peer-led workshop sessions facilitated by trained GTAs. Follow-up assessments will gauge the long-term impact of the training on inclusive teaching practices, ensuring continuous improvement and development in this crucial aspect of GTA training.

REFERENCES

Advance HE ‘Professional Standards Framework. Accessed 12th March 2023. https://www.advance-he.ac.uk/teaching-and-learning/psf

Bandura, A. "Self-efficacy: toward a unifying theory of behavioral change." *Psychological review* 84, no. 2 (1977): 191.

Breau, G.M., S.H. Campbell, C.Hilario, C.L. Goldie, J.N. Auxier, B. Garrett, and C. Varcoe. "Mentoring Graduate Students to Become Effective Teaching Assistants: Developing and Implementing a Student-Centred Program for Nursing." *Quality Advancement in Nursing Education-Avancées en formation infirmière* 6, no. 3 (2020): 3.
https://doi.org/10.17483/2368-6669.1206

Chiu, P.H.P., and P. Corrigan. "A study of graduate teaching assistants’ self-efficacy in teaching: Fits and starts in the first triennium of teaching." *Cogent Education* 6, no.1 (2019): 1579964.
https://doi.org/10.1080/2331186X.2019.1579964

Day, H. and M. Di Benedetti “Open Educational Resource - GTA Development Program”, *University of Sheffield*. (2024) Available at: https://sites.google.com/sheffield.ac.uk/oer-gtadevelopmentprogram/0-home?authuser=0

DeChenne, S.E., L.G., Enochs, and M., Needham. “Science, technology, engineering, and mathematics graduate teaching assistants teaching self-efficacy.” *Journal of the Scholarship of Teaching and Learning*, 12, no. 4 (2012): 102-123.

De Lima, J., S., Isaac, and H., Kovacs. “Teaching assistants’ contributions to creating inclusive and equitable learning spaces in engineering”. *European Journal of Engineering Education*, (2024): 1–18.
https://doi.org/10.1080/03043797.2024.2346332

Di Benedetti, M., S. Plumb, and S. Beck. "Effective use of peer teaching and self-reflection for the pedagogical training of graduate teaching assistants in engineering." *European Journal of Engineering Education* 48, no. 1 (2023): 59-74. https://doi.org/10.1080/03043797.2022.2054313.

Drescher, A., T.K. Milarsky, G. Clements, A.J. El Sheikh, R. Hannebutt, L.E. Robinson, K.A. Graves, A. Valido, D.L. Espelage, and C. Rose. "Teacher Identity and Bullying—Perspectives from Teachers During Bullying Prevention Professional Development." *International Journal of Bullying Prevention* (2023): 1-15. https://doi.org/10.1007/s42380-023-00201-w.

Funnell, A. "Using instant student satisfaction ratings to investigate large scale practical laboratory teaching." In 2020 *IEEE Frontiers in Education Conference* (FIE), (2020): 1-5.
https://doi.org/10.1109/FIE44824.2020.9274191

Gardner, G.E., and M.G. Jones. "Pedagogical preparation of the science graduate teaching assistant: Challenges and implications." *Science Educator* 20, no. 2 (2011): 31-41.

Herrick, T. and J., Shotts. "Student-staff partnership schemes at two UK universities: the impact on student and staff identities, relationships, and solidarity" *Student Engagement in Higher Education Journal* (in-print)

Lojdová, K., K. Vlčková, and J. Nehyba. "Stories of teachers' identity: between personal and professional experience." *Studia paedagogica* 26, no. 2 (2021): 113-137.
https://doi.org/10.5817/SP2021-2-6.

Plumb, S. Equality, Diversity and Inclusion in GTA Teaching (Last updated March 2024). Available at https://sites.google.com/sheffield.ac.uk/gta-edi-training/home. (Accessed 22nd March 2024)

Shum, A., P. Lau, and L. Fryer. "From learner to teacher:(re) training graduate teaching assistants' teaching approaches and developing self-efficacy for and interest in teaching." *Higher Education Research & Development* 40, no. 7 (2021): 1546-1563.
https://doi.org/10.1080/07294360.2020.1818063

Smith, C.R., and C. Delgado. "Developing a model of graduate teaching assistant teacher efficacy: How do high and low teacher efficacy teaching assistants compare?." *CBE—Life Sciences Education* 20, no. 1 (2021): ar2.
https://doi.org/10.1187/cbe.20-05-0096

Swim, J. K., and L. L. Hyers. "Excuse Me – What Did You Just Say?! Women's Public and Private Responses to Sexist Remarks." *Journal of Experimental Social Psychology* 35, no. 1 (1999): 68–88.
https://doi.org/10.1006/jesp.1998.1370.

Tormey, R., C., Hardebolle, and S., Isaac."The Teaching Toolkit: Design of a One-Day Pedagogical Workshop for Engineering Graduate Teaching Assistants." *European Journal of Engineering Education* 45, no. 3 (2019): 378–92.
https://doi.org/10.1080/03043797.2019.1584606.

Van Dusen, B., and J. Nissen. "Associations between learning assistants, passing introductory physics, and equity: A quantitative critical race theory investigation." *Physical Review Physics Education Research* 16, no. 1 (2020): 010117.
https://doi.org/10.1103/PHYSREVPHYSEDUCRES.16.010117.

Upgrading Mathematical Skills for Professional Studies: The Role of Interactive Tasks and Self-Direction in Online Courses

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ABSTRACT

This paper presents an open online course aimed at those Not in Education, Employment, or Training (NEET). The course aims to give school dropouts, unemployed, and immigrants the opportunity to return or to enrol on studies. There are plenty of labour market training available for unemployed, but this does not necessarily contribute to further studies and thus improve one's own social position. Most entrance examinations often emphasise mathematical competence, which, especially for school dropouts and for the unemployed, may have remained at a low level or been forgotten over the years. This online course under development aims to address this shortcoming. As the target group is those currently outside the labour force, special attention must be paid to promoting learning/studying skills in the design of the online course. Students' self-direction skills are tested and based on their results, they are given tips on how to improve different aspects, as taking responsibility for one's own study is essential in an online course. In addition, the technical implementation of the course must be clear, and the instructions given on the tasks sufficient. The target group may not be as experienced as typical online course students, in which case even minor adversities may lead to dropping out. To

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maintain interest, the tasks are designed to be interactive, and they also provide feedback when doing the task, not only after the return.

1 INTRODUCTION

According to the recent results of the OECD's PISA study, there is a visible decline in the level of competence in literacy, mathematics, and science in young people in Finland. Furthermore, the discrepancy in learning outcomes between pupils with an immigrant background and those without is one of the largest in the reference countries (Ministry of Education and Culture 2019). Based on Pietiläinen’s report (2021), ninth graders' proficiency in mathematics has decreased compared to previous studies. Niemi et al. (2021) also reported that the level of competence in mathematics declines if a student does not enter upper secondary school. About 14% of young people do not have upper secondary education despite the unemployment rate being lower among the more educated (Witting 2021). Witting remarks that education has a generational component, as, on average, children from less educated families are less likely to enter tertiary-level education than others. In addition, students with less educated parents seem to have a higher dropout rate than students with highly educated parents. Addressing the underlying reasons is not the subject of this paper; instead, it frames the urgent need to help youth catch up with their studies.

The shortage of labour, especially in the technology sector, is growing, and the demands of digitalisation are not helping the situation. There are not enough technology students to fill the gap, as enthusiasm for studying technology is decreasing and only 60% of engineering students graduate according to Energiateollisuus (2021). Further, sufficient mathematics skills seem to predict the progress of engineering studies better than the actual educational background. Therefore, improving mathematics skills is important to support studying and improve graduation rates.

One principal factor in succeeding in professional studies is self-direction. Students who are excellent at regulating their studies usually progress well. Thus, it is important to understand the self-direction skills of students in order to provide them with the necessary tools and methods to succeed in their studies. Self-management and self-control are important skills that are also needed in working life.

The aim of this paper is to discuss psychological aspects needed to considerate in the course development for NEET and ways of implementing those aspects in course design. Those without recent education experience or a formal education may need more guidance to complete your studies independently, but also to work on online platforms in a technical point of view. Fostering their self-efficacy in mathematical subjects will aid their studies in mathematics (Niemi et al. 2021).

2 CHALLENGES IN ONLINE STEM EDUCATION

The popularity of online courses has continued to grow due to the continuous learning required in professional fields. Online courses offer flexibility in terms of time management, and they may be the only opportunity for those on the job to continue studying. Unfortunately, the reality is not as ubiquitous as one might imagine, and the dropout rates of courses are usually high. This section examines the reasons behind why students might drop out and how they could be considered in the course design.

2.1 Psychological aspects

Psychological aspects, like motivation and self-direction, are widely seen as key elements for academic success (Lao et al. 2017; Park, Moon, and Oh 2022). Henry et al. (2019) discuss how a student's own mindset (locus of control) or belief in their ability (self-efficacy, mindset) affects how they face challenges, their engagement in completing a task, and goal orientation. A fixed mindset refers to a person believing that intelligence and capacity are unchangeable, whereas a growth mindset refers to believing that these qualities are adaptable and can promote their skills over time and effort (ibid). Individuals with a fixed mindset place the blame on others when faced with failure, such as when the task is impossible, or a teacher does not explain things clearly. Whereas a person with a growth mindset sees difficult tasks as an opportunity to learn something new. In the case of failure, they just keep trying and find new ways to accomplish the task. Failure in this context refers to a gap between an expected or desired result and what is achieved (ibid).

Pintrich (2000) remarks that students have a mastery or performance orientation. Students with mastery orientation want to achieve competence and focus on the development of skills (ibid). Students with a performance orientation focus on external requirements, such as parental approval, grades, better salary, etc. These can also be further divided into approach (positive attitude) and avoidance (negative attitude). A mastery-approach orientation refers to a need to succeed in a task to meet an internally held standard, whereas a mastery-avoidance orientation tries to avoid failing an internally held standard (Henry et al. 2019). Performance approach orientation refers to non-negative and, often, positive associations with students' self-efficacy and academic performance (Bong 2009; Henry et al. 2019). Performance-avoidance orientation for avoiding failing to meet some normative standard may result in, for example, anxiety and the use of self-defeating strategies (Bong 2009). Individuals with a fixed mindset, performance goal orientation in general, or mastery avoidance goal orientation seem to have pessimistic thinking, make excuses, and seem to reduce effort already before failure. After failure, they think they are not good enough (ability), feel helpless, lose interest, or may even be burned out. As the target group of this paper is NEET, it is important to understand their orientation so that it can be addressed in course design and engagement.

2.2 Other reasons for dropping out

Several other attributes also influence the dropout rate: age, gender, academic experience, relevant technical and management skills, and personal variables (Shaikh and Asif 2022; Yılmaz and Karataş 2022). Bawa (2016) mentions that the learning level of college students seems to affect the probability of dropping out, as students with lower levels of learning are most likely to drop out. Students with prior experience of online learning seem to be more confident. It may be related to their technical proficiency, which is a factor of success when studying online (Bawa 2016; Shaikh and Asif 2022). That may be an issue with our self-study online course, as the target group may not have positive experiences with online learning. Shaikh and Asif (2022) also remarked that motivation aspects, like financial outcomes, may contribute to persistence in education.

A recent study from Brown (2023) describes the liminal experiences of students attempting to transition to tertiary education. In open university courses or online studies, students might encounter timetabling issues, alternative and new ways of studying and learning methods, and academic and institutional expectations. Brown also notifies that many students experience feelings of confusion, which may be perceived as a barrier to learning, as they adapt to a new learning environment where they are expected to demonstrate independence (Van Rooij et al. 2017; Pennington et al. 2017). Thus, the problems for those in transition are the same but much deeper in nature. Students may lack the prerequisite cognitive skills that are required in online learning environments.

2.3 Careful course design prevents dropping out

The previously mentioned aspects must be taken into account in the planning of the assessment and learning environment. The promotion of self-directed learning skills, the authenticity of the practice and well-timed feedback form the hallmarks of a good online learning model (Hurme, Porras, and Lähteenmäki 2023). Focusing on thinking and self-directed learning skills can therefore help our target group to complete the course.

Rasila et al. (2015) state that in order to build a pleasant user experience, the presentation of mathematics plays a key role. The mathematical content should be understandable regardless of the teacher's help, and the interaction between the student and the computer should be seamless. In addition, certain problems within materials and systems can later be identified indirectly by the students' training response data collected by the e-learning environment. User feedback and subsequent revisions to the e-learning platform and learning materials are necessary to improve the user experience.

Koedinger et al. (2015) showed that engaging in interactive activities within online courses yields more significant improvements in study outcomes compared to simply watching videos or reading theoretical material. Interactive activities foster active learning, which is more effective than passive knowledge acquisition, and the learning by doing method seems to be a reasonable premise for the design of an online course. However, combining the videos with interactive activities might help the students to get better grades. Rinneheimo (2017) found that students found videos useful for enhancing learning, with a majority wanting more videos in courses as they allow students to study at their own pace and revisit content as needed.

Paiva et al. (2015) emphasise that interactive learning modules such as interactive multimedia books, online quizzes, and educational videos create an effective online learning environment for studying mathematics in higher education. The study provided evidence that interactivity could effectively improve learning outcomes, as students with weaker basic math skills showed significant improvement. Velichová (2021) concludes that learning by doing enhances learners' motivation, enthusiasm, interest, attitude towards the whole learning process and desire to acquire new knowledge. An interactive approach improves opportunities to fill learning gaps in mathematics.

3 DESIGN OF THE ONLINE LEARNING ENVIRONMENT

On this course, all students have three modules to finish: learning skills, basics of mathematics, and professional-specific advanced tasks. Learning skills give basic knowledge on calculators, word processing, and spreadsheet computation. All skills required to successfully progress on mathematical subjects. Basic mathematics goes through lower secondary school mathematics and advanced tasks focus on professional field.

The theoretical framework (Hurme, Porras, and Lähteenmäki 2023) used for this online course is based on the idea of de Brujin and Leeman (2010). Four themes with descriptive features comprise the model: authenticity, activity design, guidance, and evaluation. Authenticity has a two folded meaning. It’s naturally considered with professional specific, advanced task. The idea is to use authenticity in to evoke an 'I can' identity (self-efficacy), for example, in people thinking about a possible career change. The pedagogical idea is to captivate the desire for learning by using suitable exercises from professional fields to promote further learning of the abstract terms and structures of mathematics and physics. These advanced tasks are divided into technology, business, social and health care, and tourism and nutrition. The student chooses one of these modules according to their professional interest.

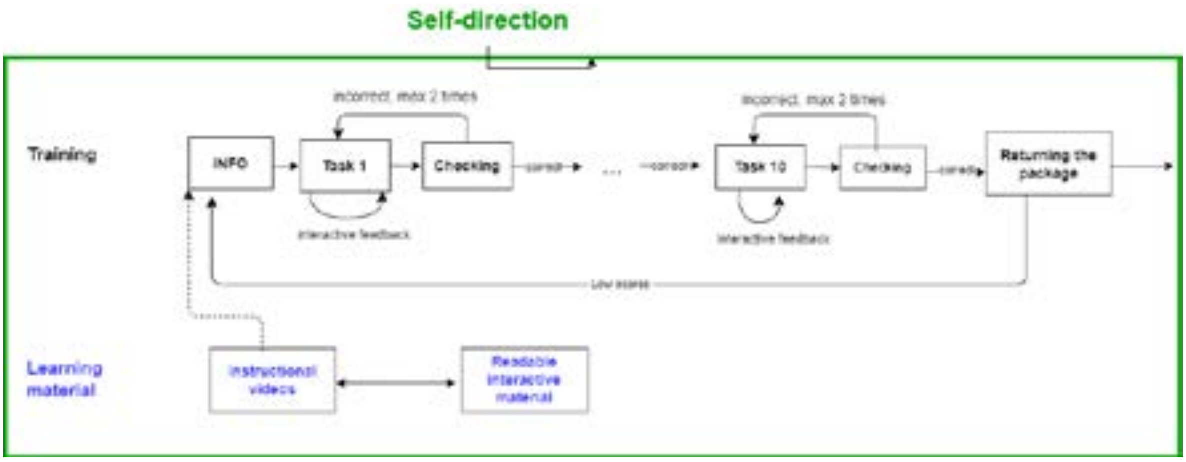

Fig. 1. Pedagogical model for online training

In the activity design, we follow the work of Bloom (1984) and Pelkola et al. (2018). The pedagogical model for online training of Hurme et al. (2023) to enwiden the basic conceptualisation and skills in mathematics is presented in Fig 1. This model emphasises the power of automated assessment and feedback to provide the seeds to support the growth in self-direction and learning for mastery of mathematical skills. Tasks are designed to provide feedback already during the execution, and not just after the checking. The purpose of this is to maintain student enthusiasm and reduce frustration. Winne (1982) states that if the learning environment is not inclusive, there is a risk of barriers for students who are less able to mediate or self-direct their own learning. If the interactive exercises and assessments performed are learner-centred, active student participation in a powerful learning environment will be promoted.

All students participate in competence level and self-regulation tests at the beginning of the course. These give them guidance which mathematical topics and self-direction aspects needs upgrading. The feedback in self-direction readiness test (Porras, Hurme, and Lähteenmäki 2023) will give the more detailed guidance the lower the scores received. After each module, students reflect their own learning with questionnaires. These include also self-direction aspects like planning and employment of time. The competence level test will be repeated after basics of mathematics to give feedback on learning.

3.1 Model for designing interactive exercises

Contemporary LMS (Learning Management Systems), such as Moodle, contain a range of interactive tasks, encompassing simple multiple-choice questions to sophisticated graphical queries, with automatic feedback being the unifying feature. STACK (System for Teaching and Assessment using Computer Algebra Kernel) is a prominent open-source e-assessment system operating within Moodle that integrates effectively with other platforms. The utilisation of tasks crafted by computer-aided algebraic systems requires extensive usage of STACK and Maxima (A Computer Algebra System). STACK utilises Maxima on calculations, but it also encompasses specific functions that are absent in Maxima but crucial for the generation of STACK tasks. For more detailed information on STACK, see Lähteenmäki et al. (2024).

A standard representation of interactive tasks requires students to type or select correct answers and passively receive immediate feedback. In this paper, interactive tasks are extended beyond that: students engage with interactive STACK tasks designed with JSXGraph, enabling them to interact with graphical interfaces using mouse or touch gestures. In the interactive task, hidden answer fields may contain diverse data types, such as coordinates of interactively manipulated objects, lists, or Boolean values.

Interactive tasks are increasingly prevalent in higher education, but effective design frameworks remain scarce. It is possible to generate interactive tasks with impact with open-source tools, but only if they utilise a learner-centred approach, simplify phenomena, and consider accessibility requirements to ensure compatibility with users' diverse needs. Interactivity should aid in comprehending underlying conceptual principles. Technical design should avoid complex structures, using clear instructions so the student can understand the task’s objectives.

3.2 Learner-centred task design and facilitative feedback

In an online course, when there is no student–teacher interaction, feedback plays a more significant role than in any other learning environment. The absence of a teacher and the live feedback without facial expressions and gestures truly challenge the learning process.

Feedback, whether it is related to guidance or assessment of activities, should be seen as an act affecting student’s future performance. Further, feedback should include answers as to why something is incorrect, how the error may be considered, and what may help solve the problem (Shute 2008; Torrance 2012; Brown 2023). These can enlighten the student on which areas are now under control, which positively affects learning. Brown (2023) and Hattie and Timperley (2007) also provide a way to provide feedback whilst maintaining a positive attitude in future learning by explaining how to reduce the identified gaps. By providing relevant positive feedback, we have the potential to affect the learner’s future performance and maintain the student’s desire for further studies.

The design of interactive tasks to ensure user-friendliness, intuitiveness, and inclusivity with a focus on pedagogically sound design play a central role. In designing interactive tasks for students, it is essential to adhere to a certain consistency: interactive elements should have consistent appearance and functionality to ensure they serve their purpose efficiently and intuitively. Particular attention must be paid to avoid confusing the student due to the perplexing functioning of the interactive task. In general, skilfully planned and executed programming should guide students so that incorrect answers do not result from syntax errors or improper response methods. It is crucial to strike a balance between simplicity and clarity of task presentation and avoid superfluous elements that may distract students.

The most common type of feedback is the immediate feedback received after the student checks the answer. If needed, the immediate feedback can be extensive, depending on the scope of the potential response tree. It has been demonstrated (Hurme, Porras, and Lähteenmäki 2023; Lähteenmäki, Hurme, and Porras 2024), that the graphical interface extends the ways of giving feedback. The graphical interface permits facilitative feedback to be shown dynamically based on the actual mouse interactions with the elements of the graphical interface. In Fig. 2 (left), there is an example of giving feedback for student during solving traditional equation task. A red question mark describes the stage at which an error occurs. Although we are not able to the specify the mistake, the instructions given below will give hints. This gives a student a possibility to fix the answer before checking.

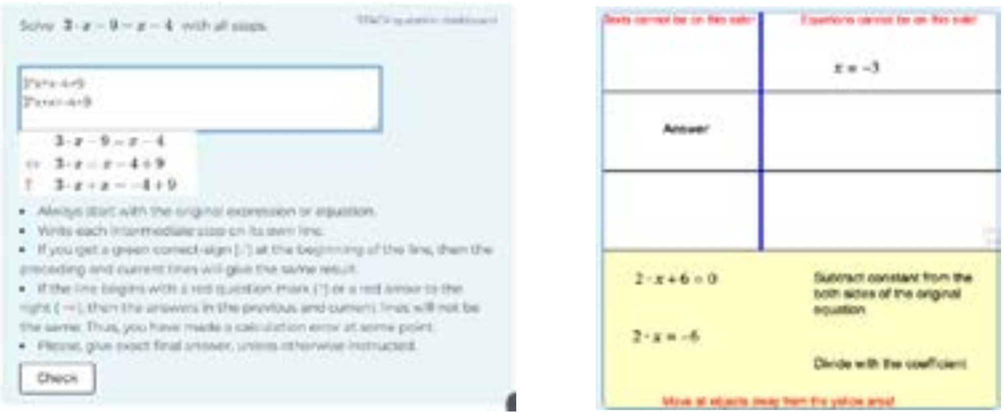

Fig. 2. Interactive feedback (left) and guidance (right) on solving equations

Gerhäuser et al. (2011) stress the benefit of using dynamical geometry software to introduce an innovative dimension to interactive tasks. Bach and Altieri (2021) confirm that dynamic geometry facilitates the development of challenging visual conceptual tasks while utilising JavaScript's versatility. In Fig 2 (right), the task utilises dynamic geometry. All steps are given but a student should order them correctly. This kind of drag-and-drop task enables forcing the student to understand intermediate steps (languaging) instead of simply following systematic instructions. The student is guided to drag objects to the correct side, but no feedback of correctness of the order is given during the task. Both kinds of tasks are needed to deepen the learning.

For example, in Figure 3, two different elements of facilitative feedback are used according to the inclusive design approach: dynamic attention messages and dynamic guidance messages. Only one row is intended to be selected in red. Thus, when a student selects another row, it turns red while the previous row reverts to black. If no row has been selected, a red dynamic attention message appears at the bottom of the window, reminding the student of the core task to be completed before checking the answer. Green arrow tips are the triggers of dynamic guidance messages that appear when hovering the mouse over them. Dynamic guiding messages can contain reflective questions or hints, just to mention a few. The main idea of dynamic guiding messages is that they point to one or many essential graphical elements and illuminate their meaning to students in a pedagogically sound way. All question types and their graphical elements must be explained thoroughly at the information part to decrease frustration.

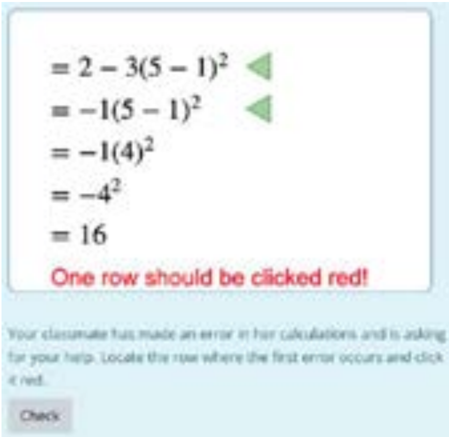

Fig. 3. Order of calculations

4 SUMMARY

The benefits arising from interactive tasks permeate all levels of education. In this paper, we demonstrate the effectiveness of these tasks in enhancing fundamental mathematical skills and solidifying foundational mathematical concepts in a purely online course. Although these aspects may not be the primary focus within higher education institutions, assuming students possess adequate competences in mathematical natural sciences, the decline in mathematical abilities is steep. Thus, there is an urgency to develop supportive measures to strengthen basic mathematical skills to facilitate successful higher education pursuits.

Poorly designed activities exacerbate the difficulties of learning online, so focusing on the level of assessment is a requirement. To promote students' learning in mathematics, both conceptions of mathematics and self-directed skills should be levelled up. Inclusive learning environments with interactive activities and learning by doing methods can address these issues.

This paper presented course aimed at NEET. We also introduced some interactive task types designed for the course to promote learning. The first pilot of this course will be during autumn 2024. At that time, we will see whether feedback and guidance has been helpful. The improvement in self-direction is not so easily explored, but indications of this are given by the ratio of students who passed the course to the number of participants. We are particularly interested in the feedback emerging on interactive exercise tasks: whether they are perceived as promoting learning, complicated, or more like gaming. This feedback affects course development.

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REFERENCES

Bach, Stephan, and Mike Altieri. 2021. "Drawing Graphs of Differentiable Functions with STACK and JSXGraph Using Hermite Splines." In *Computer Aided Assessment and Feedback in Mathematics: Contributions to the International Meeting of the STACK Community 2021*. https://doi.org/10.5281/ZENODO.4915954.

Bawa, Papia. 2016. "Retention in Online Courses: Exploring Issues and Solutions—A Literature Review." *Saga Journals* 6 (1). https://doi.org/10.1177/2158244015621777.

Bloom, Benjamin. 1984. "The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring." *Educational Researcher* 13 (6): 4–16.

Bong, Mimi. 2009. "Age-Related Differences in Achievement Goal Differentiation." *Journal of Educational Psychology* 101 (4): 879–96. https://doi.org/10.1037/a0015945.

Brown, Kenneth. 2023. "eAssessment in Engineering Mathematics: Gaps in Perceptions of Students and Academics." University of Glasgow. https://theses.gla.ac.uk/.

Brujin, Elly de, and Yvonne Leeman. 2010. "Authentic and Self-Directed Learning in Vocational Education: Challenges to Vocational Educators." *Teaching and Teacher Education* 27:694–702.

Energiateollisuus. 2021. "Kokemus vahvoista matematiikan taidoista ennustaa insinööriopintojen sujumista koulutustaustaa enemmän." Energiateollisuus. 2021. https://energia.fi/uutishuone/kokemus_vahvoista_matematiikan_taidoista_ennustaa_insinooriopintojen_sujumista_koulutustaustaa_enemman.4855.news.

Gerhäuser, M, C Miller, B Valentin, and A Wassermann. 2011. "JSXGraph--Dynamic Mathematics Running on (Nearly) Every Device." *Electronic Journal of Mathematics & Technology* 5 (1).

Hattie, J, and H Timperley. 2007. "The Power of Feedback." *Review of Educational Research* 77 (1): 81–112.

Henry, Meredith A., Shayla Shorter, Louise Charkoudian, Jennifer M. Heemstra, and Lisa A. Corwin. 2019. "*FAIL* Is Not a Four-Letter Word: A Theoretical Framework for Exploring Undergraduate Students' Approaches to Academic Challenge and Responses to Failure in STEM Learning Environments." Edited by Stephanie Gardner. *CBE—Life Sciences Education* 18 (1): ar11. https://doi.org/10.1187/cbe.18-06-0108.

Hurme, Jarkko, Päivi Porras, and Henry Lähteenmäki. 2023. "Enhancing Mathematical Skills for Vocational School Students Pursuing Undergraduate Studies." In , 557–69. https://doi.org/10.22492/issn.2435-9467.2023.43.

Koedinger, Kenneth R., Jihee Kim, Julianna Zhuxin Jia, Elizabeth A. McLaughlin, and Norman L. Bier. 2015. "Learning Is Not a Spectator Sport: Doing Is Better than Watching for Learning from a MOOC." In *Proceedings of the Second (2015) ACM Conference on Learning @ Scale*, 111–20. Vancouver BC Canada: ACM. https://doi.org/10.1145/2724660.2724681.

Lähteenmäki, Henry, Jarkko Hurme, and Päivi Porras. 2024. “Design of Interactive STACK Exercises Using JSXGraph for Online Course: Exploring Strategies for Supporting Students with Mathematical Challenges.” In *Proceedings of the 16th International Conference on Computer Supported Education*, 2:549–56.

Lao, Andrew, Hercy Cheng, Mark Huang, Oskar Ku, and Tak-Wai Chan. 2017. “Examining Motivational Orientation and Learning Strategies in Computer-Supported Self-Directed Learning (CS-SDL) for Mathematics.” *Journal of Educational Computing Research* 54 (8): 1168–88. https://doi.org/10.1177/0735633116651271.

Ministry of Education and Culture. 2019. “PISA-Study and Results 2018 (Only in Finnish).” http://urn.fi/URN:ISBN:978-952-263-678-2.

Niemi, Laura, Jari Metsämuuronen, Markku Hannula, and Anu Laine. 2021. “Matematiikan parhaiden osaajien siirtyminen toiselle asteelle: koulutusvalinnat ja matematiikan osaamisen kehittyminen.” *LUMAT: International Journal on Math, Science and Technology Education* 9 (1). https://doi.org/10.31129/LUMAT.9.1.1511.

Paiva, Rui, Milton Ferreira, Augusto Eusébio, and Ana Mendes. 2015. “Interactive and Multimedia Contents Associated with a System for Computer-Aided Assessment.” *Journal of Educational Computing Research*, no. 2, 224–56. https://doi.org/10.1177/0735633115571305.

Park, Kyongok, SeolHwa Moon, and Juyeon Oh. 2022. “Predictors of Academic Achievement in Distance Learning for Nursing Students.” *Nurse Education Today* 108 (January):105162. https://doi.org/10.1016/j.nedt.2021.105162.

Pelkola, Timo, Antti Rasila, and Christopher Sangwin. 2018. “Investigating Bloom’s Learning for Mastery in Mathematics with Online Assessment.” *Informatics in Education* 17 (2): 363–80. https://doi.org/10.15388/infedu.2018.19.

Pennington, Charlotte, Elisabeth Bates, Linda Kaye, and Lauren Bolan. 2017. “Transitioning in Higher Education: An Exploration of Psychological and Contextual Factors Affecting Student Satisfaction.” *Journal of Further and Higher Education* 42 (5): 596–607. https://doi.org/10.1080/0309877X.2017.1302563.

Pietiläinen, Virpi. 2021. “Matematiikan osaamisen taso on laskenut ja eriytynyt.” Karvi.fi. December 9, 2021. https://karvi.fi/2021/12/09/matematiikan-osaamisen-taso-on-laskenut-ja-eriytynyt/.

Pintrich, Paul. 2000. “THE ROLE OF GOAL ORIENTATION IN SELF-REGULATED LEARNING.” In *Handbook of Self-Regulation*, edited by Monique Boekaerts et al., 451–529. Academic Press.

Porras, Päivi, Jarkko Hurme, and Henry Lähteenmäki. 2023. “Improving Mathematical Skills towards Undergraduate Studies.” In *The 21st SEFI Special Interest Group in Mathematics – SIG in Mathematics*, 120–25. European Society for Engineering Education (SEFI). https://www.sefi.be/publication/mathematics-sig-seminar-2023-proceedings/.

Rasila, Antti, Jarmo Malinen, and Christopher Sangwin. 2015. “On Automatic Assessment and Conceptual Understanding.” *Teaching Mathematics and Its*

Applications: An International Journal of the IMA 34 (3): 149–59. https://doi.org/10.1093/teamat/hrv013.

Rinneheimo, Kirsi-Maria. 2017. “Enhancing Learning and Teaching in Engineering Mathematics with Technology.” In *EDULEARN17 Proceedings*. https://doi.org/10.21125/edulearn.2017.1236.

Shaikh, Umair Uddin, and Zaheeruddin Asif. 2022. “Persistence and Dropout in Higher Online Education: Review and Categorization of Factors.” *Frontiers in Psychology* 13. https://www.frontiersin.org/articles/10.3389/fpsyg.2022.902070.

Shute, Valerie. 2008. “Focus on Formative Feedback.” *Review of Educational Research* 78 (1): 153–89.

Torrance, H. 2012. “Formative Assessment at the Crossroads: Conformative, Deformative and Transformative Assessment.+.” *Oxford Review of Education* 38 (3): 323–42. https://doi.org/10.1080/03054985.2012.689693.

Van Rooij, E., J. Brouwer, M. Fokkens-Bruinsma, E. Jansen, V. Donche, and D. Noyens. 2017. “Inzicht in de verklaringsbasis voor studiesucces bij eerstejaarsstudenten in Nederland en Vlaanderen: een overzichtsstudie.” *Pedagogische Studiën* 94 (5). https://pedagogischestudien.nl/article/view/14100.

Velichová, Daniela. 2021. “The Role of Visualization in Mathematics.” In *The 20th SEFI MWG Seminar on Mathematics in Engineering Education*, 63–68. Kristiansand, Norway.

Winne, P.H. 1982. “Minimizing the Black Box Problem to Enhance the Validity of Theories about Instructional Effects.” *Instructional Science* 11 (1).

Witting, Mika. 2021. “Lukio, amis vai pelkkä peruskoulu? – Perusopetuksen jälkeisillä valinnoilla on usein kauaskantoiset vaikutukset (High school, vocational school or just elementary school?- "Choices made after primary education often have far-reaching effects).” Tilastokeskus. May 28, 2021. https://www2.tilastokeskus.fi:443/tietotrendit/artikkelit/2021/lukio-amis-vai-pelkka-peruskoulu-perusopetuksen-jalkeisilla-valinnoilla-on-usein-kauaskantoiset-vaikutukset/.

Yılmaz, Ayşe, and Serçin Karataş. 2022. “Why Do Open and Distance Education Students Drop out? Views from Various Stakeholders.” *International Journal of Educational Technology in Higher Education* 19 (1): 28. https://doi.org/10.1186/s41239-022-00333-x.

Integration of Life Cycle Assessment of full-scale Structures as part a PBL Civil Engineering Programme

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Conference Key Areas: *#1 Teaching the knowledge, skills and attitudes of sustainable engineering. #2 Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing*
Keywords: *Life Cycle Assessment, Engineering Education, Timber Engineering, Problem-Based Learning*

ABSTRACT

To prepare students for employment at enterprises that are responding to more environmentally conscious consumers and investors, coupled with expanding environmental and resource efficiency regulations, the Life Cycle Assessment (LCA) approach is being integrated into various higher education engineering programmes. This paper outlines the integration of LCA education into a Problem Based Learning (PBL) structural engineering module at University of Limerick, Ireland for a large-scale design and build bridge project. In workshop format, students with limited prior

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LCA experience, were provided with an overview of the global and local environmental challenges associated with construction, the existing and emerging policy context, and the LCA approach. The students then undertook LCA calculations to estimate the carbon footprint of their structures early in the design phase based on default life cycle inventory assumptions and impact assessment characterisation factors. Measured data for the actual amount of materials and energy utilised in fabrication, energy requirements in deconstruction and associated waste material was collected. The geographical locations of manufactured materials and the actual end-of-life destinations of materials used in project were identified. The process enabled students to make key decisions on the environmental impact of their structures during the design stage. Undertaking observations, measurements and calculations of the as-built carbon footprint of their structure engaged students in the LCA process in a practical and experiential learning approach. The process provided real-world context to theoretical concepts, and provides excellent preparation as they move on to more complex projects.

1 INTRODUCTION

1.1 Life Cycle Assessment Policy Developments for the Built Environment

Societal development patterns are placing increasing strain on the natural environment with over extraction of resources, generation of waste and associated pollution impacting human health and ecosystem functions. The input, output and stock of materials and energy needed to satisfy all human needs has accelerated greatly since the 1950s, driven by increases in human population, but also increasing throughput per capita due to rising affluence (Steffen et al. 2011; Brunner and Rechberger 2017). This increase in material and energy flows by human activities is leading to unintended environmental impacts whereby the ability of the Earth’s natural systems to self-regulate to a state of climatic and ecological stability is being disrupted by approaching or crossing safe operating limits for the nine planetary boundaries (Rockström et al. 2009).

Increasingly it is being observed that the LCA framework (ISO 14040 and ISO 14044) is being employed by policy makers and legislators to guide quantification of the environmental sustainability impacts of various products and services to identify hotspots for improvement. ISO 14040 highlights the direct applications of the Life Cycle Assessment (LCA) framework for informing public policy making, product development and improvement, strategic planning, and marketing among others (ISOa 2006). The International Life Cycle Database (JRC 2012) define LCA as a vital decision support tool to help make consumption and production more sustainable, providing a comprehensive and standardised method that quantifies all relevant emissions and resources consumed, the related environmental and health impacts, and resource depletion issues, along the entire life cycle of any good or service. The European Environmental Agency identify LCA a process for evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities (EEA 2023). Key elements of LCA process involve (1) identify and quantify the environmental loads involved, e.g., the energy and raw materials consumed, the emissions and wastes generated; (2) evaluate the potential environmental impacts of these loads; and (3) assess the options available for reducing these environmental impacts (EEA 2023).

Within this context national and international policy makers are increasingly using the LCA framework to assess the environmental impact of the built environment. LCA calculation methods and standards such as EN 15978 ‘Sustainability of construction works’ (Figure 1) and the EU Level(s) framework for sustainable buildings provide a common language for assessing and reporting on the sustainability performance of buildings and is a simple entry point for applying circular economy principles in our built environment (EC 2023).

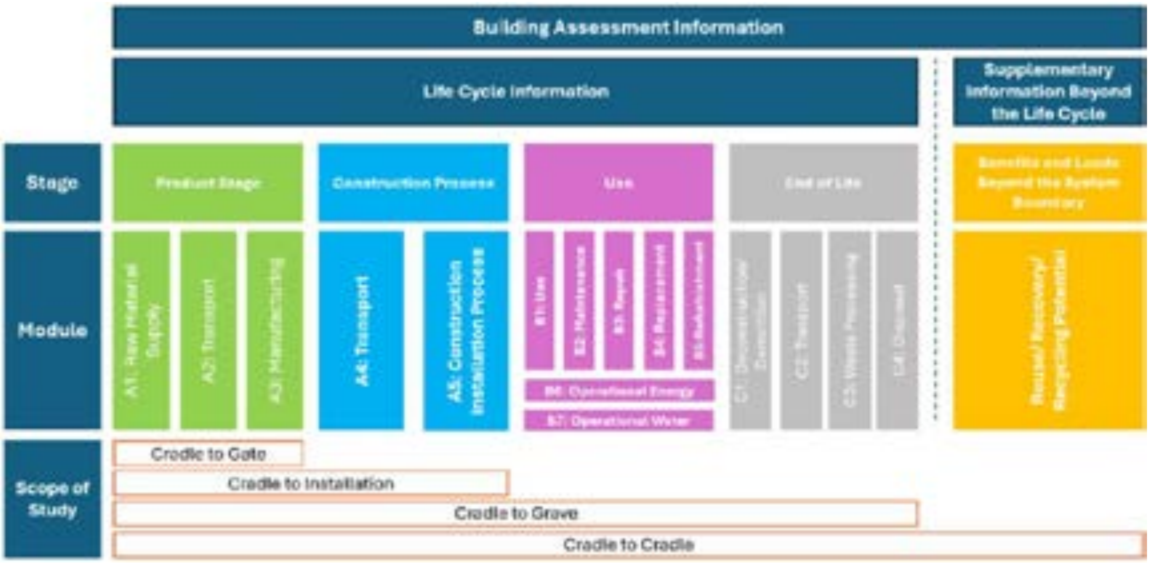


Figure 1. EN 15978 building life cycle modules

The revised Energy Performance of Building Directive was approved by the European Parliament in March 2024, with the upcoming requirement for calculating and reporting buildings' carbon footprints starting with larger buildings in 2028 and extending to all buildings by 2030 (OneClickLCA 2024).

From an Irish higher education perspective, the Irish Green Building Council have outlined the need for whole life carbon skills and competencies to be embedded in third level education with targets for third level curriculum to be infused with environmental education to increase carbon literacy and understanding of resource constraints (IGBC 2022a).

1.2 Integrating LCA into Engineering Programmes

Educating engineering students in sustainability is becoming increasingly important since engineering is expected to play a vital role in solving the sustainability challenges facing society (Olsen et al. 2018). By incorporating LCA into undergraduate and postgraduate programmes for the built environment, it is intended that upon entering industry the professionals of the future are up to speed with a method that can enhance the sustainability of buildings (Finnegan et al. 2013). It is worth noting that while there are a significant number of programmes, courses and modules focus on LCA globally, the academic literature relating to integration of LCA in educational engineering programmes is comparatively sparce (Burnley et al. 2019).

Finnegan et al. (2013) has suggested that the best way to teach LCA for the built environment is to integrate it into existing programmes instead of siloed standalone courses. Of the literature that does focus on integration of LCA into engineering programmes the predominant focus has been on integrating LCA learning objectives at programme level with increasing levels of complexity, ranging from bachelor's to PhD level, based on Blooms Taxonomy and revised Taxonomy (Olsen et al. 2018; Cosme et al. 2019, Viere et al. 2021).

1.3 The University of Limerick Civil Engineering Programme

The Civil Engineering programme at the University of Limerick, Ireland commenced in 2008 with a goal to develop people with a life-long research orientation who can address complex problems in the built and managed environment, developing solutions rationally but creatively by collaborating within teams (Cosgrove et al. 2010). Problem Based Learning (PBL) was identified as an effective means to achieve these ends as the programme team believe that attitudes and habits are not formed by transmitting content, but by embedding work with appropriate content within an effective process. PBL activities, or 'triggers', are integrated throughout the four-year undergraduate and five-year postgraduate degree programmes. Within these activities, technical content teaching endeavours to meet a 'just in time' delivery to coincide with the learning needs of the student at each stage of the PBL trigger (Phillips and Quilligan 2014). In addition, each PBL trigger requires students to complete a full design process from problem to solution. As students progress through the programme the PBL problem solving process remains the same, but the complexity of the challenges increases (Figure 2).

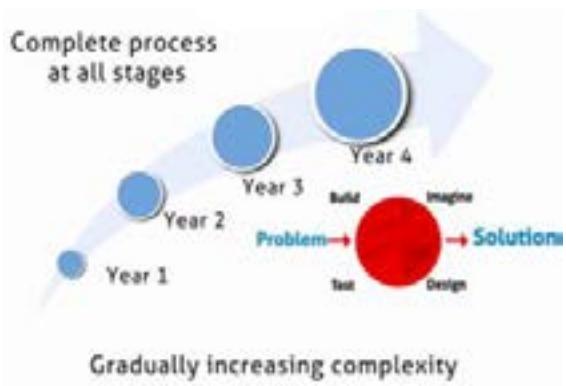


Figure 2. Progression of complexity in PBL triggers through programme

Figure 3. Tutor discussing LCA calculations with group in PBL workshop

2 METHODOLOGY

This paper outlines the integration of LCA education into the trigger which drives the 'Structural Engineering Design 2' module (6 ECTS credits) in Year 2 of the programme. The trigger challenges students to provide a safe means for a staff member to cross a specified body of water on the university campus. The aim of the trigger, before the consideration of LCA impacts, is to instil key engineering skills relating to structural design and optimisation through a PBL approach. Students work in 8 groups of approx. 7 students (Figure 3) to design a solution over a period of 12 weeks. Student contact time each week consists of 2 x 2-hour PBL sessions moderated by 2 tutors with significant industry experience and 1 x 1-hour lecture. The structures are fabricated over a 4-day period and then placed in position by the students with help of university technical staff. Due to nature of the brief with requirement for student fabrication, timber is the predominant material of choice for the structures, with structural forms typically spanning 5 m. The tutors encourage the groups to explore a range of structural forms which enables students to see the multiplicity of design choices available to them. While bridge structures are generally chosen to solve the brief, rafts have often been chosen as an efficient and effective solution.

This paper describes how integration of LCA education into the trigger was approached via:

- LCA Design Workshop: providing students with a background context for the need to perform LCA and an understanding of the LCA approach;
- LCA Design Stage Calculations: practical calculations based on default assumptions and characterisation factors provided from the literature;
- LCA As-built Observations and Measurements: observation and measurement of data relating to supplied product, construction process, end of life and benefits beyond the system boundary;
- LCA Review Workshop and As-built Calculations: real-world observation carbon footprint calculations based on project generated inventory data and Irish specific data sources and assumptions.

This is the 3rd iteration of LCA integration into the module. Spreadsheet templates were recently introduced to help improve data recording and presentation of key outputs.

2.1 LCA Design Workshop and Design Stage Calculations

The development of the LCA Design Workshop entailed a review of existing environmental education and engineering LCA literature. A high-level overview of the global and local environmental challenges associated with construction for the workshop drew on publicly available resources to contextualise the need for LCA in the construction sector. EU and national governmental and public body materials relating to upcoming LCA methodologies and regulations were also summarised.

The main phases of the LCA approach outlined in ISO 14044 provided the overarching framework for the workshop, i.e. (1) identification of the goal and scope of the LCA, (2) the life cycle inventory analysis phase, (3) the life cycle impact assessment phase, (4) the life cycle interpretation phase (ISOb 2006).

To aid with the LCA Design Stage Calculations, educational material and design stage calculation sheets were developed and aligned to these 4 phases with illustrative case studies for each phase of LCA from a construction perspective. Specific attention was given to EN 15978 for building LCA system boundary (Figure 1) due to its relevance to upcoming EU environmental regulations. A design stage calculation sheet was developed using default LCA assumptions and characterisation factors based on the Institution of Structural Engineers 'How to Calculate Embodies Carbon' (Gibbons et al. 2022).

2.2 LCA As-built Observations and Measurements

To aid students in collection of real-world observation LCA data associated with their as-built timber bridge project (Figure 3), a data collection sheet was developed to log volume and mass of ordered materials, source of materials, material losses during fabrication, waste material after deconstruction (i.e. all the wood used in project) and reused materials (i.e. metal screws, plates, and cables). Energy associated with construction and deconstruction was measured using kWh measurement devices at electrical sockets for the bench saw, sawdust collector and charging of electric drill batteries.

2.3 LCA Review Workshop and As-built Calculations

Based on the as-built data, an updated LCA calculation template was developed. Irish specific LCA assumptions and characterisation factors were utilised where available, for example, EPD Ireland Product Category Rules (IGBC 2022b), and IGBC National Inventory of Generic Construction Materials Data (IGBC 2024).

(a)

(b)

(c)

(d)

Figure 4. a,b) Structures fabricated by students in lab area; c) As-built structures in place over pond; d) Disassembly of structures undertaken by students

Characterisation factors not available for Modules C and D were sourced from the Ecoinvent V3.91 database for Ireland, and proxy data from Europe if Irish data was absent. Suppliers were contacted to ascertain if they had Environmental Product Declarations for their product or if not available the country of manufacture to allow for estimation of supply transportation distances and country specific production processes.

In addition, university department staff and waste service providers were contacted to identify end-of-life destination of wood after bridge deconstruction to estimate transportation distances, and potential impacts beyond the system boundary either through reuse, recycling, incineration, or landfilling.

2.4 Functional Unit and System Boundary

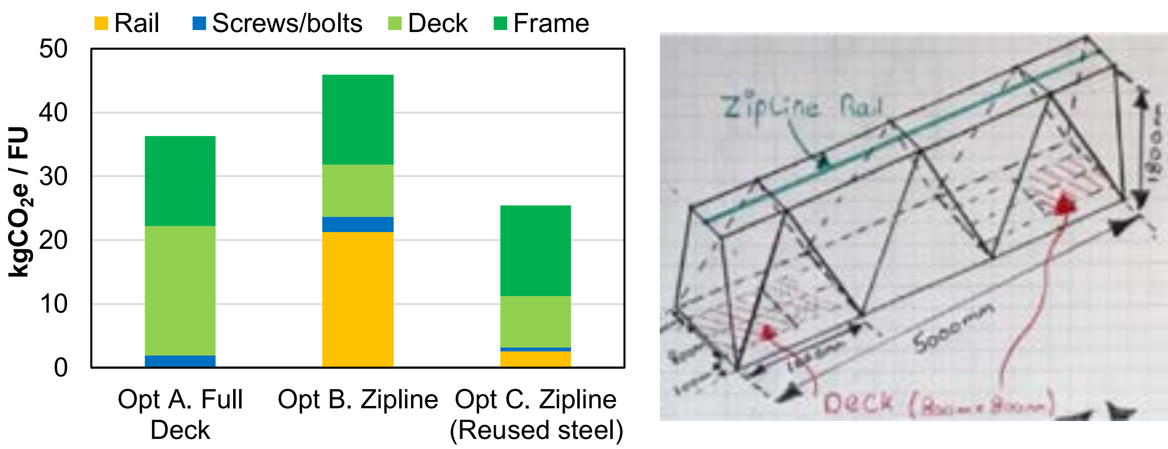
The Functional Unit (FU) of this study is a bridge structure to support a single person (1000 N characteristic load) over a 5 m span. A FU enables objective comparison of different systems that serve the same final function. The system boundary of the study included the environmental impacts of materials and energy associated with the bridge superstructure only. The substructure of the bridge was excluded as supports are reused every year and not part of student brief. The design stage workshop and calculations only included modules A1-5 of EN 15978 so as not overwhelm students with too much information as they had limited experience with LCA. Gibbons et al. (2022) state that biogenic carbon should not be included if only modules A1-5 are analysed due to uncertainties surrounding end-of-life. As such biogenic carbon was not included in this analysis due to the added complexity associated with accounting for sequestration and release of emissions. The as-built workshop and calculations considered C and D modules, due to data availability on end of life and loads beyond system boundary, providing students with experiential learning opportunities in tandem with introduction to theoretical concepts.

3 RESULTS

In this section a sample structure from a group in the 2023 running of the module is selected to illustrate and provide insights into the implemented process.

3.1 Design Stage

Figure 5a presents a breakdown of embodied carbon for a truss structure that was developed by a student group. It became apparent during the design stage that the deck material upon which the bridge user would walk accounted for a significant proportion of the structure's mass and resultant embodied carbon. The group proposed a design Option B whereby the deck would be replaced by a high-level rail from which the user would slide to create a 'zipline' (Figure 5b). This option had a lower amount of embodied carbon associated with the deck component, however overall emissions for Modules A1-3 increased from 36.3 to 46.0 kgCO_2e due to the higher emissions associated with the steel rail.



a) *b)*

Figure 5. a) Breakdown of embodied carbon for 3 design options for sample structure (Modules A1-3); b) Student sketch of proposed zipline structure

The calculation for Option B assumed that the rail was using virgin metal, however a rail was available for use that had been used in a number of previous projects. Based on tutor experience it was estimated that the rail would be available to provide

8 uses, whereas metal screws and cables are typically able to provide 4 uses. Calculated virgin emissions for the metal were therefore reduced proportionally by a factor of 8 to account for reusability. A significant reduction from 36.3 to 25.4 $kgCO_2e$ was therefore achieved compared to the full deck bridge. This information provided the student designers with key quantifiable LCA data to aid with decision-making.

3.2 As-built Stage

Figure 6 presents the results of the as-designed structure accounting for Modules A1-5, and the as-built structure accounting for Modules A-C, D. For Modules A1-5 which account for 'cradle-to-installation', the as-built emissions (34.2 $kgCO_2e$) were approx. 30% higher than the as-designed (26.3 $kgCO_2e$).

There were two main sources for the difference. First, at design stage a wastage in material of 10% for timber elements was assumed. Due to the overall length of the structure being 5 m and common timber lengths being 4.8 m, there was much more wastage encountered during fabrication. Secondly the A4 transport emissions associated with plywood for the as-built calculation was significantly higher due to the wood being manufactured in China, while at the design stage it was assumed that all wood was sourced in Ireland.

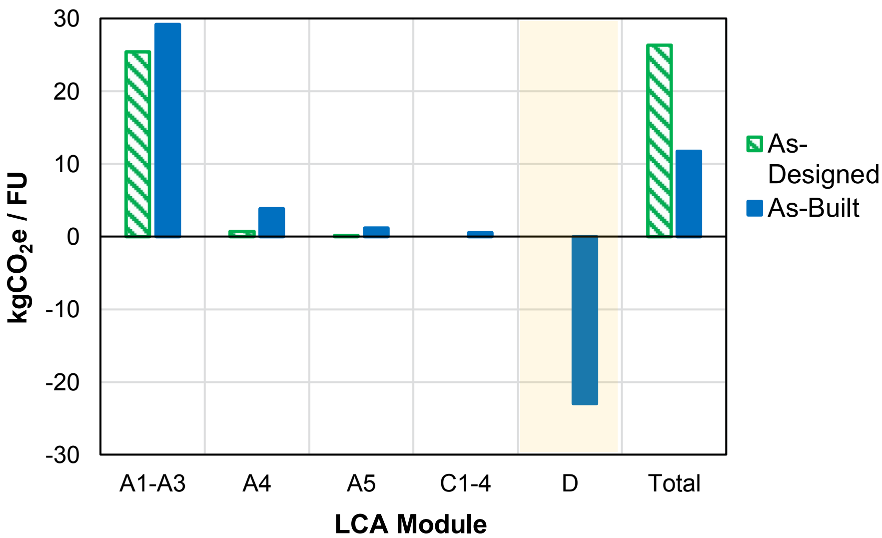


Figure 6. Breakdown of embodied carbon for sample structure as-designed (A1-5) and as-built (A-D).

The as-built structures were disassembled at their end of life (Modules C1-4) and 75% of the timber was reused for other timber projects in an education environment, while 25% was incinerated in a waste-to-energy plant. As biogenic carbon was not accounted for, the impacts associated with reuse were only due to local transportation impacts, while the wood that was burned was assumed to be transported locally and incinerated in a waste-to energy plant to generate heat and avoid heat production from natural gas as per Irish product category rules guidance. This resulted in a significant offsetting of net total emissions compared to the as-designed calculations due to the benefits beyond the system boundary in avoiding natural gas for heating. The as-built structure is associated with a total embodied carbon value of only 11.7 $kgCO_2e$.

4 Summary

This paper showcases an innovative approach to embedding LCA thinking and skills in a higher education PBL engineering design and build project. This was achieved via design stage workshops and calculations, as-built observations, measurements and calculations, and a review workshop.

The approach enabled students to make key decisions on the environmental impact of their structures during the design stage. For the sample structure a significant saving in embodied carbon was achieved based on LCA decisions at design stage.

Undertaking observations, measurements and calculations of the as-built carbon footprint of their structure engaged students in the LCA process in a practical and experiential learning approach. A comparison of the as-built and as-designed calculations has the significant benefit of showcasing the limits of theoretical assumptions and calculations which rely on default data, and the need for actual measurement of life cycle inventory parameters and assumptions to ensure transparent reporting of environmental impacts for construction projects.

The process provided real-world context to theoretical concepts, and provides excellent preparation as they move on to more complex projects.

References

Brunner, P.H. and Rechberger, H. 2017. *Handbook of Material Flow Analysis*, 2nd ed. Boca Raton: CRC Press.

Burnley, S., Wagland, S. and Longhust, P. 2019. “Using life cycle assessment in environmental engineering education.” *Higher Education Pedagogies* 4, 1: 64-79. https://doi.org/10.1080/23752696.2019.1627672.

Cosgrove, T. Phillips, D. and Quilligan, M. 2010. “Educating engineers as if they were human: PBL in Civil Engineering at the University of Limerick.” *3rd international symposium for engineering education ISEE2010, University College Cork.*

Cosme, N., et al. 2019. “Learning-by-doing: experience from 20 years of teaching LCA to future engineers.” *International Journal Life Cycle Assessment* 24: 553–565. https://doi.org/10.1007/s11367-018-1457-5.

EC. No date. “Level(s) European framework for sustainable buildings”, accessed on April 5, 2024. https://environment.ec.europa.eu/topics/circular-economy/levels_en.

EEA. “Life cycle assessment.” Accessed April 5, 2024. https://www.eea.europa.eu/help/glossary/eea-glossary/life-cycle-assessment.

Finnegan, S., et al. 2013. “Life Cycle Assessment (LCA) and its role in improving decision making for sustainable development.” *Engineering Education for Sustainable Development, Cambridge, UK, September 22-25.*

Gibbons, O.P., Orr, J.J., Archer-Jones, C., Arnold, W. and Green, D. 2022. *How to calculate embodies carbon. 2nd Edition.* London: The Institution of Structural Engineers, 2022.

IGBC. 2022a. *Building a Zero Carbon Ireland- A roadmap to decarbonise Ireland’s Built Environment across its Whole Life Cycle*, Dublin: Irish Green Building Council.

IGBC. 2022b. *Product Category Rule: Part A*, Dublin: Irish Green Building Council.

IGBC. 2024. "Generic Data." Accessed on April 5, 2024. https://www.igbc.ie/generic-data/.

ISO. 2006a. "ISO 14040:2006 Environmental management Life cycle assessment Principles and framework." Accessed on April 5, 2024. https://www.iso.org/standard/37456.html.

ISO. 2006b. "ISO 14044:2006 Environmental management Life cycle assessment Requirements and guidelines." Accessed on April 5, 2024. https://www.iso.org/standard/38498.html.

Olsen, S.I., et al. 2018. "Sustainability and LCA in Engineering Education- A Course Curriculum" *Procedia CIRP* 69: 627-632. https://doi.org/10.1016/j.procir.2017.11.114.

OneClickLCA. No date. "EU Parliament approves revised EPBD- a milestone in 'Fit for 55' climate initiative." Accessed April 5, 2024. https://oneclicklca.com/en/resources/articles/eu-parliament-approves-revised-epbd-fit-for-55-initiative.

Phillips, D., and Quilligan, M. 2014. "Teaching an introductory course in soil mechanics using problem based learning." *iCEER 2014- McMaster, Hamilton, Ontario, Canada, August 24-26.*

Rockström, J., et al. 2009. "Planetary boundaries: exploring the safe operating space for humanity." *Ecology and Society* 14(2): 32.

Steffen, W., Grinevald, J., Crutzen, P. and McNeill, J. 2011. "The Anthropocene: a conceptual and historical perspective." *Philosophical Translations of the Royal Society* 369: 842-867. https://doi.org/10.1098/rsta.2010.0327.

Viere, T., et al. 2021. "Teaching life cycle assessment in higher education. *Int J Life Cycle Assess* 26: 511-527. https://doi.org/10.1007/s11367-020-01844-3.

Wolf, M., et al. 2012. *The International Reference Life Cycle Data System (ILCD) Handbook: Towards more sustainable production and consumption for a resource-efficient Europe.* Luxembourg: Publication Office of the European Union.

Integrating Responsible Innovation into Engineering Education: Insights from Scenario Leads at UCL's Integrated Engineering Programme

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ABSTRACT

This paper explores the integration of responsible innovation into engineering education through a case study of UCL's Integrated Engineering Programme. Focusing on the Design and Professional Skills (DPS) modules, which includes scenarios designed to simulate real-world engineering challenges, the study investigates the perspectives of scenario leads on incorporating topics related to responsible innovation, such as ethics, sustainability, risk management, and inclusivity. Drawing on interviews with scenario leads, the paper identifies challenges and successes in integrating responsible innovation into DPS scenarios, including time constraints, disciplinary-specific contextualization, and means of assessment. Despite these challenges, certain success stories highlight the potential for meaningful integration of responsible innovation topics. Through a review of literature on responsible innovation and engineering education, the paper

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contextualizes the findings within broader discussions of curriculum development and interdisciplinary approaches to teaching ethics and social responsibility. Emphasizing the importance of ongoing dialogue and collaboration, the paper concludes by envisioning a forward-looking approach to curriculum development that prioritizes responsible innovation and prepares engineering students to address complex societal challenges in their future careers.

1 INTRODUCTION

Climate change stands out as one of the most pressing issues facing humanity due to its profoundly destructive effects on the livelihoods of numerous communities across the world (Fetting, 2020). Europe, in particular, has set ambitious goals, aiming for zero climate impact by 2050 (Tsiropoulos et al., 2020), supported by initiatives like the European Green Deal, spearheaded by the European Commission to foster sustainability in the EU economy (Fetting, 2020). Towards achieving these goals, efforts are underway to develop strategies for a more resource-efficient economy, reflecting a broader commitment to sustainable development (Fetting, 2020). European policies further emphasize transitioning towards a circular economy and promoting sustainable resource management practices (Kasinathan et al., 2022). These initiatives align with global frameworks such as the UN Sustainable Development Goals (SDGs), which play a significant role in shaping engineering education policies (Kasinathan et al., 2022; Scoones et al. 2020).

Indeed, engineers today face a growing demand to tackle intricate socio-technological challenges as part of their practice (Perkins, 2013). Within this context, the Accreditation of Higher Education Programmes (AHEP4) framework in the UK underscores the importance of the social dimension in engineering (Engineering Council, 2020). In fact, AHEP4 encompasses various facets of Responsible Innovation, such as sustainability, ethics, risk management, and inclusivity. Through its language and learning outcomes, AHEP4 underscores the importance of addressing these societal and ethical considerations alongside technical expertise in engineering curricula. (Engineering Council, 2020; Wint, 2022, Truslove et al. 2023). However, despite widespread acknowledgment, current higher education structures often fall short in adequately preparing engineering students for the complexities of social responsibility (Bowen, 2009). This deficiency is compounded by a lack of clarity regarding the exact societal role engineers are expected to fulfill (Zandvoort, 2008; Riley & Lambrinidou, 2015; Bielefeldt, 2018). Engineering student disengagement with societal issues poses a serious problem, because it limits their capacity to devise socially equitable and sustainable solutions (Litchfield & Javernick-Will, 2015; Dornick, 2023).

Universities are responding to accreditation requirements by developing specialized courses for sustainability by defining competencies that promote Education for Sustainable Development (ESD). However, there is a concern that these courses may lack a holistic understanding of sustainable development or general sustainability competencies (Giannopoulos et al. 2023). Studies indicate a lack of design and implementation of engineering courses that address both technical and sustainability-oriented issues simultaneously (Stock & Kohl, 2018; Block & Guerne, 2022; Bjornberg et al. 2015, Sanchez-Carracedo et al., 2020; Watson et al., 2013).

Despite this, sustainable practices are being integrated into engineering programs through stand-alone courses or integration into existing ones (Mesa et al., 2017).

One approach to better integrate Sustainable Development Goals (SDGs) into engineering curricula is by embedding them within existing technical courses, such as environmental engineering, where exploration of engineering solutions can align with specific SDG targets like clean water and sanitation or sustainable cities and communities (Leal Filho et al., 2022). Additionally, in engineering design courses, ethical considerations can be seamlessly integrated into design decisions to address potential social and environmental impacts (Leal Filho et al., 2022). Furthermore, creating dedicated courses or modules explicitly focused on SDGs and ethics can provide in-depth discussions on the ethical implications of engineering practice and the pivotal role of engineering in achieving sustainable development goals (Leal Filho et al., 2022).

Emphasizing the significance of SDGs and ethics across the curriculum is paramount. This comprehensive approach involves modelling ethical behaviour, promoting ethical inquiry and reflection, fostering open dialogue on ethical issues, and providing opportunities for students to engage in ethical decision-making exercises (Martin et al., 2021). Real-life events can serve as valuable contextual frameworks, enhancing understanding and competence in sustainable development (Leal Filho et al., 2022). Collaboration with external stakeholders and guest speakers further enriches the learning experience, facilitating the implementation of ethics scenarios within the curriculum (Martin et al., 2021). This integrated approach aligns with the proposition made by Holmberg et al. (2008) and Segalàs et al. (2010) that experiential active learning enhances cognitive understanding of sustainable development, advocating for a constructive and community-oriented pedagogical approach.

Since its inception a decade ago, the Integrated Engineering Programme at UCL has been actively exploring methods to incorporate various aspects of responsible innovation, including the integration of Sustainable Development Goals (SDGs) across engineering curricula (Hailes et al., 2021; Mitchell at al., 2021; Roach et al., 2022) . One avenue through which this integration occurs is via the courses Design and Professional Skills I and II (DPS). These courses are specifically designed for BEng/MEng students in Biochemical, Biomedical, Chemical, Civil, Electronic & Electrical, and Mechanical Engineering, as well as BSc/MEng students in Computer Science. Throughout the Design and Professional Skills courses, students delve into crucial aspects such as communication, academic research, ethics, teamwork, sustainability, project management, the engineering design cycle, and various technical skills pertinent to their chosen discipline. An integral part of Design & Professional Skills are the Scenarios - week-long team projects where regular lectures pause, allowing students to focus solely on a collaborative technical engineering design endeavour(Mitchell et al., 2014). Led by the department, Scenarios provide a platform to apply the coursework-related knowledge to subject-specific issues, offering invaluable insights into engineering practices. Participation in Scenarios is designed to offer UCL engineering students a first-hand glimpse into real-world engineering challenges.

This paper explores the experiences of scenario leads—lecturers who guide scenario sessions—examining their approaches, challenges, and successes in integrating responsible innovation during scenario weeks. By delving into their experiences, the paper aims to uncover strategies for embedding responsible innovation into scenario-based learning, offering insights for fostering sustainability and ethical considerations in engineering education. Identifying challenges encountered by scenario leads can inform the development of support mechanisms to address integration barriers.

2 METHODOLOGY

The methodology involved conducting semi-structured interviews with 10 scenario leads for Design and Professional Skills from each of the different engineering disciplines within the Faculty of Engineering. Each lead was interviewed individually, allowing for in-depth exploration of their experiences and perspectives. The interviews were guided by a set of predetermined questions, tailored to elicit insights into various aspects of scenario design and implementation.

The interview questions covered multiple dimensions of the scenarios, including their content, learning objectives, context, assessment methods, and connections to core modules or other scenarios. Additionally, the questions addressed the inclusion of key topics such as ethics, responsibility, risk, safety, sustainability, and societal/community impact within the scenarios.

Furthermore, the interviews sought to ascertain the scenario leads' familiarity with and coverage of the Accreditation of Higher Education Program (AHEP4) criteria. They also explored whether the scenarios were standalone or interconnected with others, as well as any perceived gaps or areas for improvement.

Importantly, the interviews aimed to highlight the extent to which the scenarios supported Education for Sustainable Development (ESD) competencies and Sustainable Development Goals (SDGs). Additionally, the scenario leads were asked about their preferences regarding the introduction of sustainability content to undergraduate students and their openness to embedding more ESD into the scenarios.

As part of each interview, we inquired about the barriers they faced in terms of incorporating topics related to responsible innovation and how they believed they could be best supported in overcoming these barriers. This aspect aimed to identify challenges and potential areas for intervention to facilitate the integration of responsible innovation into scenario-based learning effectively.

3 RESULTS

The results section provides an overview of the findings obtained from interviews conducted with scenario leads regarding their experiences - challenges, successes, and support needs in integrating responsible innovation into their scenarios within engineering education. Through a qualitative analysis of the interview data, key themes emerged, shedding light on the complexities and nuances involved in embedding sustainability principles, ethical considerations, and social impact awareness into engineering curricula.

3.1 Challenges In Integrating Sustainability

- Resistance from certain departments towards integrating sustainability due to differing priorities poses challenges in balancing technical knowledge with sustainability considerations, reflecting the varying perspectives within engineering education.
- Embedding sustainability into the curriculum presents multifaceted challenges, encompassing the necessity for contextualization and gradual introduction of concepts, aligning teaching activities with accreditation requirements while preserving flexibility for innovation, and addressing difficulties in mapping learning outcomes against accreditation criteria and aligning learning objectives across different levels of study.
- Time constraints within modules pose challenges in effectively delivering theoretical content and fitting it into structured curricula, while challenges associated with financial constraints, staff availability, and resource limitations hinder the implementation of sustainability aspects, such as securing external speakers.

3.2 Success Stories In Promoting Responsible Innovation

- Utilizing scenario-based learning integrates real-world problems, ethical considerations, and awareness of global initiatives like the SDGs, fostering student engagement, critical thinking, and social responsibility.
- Encouraging collaboration among student teams and with external mentors fosters diverse perspectives and enhances learning outcomes through assignments on varied scenario topics, promoting inclusivity and exposure to a range of sustainability issues and solutions.
- The implementation of practical sustainability projects, such as green hydrogen generation and waste-to-energy alternatives, showcases students' growing awareness in engineering sustainability, while integrating lifecycle assessment considerations into project design and material selection fosters environmentally conscious decision-making and innovation.

3.3 Call For Collaborative Resource Development

- There is a keen interest in joining workshops, communities of practice, and summer programs aimed at exchanging best practices and experiences regarding the integration of sustainability in engineering education.
- There's a demand for practical tools, resources, and support to scaffold sustainability education, contextualize topics, and integrate responsible innovation into the curriculum, reflecting an interest in early education on ethics and responsible innovation in engineering.
- Advocating for the importance of proper support mechanisms, including quick and detailed feedback for students, to enhance the learning experience, effectively integrate sustainability principles into teaching practices, and create signposting resources that draw connections to existing content without overwhelming students with new material.
- Acknowledging the necessity of continuous adaptation and innovation in engineering education to meet evolving challenges and industry demands,

there's an openness to integrating more sustainability aspects into scenarios without overwhelming students or lecturers, emphasizing the need for flexible approaches and ongoing support in curriculum development.

4 DISCUSSION

The insights shared by the scenario leads concur with findings in the literature that report the experiences of several engineering educators who are recognizing the possibilities and limitations of embedding facets of responsible innovation into their curricula. Instructors are pivotal in the integration of sustainable development into curriculum and course content (Park et al., 2022). However, successful integration requires professional development opportunities and faculty support. This also involves reaching out to individual academic staff because all instructors may not perceive sustainable development and ethics as relevant (Tepsa et al., 2023). The process of embedding topics such as climate justice into the curriculum necessitates more than just adding new content; it must become part of the paradigm and everyday thinking (Sterling, 2001). An integrated approach to teaching sustainable development is essential, providing students with a comprehensive understanding and raising awareness of sustainable practices (Perdan et al., 2000). Furthermore, Education for Sustainable Development (ESD) demands teaching and learning approaches that enhance knowledge, promote ethical reasoning, and motivate participation in community affairs. Accordingly, pedagogical strategies should be designed to support sustainability learning outcomes (Svanström et al., 2008).

The learnings from this paper should ideally serve as a practical guide for engineering programs at other universities that intend to incorporate responsible innovation into their curricula. By adopting the scenario-based approach highlighted in our study and heeding the experiences of our scenario leads, these universities can facilitate an immersive and collaborative learning experience for students. We share our methods and outcomes with the hope of inspiring other educators to implement similar strategies, but adapted to their local context. Thus, we may foster a community of practice dedicated to advancing climate justice and earth science topics in engineering education.

Engineers wield significant influence in addressing and responding to the challenges posed by climate change. Yet, the multifaceted nature of the problem and the far-reaching sociocultural ramifications of engineering interventions make it a complex issue to navigate. The work reported in this paper is part of an ongoing study to better understand the landscape of responsible innovation within the Faculty of Engineering. The aim is to help engineering educators foster a culture that equips future engineers with the knowledge, skills, and mindset needed to tackle the challenges of climate change and contribute meaningfully towards communal development.

REFERENCES

Bielefeldt, Angela R. "Professional Social Responsibility in Engineering." Social Responsibility 41 (2018).

Block, Brit-Maren, and Marie Gillian Guerne. "Sustainable engineering education in research and practice." In Towards a new future in engineering education, new scenarios that european alliances of tech universities open up, European Society for Engineering Education (SEFI), 2022.

Edvardsson Björnberg, Karin, Inga-Britt Skogh, and Emma Strömberg. "Integrating social sustainability in engineering education at the KTH Royal Institute of Technology." International journal of sustainability in higher education 16, no. 5 (2015): 639-649.

Bowen, William Richard. Engineering ethics: Outline of an aspirational approach. Springer Science & Business Media, 2008.

Dornick, Sahra. "Addressing The Challenges Of Climate Change And Sustainability." European Society for Engineering Education (SEFI) (2023).

Engineering Council. The Accreditation of Higher Education Programmes (AHEP). 4th Edition. (2020)

Fetting, Constanze. "The European green deal." ESDN report 53 (2020).

Giannopoulos, George, Vasiliki Kioupi, Alfred Oti, and Tatiana Vakhitova. "Investigating The Perceptions Of Science And Engineering University Educators And Students Around Sustainability Integration And The Role Of Digital Tools." European Society for Engineering Education (SEFI). (2023).

Hailes, Stephen, Liz Jones, Martina Micheletti, John E. Mitchell, Abel Nyamapfene, Kate Roach, Emanuela Tilley, and Fiona Truscott. "The UCL Integrated Engineering Programme." Advances in Engineering Education (2021).

Holmberg, John, Magdalena Svanström, D-J. Peet, Karel Mulder, Didac Ferrer-Balas, and Jordi Segalàs. "Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities." European Journal of Engineering Education 33, no. 3 (2008): 271-282.

Tsiropoulos, Ioannis, Wouter Nijs, Dalius Tarvydas, and P. Ruiz. "Towards net-zero emissions in the EU energy system by 2050." Insights from Scenarios in Line with the 2030 (2020).

Kasinathan, Padmanathan, Rishi Pugazhendhi, Rajvikram Madurai Elavarasan, Vigna Kumaran Ramachandaramurthy, Vinoth Ramanathan, Senthilkumar Subramanian, Sachin Kumar et al. "Realization of sustainable development goals with disruptive technologies by integrating industry 5.0, society 5.0, smart cities and villages." Sustainability 14, no. 22 (2022): 15258

Leal Filho, Walter, Amanda Lange Salvia, Claudio Ruy Portela Vasconcelos, Rosley Anholon, Izabela Simon Rampasso, João Henrique Paulino Pires Eustachio, Olena

Liakh et al. "Barriers to institutional social sustainability." Sustainability Science 17, no. 6 (2022): 2615-2630.

Litchfield, Kaitlin, and Amy Javernick-Will. "“I am an Engineer AND”: a mixed methods study of socially engaged engineers." Journal of Engineering Education 104, no. 4 (2015): 393-416.

Martin, Diana Adela, Eddie Conlon, and Brian Bowe. "Using case studies in engineering ethics education: The case for immersive scenarios through stakeholder engagement and real life data." Australasian Journal of Engineering Education 26, no. 1 (2021): 47-63.

Mesa, Jaime A., Ivan E. Esparragoza, and Heriberto E. Maury. "Sustainability in engineering education: A literature review of case studies and projects." In 15th LACCEI International Multi-Conference for Engineering, Education Caribbean Conference for Engineering and Technology, LACCEI 2017. Latin American and Caribbean Consortium of Engineering Institutions, 2017.

Mitchell, John E., Abel Nyamapfene, Kate Roach, and Emanuela Tilley. "Faculty wide curriculum reform: the integrated engineering programme." European Journal of Engineering Education 46, no. 1 (2021): 48-66.

Mitchell, John E., Emanuela Tilley, and J. Peters. "Teaching self-awareness, diversity and reflection to support an integrated engineering curriculum augmented with problem and scenario-based learning." SEFI-European Society for Engineering Education, 2014.

Park, Hye Yeon, Carlos V. Licon, and Ole Russell Sleipness. "Teaching sustainability in planning and design education: A systematic review of pedagogical approaches." Sustainability 14, no. 15 (2022): 9485

Perdan, Slobodan, Adisa Azapagic, and Roland Clift. "Teaching sustainable development to engineering students." International journal of sustainability in higher Education 1, no. 3 (2000): 267-279.

Perkins, John. "Professor John Perkins’ review of engineering skills." London, Department for Business Innovation and Skills (2013).

Riley, Donna M., and Yanna Lambrinidou. "Canons against cannons? Social justice and the engineering ethics imaginary." age 26 (2015)

Roach, Kate, Emanuela Tilley, Abel Nyamapfene, Matthew Seren Smith, and Stephen Hughes. "Responsible Innovation as a vehicle for teaching ethical and social dimensions of technology." In Towards a new future in engineering education, new scenarios that european alliances of tech universities open up, European Society for Engineering Education (SEFI) (2022).

Sánchez-Carracedo, Fermín, Bàrbara Sureda Carbonell, and Francisco Manuel Moreno-Pino. "Analysis of sustainability presence in Spanish higher education." International Journal of Sustainability in Higher Education 21, no. 2 (2020): 393-412.

Scoones, Ian, Andrew Stirling, Dinesh Abrol, Joanes Atela, Lakshmi Charli-Joseph, Hallie Eakin, Adrian Ely et al. "Transformations to sustainability: combining structural, systemic and enabling approaches." Current Opinion in Environmental Sustainability 42 (2020): 65-75.¨

Segalàs, Jordi, Dídac Ferrer-Balas, and Karel F. Mulder. "What do engineering students learn in sustainability courses? The effect of the pedagogical approach." Journal of Cleaner production 18, no. 3 (2010): 275-284.

Sterling, Stephen R., and David Orr. Sustainable education: Re-visioning learning and change. Vol. 6. Totnes: Green Books for the Schumacher Society, 2001.

Stock, Tim, and Holger Kohl. "Perspectives for international engineering education: Sustainable-oriented and transnational teaching and learning." Procedia Manufacturing 21 (2018): 10-17.

Svanström, Magdalena, Francisco J. Lozano-García, and Debra Rowe. "Learning outcomes for sustainable development in higher education." International Journal of Sustainability in Higher Education 9, no. 3 (2008): 339-351.

Tepsa, Tauno Aki, Maisa Tuulikki Mielikäinen, and Juhani Angelva. "Instructors´ Expectations And Objectives For Integrating Sustainable Development And Ethical Issues Into The Curriculum." European Society for Engineering Education (SEFI) (2023).

Truslove, Jonathan, Sarah Jayne HITT, Emma Crichton, John Kraus , and, Juliet Upton. "Tools To Reshape Engineering Education To Prepare Students And Professionals To Be Globally Responsible." European Society for Engineering Education (SEFI)(2023).

Watson, Mary Katherine, Caroline Noyes, and Michael O. Rodgers. "Student perceptions of sustainability education in civil and environmental engineering at the Georgia Institute of Technology." Journal of Professional Issues in Engineering Education and Practice 139, no. 3 (2013): 235-243.

Wint, Natalie. "The powerless engineer: questioning approaches to teaching social responsibility." In Towards a new future in engineering education, new scenarios that european alliances of tech universities open up, pp. 851-861. Universitat Politècnica de Catalunya, (2022).

Zandvoort, H. "Preparing engineers for social responsibility." European Journal of Engineering Education 33, no. 2 (2008): 133-140.

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Uses and Impacts of LLMs on the Learning Experience of Future Engineers: Case Studies in the Context of a French Engineering School

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ABSTRACT

In November 2022, the release of ChatGPT to the public challenged the established order of our educational systems. Faced with this disruptive innovation, traditional educational structures were unprepared to handle this complexity and manage its uses. Consequently, the burden of social regulation became the responsibility of individuals and collectives. In this context, students' and teachers' practices adapted

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and evolved to both take advantage of the opportunities offered by this new tool, and/or to establish a regime of "new normal" that would appease tensions and improve learning. This article aims to empirically detail the mechanisms of social reconfiguration deployed to integrate ChatGPT more harmoniously in classrooms. It focuses on initiatives within a French engineering school, on both institutional and individual levels. Firstly, it outlines strategy and actions settled by the "*pedagogical and digital innovation*" team to support and guide teachers in this transition. Secondly, through three case studies, it describes the activities set up by teachers to make ChatGPT an effective resource for diversifying pedagogical practices and questioning students' learning processes. The first case concerns the design of a course aimed at creating a charter for the responsible use of ChatGPT for and by students. The second case covers the adoption of a problem-based learning approach so students can overcome their problematic use of ChatGPT. The last case reports an experiment to help students use ChatGPT more effectively in learning English. With this contribution, the authors hope to inspire similar initiatives and strengthen the existing teaching communities of practice.

1 INTRODUCTION

The introduction of new technologies in society has almost always been followed by waves of "moral panic" (Cohen 1972) in the educational system (Reich 2020). The emergence of Wikipedia and the vast amount of knowledge it shared with everyone (Reagle and Koerner 2020), and the arrival of calculators in mathematics (Ellington 2003), are concrete examples of such a phenomenon. In many cases, these sensationalistic discourses have faded with time, leaving place for a normalization of their uses in teaching practices. The same scenario occurred again after the release of ChatGPT in November 2022 (Fütterer et al. 2023). While the use of ChatGPT is still controversial in education, initiatives are multiplying to make generative AI a useful learning resource. Aiming to nurture this growing "community of practice" (Lave and Wenger 1991) through feedback, this article presents the actions taken within a French engineering school by three teachers and a pedagogical coordinator.

2 GUIDING TEACHERS TO BETTER INTEGRATE CHATGPT: PDI TEAM ACTIONS AND STRATEGY

Several institutional reports have been published on the impacts and potential uses of ChatGPT in education since its release (Romero and Heiser 2023, Sabzalieva and Valentini 2023), but teachers don't always have time to familiarize themselves with this literature. Within our engineering school, teachers' concerns about the use of ChatGPT in classrooms were addressed by the Pedagogical and Digital Innovation team (PDI). The PDI's main mission is to support teachers in the pedagogical innovation process. Through its local coordinators, the PDI team can offer guidance and recommendations across multiple campuses (7 in France, and 2 in Africa).

As part of a proactive approach, an educational half-day was organized by the PDI team in May 2023 to present the possibilities of using LLMs to help design teaching programs. The aim of this initiative was to raise teachers' awareness of the potential of these technologies to enhance their teaching practices. Concrete examples of the use of LLMs in the creation of course materials and the running of practical workshops enable teachers to test and experiment with these tools. The main objective was to provide teachers with the skills they need to: integrate LLMs into their teaching practices in a thoughtful and effective way, design innovative learning situations adapted to students' needs, and support students in the responsible use of these technologies. This first step offered an opportunity for discussion and reflection on the implications of these tools for the various courses.

At the same time, teachers questioned the local PDI coordinator about the challenges posed by the use of LLMs by students in the context of assessments. They particularly shared their fears on three issues.1) **Cheating**: students use LLMs to produce non-personal content without bothering about their learning. 2) **Unequal access**: not all students have the same skills or the same level of access to these technologies. 3) **Loss of meaning**: assessment would no longer focus on students' actual skills but on their ability to use LLMs.

Aware of the importance of this topic, a workshop was organized in February 2024 to gather their views and proposals (several workshops were held in parallel, combining fields and courses). Feedback from the 24 participants (teachers and researchers) highlighted the need to train students in the ethical and responsible use of LLMs, as well as the relevance of identifying options to guarantee the integrity and validity of assessments. Discussions also focused on the need to rethink assessment formats to make them more resilient to students cheating using ChatGPT.

To address these concerns, several initiatives have been implemented. One of the first actions taken was to set up a working group with some of the volunteers present at the workshop. Among other missions, the group will monitor the opportunities offered by LLMs for teachers. A second action currently underway consists of testing the various existing AI-generated text detection software to limit fraudulent use of ChatGPT in exams and reassure teachers. These tools will be used in conjunction with preventive measures such as the introduction of a clear policy on the use of LLMs in assessments. Thirdly, a series of new workshops and training courses have already been scheduled to meet the needs of teachers and students. More globally, the PDI team will continue to follow the development of LLMs, support teachers in their use of these technologies, and stimulate a collective reflection on the appropriate solutions to guarantee the integrity and quality of training.

3 ADAPTING TEACHING PRACTICES TO BETTER INTEGRATE CHATGPT: THREE CASE STUDIES

3.1 ChatGPT and Ethics: a charter for and by students to guide their uses

The following case study reports the implementation of a teaching initiative focused on elaborating a charter for a socially responsible use of ChatGPT by and for students. The main inspiration for designing this teaching was the early feedback from teachers like Ethan and Lilach Mollick. Sharing the principles for successful integration of ChatGPT in education (Mollick and Mollick 2023) they emphasized the crucial role of providing students with a document defining clear guidelines for the use of AI in class. Seeking to reverse this top-down pedagogical approach, this course invited students to build their own AI usage charter.

This course took place in the context of a teaching module entitled "Adopting a Position". In this module, teachers must conceive a series of workshops that immerse students in a project-based teaching approach and seek to actively engage them in a creative process, leading to a production that expresses a real standpoint. After reading a booklet presenting the proposed workshops[2], students chose the project

[2] The presentation of the Chatgpt charter workshop is available at the following link:

they would like to contribute to. Project groups were then set up by teachers. The first 8 sessions were devoted to the group production process, the 9th session was a whole-class presentation of each group's productions, and the last session was a written exam inviting students to individually review their own experience[3].

Fig. 1. Gantt chart of the ChatGPT charter creation project.

In the case depicted here, 5 teachers proposed 6 workshops to a class of 84 students in their second year of preparatory studies for engineering schools. The class was divided into 9 groups of 6 to 12 students. Workshops exceeding 12 students were split into two groups working on the same project. Thus, two parallel projects on ChatGPT were directed. They were managed similarly, resulting in two different but close charters. The class ran from February to May 2023 (Fig. 1).

The first 8 sessions were organized into weekly two-hour classes. They were split into 2 phases. The first phase, from session 1 to session 3, consisted in a series of 3 introductory courses on AI, generative AI, ethics and the basics of charter writing. The purpose of these sessions was to provide a common base from which students could build these charters. Although students had benefited from computer science courses, notably in their first year via a programming project for a low-complexity symbolic AI system, their "digital culture" (Crepel et al. 2018) was strongly disparate and relied mainly on watching YouTube videos.

To address these gaps, the first session traced the history of AI from its founding fathers (McCarthy et al. 2006) to ChatGPT, covering topics such as AI systems functioning and their applications, the paradigmatic separation between symbolic and connectionist AI (Cardon et al. 2018), an overview of language models and chatbots, the Transformer model revolution (Vaswani et al. 2017), and the social actors and stakes behind the release of ChatGPT. To help them self-diagnose their knowledge, students were invited, after the class, to answer a consultation led in Occitania (France) to assess citizens' level of awareness and acceptability of AI[4].

The second session addressed the ethical stakes raised by AI, avoiding speculative debates on the consequences of the emergence of a strong AI (Ganascia 2017). To nurture a reflexive perspective on ChatGPT, chatbots with controversial applications, uses or developments were presented to students, such as HereAfter AI (2022), Xiaoice (Zhou et al. 2020), Tay (Suárez-Gonzalo et al. 2019), Koko (Germain 2023), precarious workers training AI systems (Perrigo 2023), or the prohibition of ChatGPT

https://drive.google.com/file/d/1eCbgH-li1LDfUP32T0nG3pg_JEDus7N0/view?usp=sharing

[3] The standard exam subject proposed to students for this module is available at the following link: https://drive.google.com/file/d/1M-eLJLDaUyPQ4RQMq7H84wPH31st_zPd/view?usp=sharing

[4] More informations about this consultation are available at the following link: https://aniti.univ-toulouse.fr/en/2023/11/23/consultation-citoyenne-sur-lia-les-resultats-sont-disponibles/

in school (Yang 2023) or workplace (Ray 2023). Several questions from the public consultation presented in CNPEN (French national digital ethics pilot committee) opinion on chatbots were collectively discussed (Devillers et al. 2021).

The third session was split into two parts. During the first hour, students were set in pairs, and each group had to analyze one of the 5 proposed charters: OpenAI charter (2018), Montreal Declaration for a responsible development of AI (Dilhac et al. 2018), guidelines for AI in class (Mollick and Mollick 2023), the Responsible engineer and scientist charter of the association of French Engineers and Scientists (Anstett et al. 2022) and the values charter of our school. To analyze these documents, students were allowed to mobilize all the resources at their disposal: including ChatGPT to translate, summarize, vulgarize, criticize, etc. the text. During the second hour: students presented their text in 5 minutes, followed by a 5-minute discussion with the class on the resources they used to study the text and how they used them, on the relevant points to remember that could provide inspiration for their ChatGPT charter, or bringing further explanations from the teacher on this document.

The second phase, from sessions 4 to 8, consisted in the creation of the charter by students. For this, students could mobilize all possible resources. After discussing the plan of the charter as a group, students divided into pairs to write a first draft of each part for which they were responsible. The writing was done in a shared document on the cloud, from which they were able to exchange ideas in real time. To adopt an iterative logic, encourage debates and make the process more dynamic, several techniques were employed. Firstly, a system of rotating pairs so that each participant could collaborate with different colleagues and bring a fresh perspective to the various written parts. Secondly, close supervision by the teacher to guide them towards questions or resources they might not have considered. Finally, encouraging discussions within the group on best practices for using ChatGPT.

These discussions led to several observations. Firstly, the students' use of ChatGPT remained poor, usually limited to a single iteration, which didn't allow them to meet the requirements of the charter-writing exercise. Secondly, like any other tool, skills development were necessary (notably in prompting) to maximize the effectiveness of ChatGPT's use. Finally, they realized that to really perform in this exercise, the essential points were to understand the methodological expectations, to multiply the confrontations of various points of view (colleagues, ChatGPT, articles, etc.), and to be able to converge all these views in a coherent way in a single document. A long and complex task which cannot be substituted by a superficial use of ChatGPT.

This process led to the production of two 4-page charters[5], both containing: 1) a preamble, providing background information on the implications of these charters and the conditions under which they were produced; 2) definitions, to ensure that these charters are accessible to everyone; 3) a series of articles setting out recommendations and warnings on the use of ChatGPT. These articles include critical analysis on the use of ChatGPT by students to cheat, advice on how to improve the effectiveness of prompts for learning purposes, and the potential "hallucinations" (Alkaissi and McFarlane 2023) of ChatGPT. Are also included the responsibility that students must have when using erroneous information, the importance of critical thinking and comparing different sources without becoming dependent on ChatGPT, the data collection done by OpenAI, or ChatGPT's environmental impact and the

[5] These two charters can be consulted at the following link: https://drive.google.com/file/d/15nWJQeVxaeByheMq1oTOcer8gGY-LY0T/view?usp=sharing

importance of considering the relevance of its usage. This work was then presented to the rest of the class during session 9, in a 15-minute presentation, followed by a discussion with the audience.

Throughout this workshop, using ChatGPT as a starting point and through the creation of a charter, students were able to think critically on innovation, which is essential for any engineer. Beyond nurturing a reflection on the uses of chatgpt, this charter acted as an intermediary for students, to inform, debate, argue and defend their opinions, but also to listen and make concessions, to produce a document that could reach a consensus within the group. This workshop was repeated from February to May 2024, with a single group this time, assigned to synthesize these two charters into a single one and focus solely on the recommendations section in order to simplify the document and encourage its appropriation and discussion in the school. Students will be recontacted, in a few years, in order to evaluate any lasting impacts of this course on their use of ChatGPT.

3.2 ChatGPT and coding: problem-based learning to empower students

Programming is an ever-present subject when learning engineering, be it for specialized fields or generalized tracks (like in our school). Students must and need to learn one or several programming languages. Tools like ChatGPT have become commonplace as they can quite easily, and with very basic prompts, generate functional snippets of code. Positive impacts of using ChatGPT in a classroom setting, when learning to code, have been observed (Yilmaz and Yilmaz 2023). In this study the authors demonstrated that students who used ChatGPT when learning had increased levels of computational thinking and programming skills, as well as programming self-efficacy and motivation. However, AI coding bots do struggle with more complex problems, especially when using badly constructed prompts. We thus must address questions like, how can the students subdivide the problem at hand? How can they plan to reach a useful solution? And most importantly, what process pushes them to learn? In this setting, AI can be a source for co-creation (Jonsson and Tholander 2022) and an agent aiding the students to learn.

To showcase our approach, and attempt to answer these questions, we detail a use case pertaining to two PBL activities (Problem Based Learning) conducted with first year engineering students. Generally speaking, a PBL is any activity centered around a given problem situation where students learn and work in groups in order to find a possible solution. The aim of these two PBLs was to teach students the basics of algorithmic thinking and its applications using Python. In the first PBL, their task was to find a way of converting text into an image containing an encrypted message generated using a simple substitution cipher. In the second, students had to improve a program with a user interface using the tkinter Python library.

The format of PBLs adopted in our institution is as follows: the activity stretches out over two to three weeks and the class is divided into groups of 6 to 8 students (called PBL groups). The PBL is composed of five main phases (Fig. 2). Starting with the "Go Phase" where the problem situation is introduced to students, followed by the "Self-Study" phase where students discover resources (textbooks, technical reports, online articles, etc.). In these two phases, interactions between the tutor and students are limited. Next comes the "Practical Session" which is more classical and can consist of guided exercises and practical work. The activity ends with the "Group Return" phase where each PBL group presents its results. This can be done under a variety of formats depending on the main topic of the PBL. Then comes the "Common Return" phase with the whole class where direct feedback is given to the students. It is also important to highlight that the adopted evaluation method is based on competencies and not grades. This means that the metric used to assess success or failure in learning is the ability of a student to demonstrate specific skills.

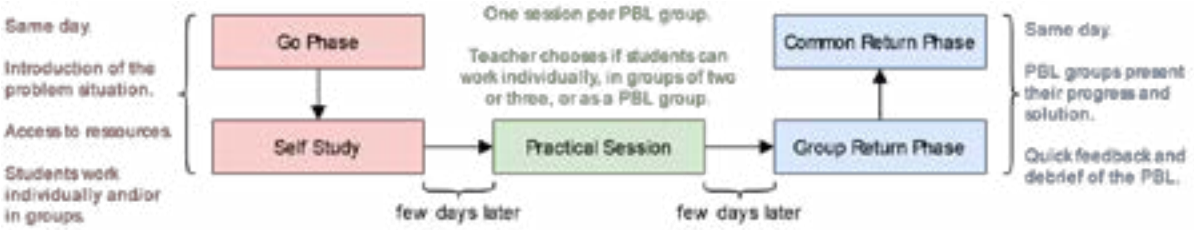

Fig. 2. Diagram representing a typical organisation of a PBL.

In the first PBL, after introducing the problem situation, students were asked to work collaboratively in groups. However, and as anticipated, a good deal of them directly sought refuge in ChatGPT, which started outputting answers that students simply could not comprehend as they lacked the basics that they are supposed to learn throughout this PBL. The more the students went back and forth with ChatGPT, trying to inefficiently modify the increasingly complex generated code, the more they struggled to comprehend it.

This situation should be treated as any other engineering problem. First, the main issue has to be clearly identified. When discussing this topic with students, it became clear that their rush to use ChatGPT was due to three main reasons. First, a lack of confidence in their abilities to tackle new topics. Second, a lack of patience and sometimes, an inability to deal with their frustrations when their solutions “do not work”. Third, the importance they give to obtaining results over the learning process. Student self-efficacy (Zimmerman 2000) is key when studying the implication of students. As they leave high-school and enter higher education, the paradigm shift can be brutal. Not only are the subjects of their courses more complex, but their autonomy becomes crucial for their progress. In this context, ChatGPT became an easy way to face their lack of confidence and patience. Thus, the path towards autonomy and critical thinking is slowed by a growing dependence on ChatGPT.

It has become abundantly clear that ChatGPT is influencing learning both positively and negatively (Bai et al. 2023). Such tools can on the one hand introduce bias, superficial and false information, while on the other hand offer a flexible and creative environment to learn. This is why during the PBL, and in parallel to the technical skills, one of the main goals was to show students how to properly divide and conquer a problem. Instead of jumping steps and expecting to arrive at a solution in one go using ChatGPT, students needed to be explicitly guided through this fundamental approach, which is necessary no matter what tools they might use to find information. However, a new question arises: How can they identify steps to solve a given problem if they haven't faced it before? To solve this issue, the students’ sense of curiosity and desire to understand must be nurtured. Without this, it will become quite impossible to converge towards an impactful and long-lasting solution. Even if the students use tools to generate answers, their new posture will automatically push them to strive to comprehend what they have in hand and to go and seek information at its source, and not only through the filters of AI.

Throughout the practical sessions of the PBL, a plan to solve the main problem situation was iteratively co-constructed with the students (Fig. 3). For each new step, the main objective was recalled, as well as all the steps taken thus far, and the global plan readjusted due to newfound information. A rhythm was imposed where for each new arising question, students had to either go through technical documents, or use AI to help zoom into the issue so they could tune their search. This tempo was heavy on the students, and by the end of the four-hour session most of them felt like they just went through a rigorous class of mental gymnastics. The impact of this approach became quite apparent in the second PBL, as during the practical sessions, students were presented with basic building blocks for adapting a functioning user interface, and were free to explore other existing methods on their own, and they were of course allowed to use AI. However, some wanted to go through the same hard process as the previous PBL. Surprisingly, students seemed more patient and rather eager to show what they are capable of.

Research has shown that students benefiting from using AI to learn can indeed be more creative and propose more original solutions (Urban et al. 2024). Yet, awakening the students' desires to learn is intimately coupled to their confidence and patience. Once the students witnessed that they are indeed capable, they became bolder and more structured in their approach, and their willingness to construct unique solutions to a given problem became much more apparent. Of course, this approach will not totally solve all ChatGPT related issues, but it can certainly nourish reflections that can push students towards becoming responsible future engineers.

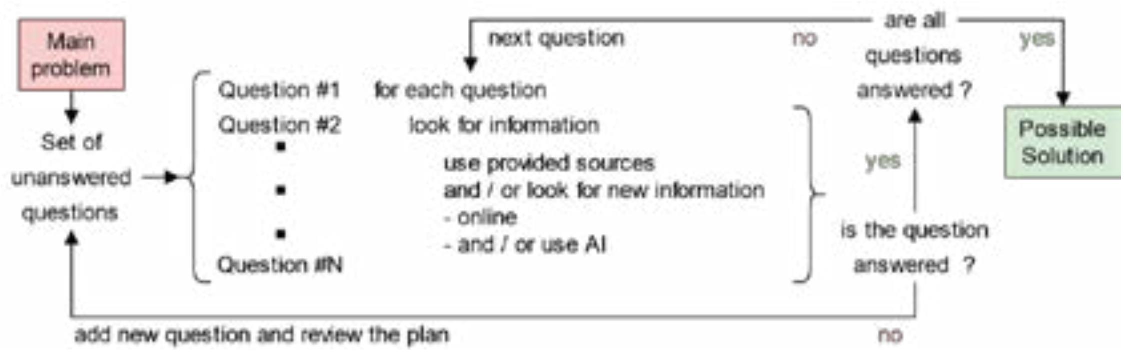

Fig. 3. Flow diagram showing the problem-solving approach shared with students.

3.3 ChatGPT and language courses: AI tutor to improve learning efficiency

The following case study reports an experimentation to help students use ChatGPT more efficiently in learning English. In a very traditional way, we regularly ask our students to read a text and answer comprehension questions. Digital tools are usually forbidden during these courses, in order to particularly avoid the use of automatic translators. But, several considerations led us to make the use of ChatGPT compulsory during one particular course. Firstly, the fact that multiple studies have shown the benefits of chatbots for language learning (Haristiani 2019, Jeon 2021, Godwin-Jones 2022). Secondly, inspired by a questionnaire conducted among students by Czech-Norwegian researchers to assess ChatGPT usefulness and effectiveness for English learning (Shaikh et al. 2023), we decided to conduct our own experiment to analyze student practices and see how ChatGPT could help them improve their English language learning.

As usual, students had a text to read and comprehension questions to answer. They had 10 minutes to read and understand the text, then they could use ChatGPT for 10 minutes. The only instruction was to use ChatGPT to help them understand the text. They were then asked to send their conversations with ChatGPT to the teacher, and we analyzed them. The analysis showed that they mainly used ChatGPT to translate words or sentences, to ask for explanations on specific words, and to summarize the text. One student asked ChatGPT to generate questions on the text and to give the answers to these questions. Another one asked ChatGPT to ask him questions, and give feedback on his answers. Most of the students considered their use of ChatGPT very basic. Then, they were asked to use this prompt:

“Assist a French student with an A2 level in English in text comprehension. Begin by asking 10 easy questions, then gradually increase the difficulty of the comprehension questions. Continue this process until the student says 'Now, move on to questions focusing on vocabulary'. Present one question at a time, each with three possible answers, concerning the meaning of the text and its vocabulary. After the student answers, provide feedback on correctness, offer a brief debriefing, and then present the next question. This is the text: [...]”

They had 10 minutes to chat with ChatGPT, then sent their conversations to the teacher. All students said that this conversation was more interesting than their traditional use of ChatGPT. To get a more objective view of this experience, the 11 present students were asked to complete a questionnaire[6] structured around 4 questions, to which they could respond via a 5-level Lickert scale (1=more negative, 5=more positive), with indications to better situate themselves towards each level. Those questions concerned: 1) relevance of comprehension; 2) relevance of vocabulary; 3) clarity of feedback; 4) activity efficiency for learning. Figure 4 shows the results of this survey. They could finally answer the usual comprehension questions. The success rate was the same as usual, but students felt more confident and said they would use this prompt again. They even asked if we could create another prompt to help them during the other technical project-based courses, as they often feel alone and confused.

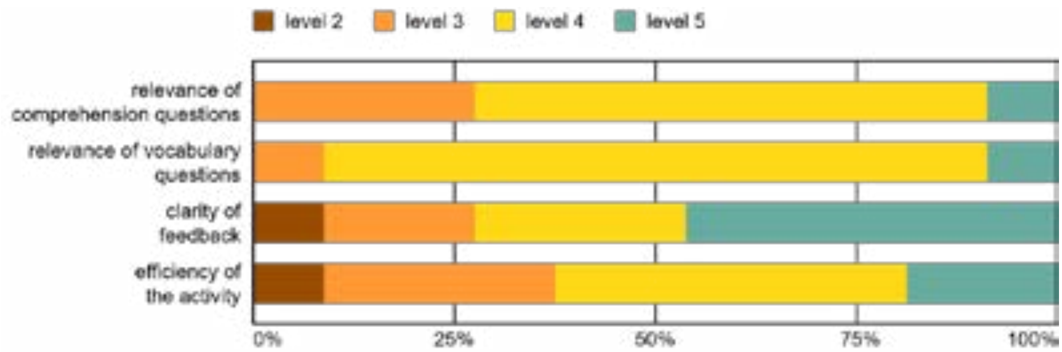

Fig. 4. Chart depicting student satisfaction levels.

Although the small sample size makes it impossible to generalize results, this short experiment has strengthened the trust relationship between teacher and students, and helped students to identify more efficient ways of using ChatGPT for learning. As predicted, their initial use was really basic. They were convinced of the usefulness of writing more complex prompts to help them reflect and check their understanding. This experiment reinforced our belief that students should be taught to use ChatGPT, and that they are willing to use it more as a tutor (Mollick and Mollick 2023) than a simple tool that gives them the correct answer that just has to be copied and pasted. Using ChatGPT in this way, can improve the students’ autonomy and learning experience by giving them personalized feedback, something a teacher cannot easily achieve in large classrooms.

[6] The questionnaire addressed to students is available at the following link: https://drive.google.com/file/d/15atk4Vaak3G5zX8eLlprR54hXVKFxZoL/view?usp=sharing

4 SUMMARY AND ACKNOWLEDGEMENTS

This article explores the potential impacts and uses of LLMs in higher education, by sharing initiatives conducted at institutional and individual levels in a French engineering school. It illustrates the conditions under which students and teachers can appropriate LLMs by sharing the actions led by a pedagogical advisor within the "*Pedagogical and Digital Innovation*" team, and by three teachers through various case studies: 1) the creation of a ChatGPT charter for and by students in an ethics course to help them develop sociotechnical reflexivity on this tool, 2) the adoption of problem-based learning approach in a programming course to emancipate students from ChatGPT dependency, 3) a prompt experiment turning ChatGPT into a tutor to help students become more autonomous and efficient in language learning courses. Far from speculative debates and moral panics, these case studies demonstrate that when ChatGPT is used with creativity while keeping the educational objectives at the heart of the process, it can be a versatile and useful tool for students and teachers. Moreover, enriching the growing corpus of pedagogical experiments conducted since the arrival of ChatGPT, such feedback contributes to paving the way towards a more responsible use of ChatGPT in the learning experience of future engineers.

REFERENCES

Alkaissi, Hussam, and Samy I McFarlane. “Artificial Hallucinations in ChatGPT: Implications in Scientific Writing.” *Curēus* 15, no. 2 (February, 2023). https://doi.org/10.7759/cureus.35179.

Anstett, Albert, Jacques Berbey, Michel Coureau, Hervé Filloux, Mehdi Medmoun, Solinne Moretti, Carine Niez, and Jérémie Supiot. *Charte de l’ingénieur et du scientifique responsables*. IESF, 2022. https://www.iesf.fr/752_p_49680/charte-ethique-de-l-ingenieur.html.

Bai, Long, Xiangfei Liu, and Jiacan Su. “ChatGPT: The Cognitive Effects on Learning and Memory.” *Brain-X* 1, no. 3 (September, 2023). https://doi.org/10.1002/brx2.30.

Cardon, Dominique, Jean-Philippe Cointet, and Antoine Mazières. “La Revanche Des Neurones.” *Réseaux/RéSeaux* 211, no. 5 (November, 2018): 173–220. https://doi.org/10.3917/res.211.0173.

Cohen, Stanley. F*olk Devils and Moral Panics*. MacGibbon et Kee, 1972.

Crépel, Maxime, Dominique Cardon, and Thomas Tari. “Coder Décoder pour enseigner le numérique.” Presented at *Journées Annuelles Réseau MATE-SHS*, L*yon, France, 2018*.https://25images.msh-lse.fr/ja-mate-shs-dec2018/video/maxime-crepel-ingenieur-de-recherche-et-pedagogique-sciences-po-medialab-cen/.

Devillers, Laurence, Alexei Grinbaum, Gilles Adda, Raja Chatila, Caroline Martin, Serena Villata, and Célia Zolynski. *Agents conversationnels: Enjeux d'éthique*. CNPEN, 2021. https://www.ccne-ethique.fr/fr/publications/cnpen-agents-conversationnels-enjeux-dethique.

Dilhac, Marc-Antoine, Christophe Abrassart, and Nathalie Voarino (dir.). *Rapport de la Déclaration de Montréal pour un développement responsable de l'intelligence* *artificielle.* Montréal, Canada: Université de Montréal, 2018. www.declarationmontreal-iaresponsable.com.

Ellington, Aimee J. "A Meta-Analysis of the Effects of Calculators on Students' Achievement and Attitude Levels in Precollege Mathematics Classes." *Journal for Research in Mathematics Education* 34, no. 5 (November, 2003): 433-463. https://doi.org/10.2307/30034795.

Fütterer, Tim, Christian Fischer, Anastasiia Alekseeva, Xiaobin Chen, Tamara Tate, Mark Warschauer, and Peter Gerjets. "ChatGPT in Education: Global Reactions to AI Innovations." *Scientific Reports* 13, no. 1 (September, 2023). https://doi.org/10.1038/s41598-023-42227-6.

Ganascia, Jean-Gabriel. *Intelligence artificielle: Vers une domination programmée ?*. Le Cavalier Bleu, 2017.

Germain, Thomas. "A mental health app tested ChatGPT on its users. The founder said backlash was just a misunderstanding." *Gizmodo*, January 11, 2023. https://gizmodo.com/mental-health-therapy-app-ai-koko-chatgpt-rob-morris-1849965534.

Godwin-Jones, Robert. "Chatbots in language learning: AI systems on the rise." In *Intelligent CALL, Granular Systems, and Learner Data: Short Papers from EUROCALL*, dir. Birna, Arnbjörnsdóttir, Branislav Bédi, Linda Bradley, Kolbrún Friðriksdóttir, Hólmfríður Garðarsdóttir, Sylvie Thouësny, and Matthew James Whelpton, 124–128. Research-publishing.net, 2022. https://doi.org/10.14705/rpnet.2022.61.1446.

Haristiani, Nuria. "Artificial Intelligence (AI) Chatbot as Language Learning Medium: An Inquiry." *Journal of Physics. Conference Series* 1387, no. 1 (November, 2019): 012020. https://doi.org/10.1088/1742-6596/1387/1/012020.

HereAfter AI. "HereAfter AI: Where Memories Live Forever". YouTube [Video], September 16, 2022. https://www.youtube.com/watch?v=-QqLbaP8nVA.

Jeon, Jaeho. "Chatbot-assisted dynamic assessment (CA-DA) for L2 vocabulary learning and diagnosis". *Computer Assisted Language Learning* 36, no. 7 (October, 2021): 1338-1364. https://doi.org/10.1080/09588221.2021.1987272.

Jonsson, Martin, and Jakob Tholander. "Cracking the Code: Co-coding With AI in Creative Programming Education." In *Proceedings of the 14th Conference on Creativity and Cognition* (June, 2022): 5-14. https://doi.org/10.1145/3527927.3532801.

Lave, Jean, and Etienne Wenger. *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press, 1991.

McCarthy, John, Marvin L. Minsky, Nathaniel Rochester, and Claude E. Shannon. "A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence, August 31, 1955." *AI Magazine* 27, no. 4 (December, 2006): 12. https://doi.org/10.1609/aimag.v27i4.1904.

Mollick, Ethan, and Lilach Mollick. "Why All Our Classes Suddenly Became AI Classes: Strategies for Teaching and Learning in a ChatGPT World". *Harvard Business Publishing*, February 9, 2023. https://hbsp.harvard.edu/inspiring-minds/why-all-our-classes-suddenly-became-ai-classes.

Mollick, Ethan, and Lilach Mollick. “Assigning AI: Seven Approaches for Students, With Prompts.” *arXiv* preprint arXiv:2306.10052, (June, 2023): 1-46. https://doi.org/10.48550/arXiv.2306.10052.

OpenAI. “OpenAI charter”. Published in April 2018. https://openai.com/charter.

Perrigo, Billy. “Exclusive: OpenAI used Kenyan workers on less than $2 per hour to make ChatGPT less toxic.” *Time Magazine*, January 18, 2023. https://time.com/6247678/openai-chatgpt-kenya-workers/.

Ray, Siladitya. “Samsung bans ChatGPT among employees after sensitive code leak.” *Forbes Magazine*, May 2, 2023. https://www.forbes.com/sites/siladityaray/2023/05/02/samsung-bans-chatgpt-and-other-chatbots-for-employees-after-sensitive-code-leak/?sh=70e128fc6078.

Reagle, Joseph, and Jackie Koerner. *Wikipedia @ 20: Stories of an Incomplete Revolution*. MIT Press, 2020.

Reich, Justin. *Failure to Disrupt: Why Technology Alone Can’t Transform Education*. Harvard University Press, 2020.

Romero, Margarida, and Laurent Heiser. *Enseigner et apprendre à l’ère de l’intelligence artificielle*. Canopé, Livre blanc, 2023. https://hal.science/hal-04013223v2.

Sabzalieva, Emma, and Arianna Valentini. *Review of ChatGPT and Artificial Intelligence in Higher Education: Quick Start Guide*. UNESCO, 2023. https://unesdoc.unesco.org/ark:/48223/pf0000385146.

Shaikh, Sarang, Sule Yildirim Yayilgan, Blanka Klimova and Marcel Pikhart. “Assessing the Usability of ChatGPT for Formal English Language Learning”. *European Journal of Investigation in Health, Psychology and Education* 13, no. 9 (September, 2023): 1937–1960. https://doi.org/10.3390/ejihpe13090140.

Suárez-Gonzalo, Sara, Lluís Mas-Manchón, and Frederic Guerrero-Solé. “Tay Is You. The Attribution of Responsibility in the Algorithmic Culture.” *Observatorio (OBS*)* 13, no. 2 (June, 2019): 1-14. http://dx.doi.org/10.15847/obsOBS13220191432.

Urban, Marek, Filip Děchtěrenko, Jiří Lukavský, Veronika Hrabalová, Filip Svacha, Cyril Brom, and Kamila Urban. “ChatGPT Improves Creative Problem-solving Performance in University Students: An Experimental Study.” *Computers and Education/Computers & Education* 215 (July, 2024): 105031. https://doi.org/10.1016/j.compedu.2024.105031.

Vaswani, Ashish, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N. Gomez, Lukasz Kaiser, and Illia Polosukhin. “Attention is all you need.” Paper presented at *31st Conference on Neural Information Processing Systems (NIPS 2017), Long Beach, CA, USA, 2017.* https://doi.org/10.48550/arXiv.1706.03762.

Yang, Maya. “New York City schools ban AI chatbot that writes essays and answers prompts.” *The Guardian*, January 6, 2023. https://www.theguardian.com/us-news/2023/jan/06/new-york-city-schools-ban-ai-chatbot-chatgpt.

Yilmaz, Ramazan, and Fatma Gizem Karaoglan Yilmaz. “The Effect of Generative Artificial Intelligence (AI)-based Tool Use on Students’ Computational Thinking Skills, Programming Self-efficacy and Motivation." *Computers and Education: Artificial Intelligence* 4 (January, 2023): 100147. https://doi.org/10.1016/j.caeai.2023.100147.

Zimmerman, Barry J. "Self-Efficacy: An Essential Motive to Learn." *Contemporary Educational Psychology* 25, no. 1 (January, 2000): 82–91. https://doi.org/10.1006/ceps.1999.1016.

Zhou, Li, Jianfeng Gao, Di Li, and heung-Yeung Shum. "The design and implementation of Xiaoice, an empathetic social chatbot." *Computational Linguistics* 46, no. 1 (March, 2020): 53-93. https://doi.org/10.1162/coli_a_00368.

INTEGRATING SUSTAINABILITY IN HIGHER EDUCATION INSTITUTIONS: A CASE STUDY FROM EPFL

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ABSTRACT

As concerns regarding sustainability and ethical responsibility in engineering practices continue to rise, it becomes imperative for Higher Education Institutions (HEIs) to

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equip future engineers with the necessary knowledge and skills to address these challenges. This practice paper presents the introduction of a mandatory sustainability course for first-year students, designed to foster a deeper understanding of the ethical implications of engineering solutions and promote sustainability in engineering practices. The course is structured to integrate theoretical foundations of sustainability science with practical applications, utilizing innovative pedagogical approaches to engage students in systems thinking group projects and develop critical thinking. Through this course, École Polytechnique Fédérale de Lausanne (EPFL) aims at cultivating a new generation of responsible engineers, architects, chemists, mathematicians and physicists equipped to address complex societal and environmental challenges in their future careers.

1 INTRODUCTION

In recent years, the intersection of technology and sustainability has emerged as a pressing concern highlighting the need for engineers to consider the ethical implications and environmental and societal impacts of their work (Martin, Conlon, and Bowe 2021). The establishment of a first-year mandatory course on sustainability at EPFL reflects a concrete response to this imperative, recognizing the pivotal role of engineering education in ensuring an ethical and sustainable conduct of engineers as responsible citizens. This paper outlines the roots of the sustainability course, including the institutional context, logistical challenges, objectives and pedagogical structure, as well as its significance in cultivating responsible engineering practices and fostering a culture of sustainability within the larger academic community.

1.1 Related work and Benchmarking

Hereunder, we briefly present a non-exhaustive range of initiatives and perspectives on integrating sustainability into engineering education considered for the introduction of a new common sustainability course in the curriculum. (Børsen et al. 2021) presents the efforts of the Social Ecological Responsibility in Science and Engineering Education Network in discussing and promoting social and ecological responsibility teaching practices, while (Guerra and Rodriguez-Mesa 2021) focuses on the future of engineering education, particularly in response to the Sustainable Development Goals (SDGs), through problem and project-based learning. (Mann et al. 2021) proposes a shift from problem-based learning (PBL) to practice-based education (PBE) to address complex challenges, advocating for a holistic approach to engineering education.

Furthermore, the sustainability approaches of engineering Danish students are investigated in (Haase 2014), identifying distinct clusters of attitudes and practices. (Lozano et al. 2017) offers a framework connecting competences and pedagogical approaches for sustainable development education, aiming to enhance the effectiveness of courses in delivering sustainability education. Finally, (Smith, Tran, and Compston 2020) reviews engineering education programs integrating humanitarian action and development principles, emphasizing the need for discussion and collaboration to ensure effective outcomes and ethical practice.

1.2 Why a sustainability course

As a result of a 2022 survey to EPFL's alumni, environmental responsibility emerged as the second most crucial skill for their current jobs. Nonetheless, 60% indicate weaknesses in their environmental skills, and 30% express the absence of sustainability education in their curriculum (Duvilard, 2022). Additionally, companies increasingly seek profiles with sustainable competencies, highlighting a growing demand for sustainability expertise (Engineering Technology 2023).

There is a growing concern among young people about future challenges, particularly regarding climate change, as evidenced by a survey of 10,000 individuals aged 16-25, where 84% expressed worry, and over 50% reported feelings of sadness, anxiety, anger, discouragement, or guilt (Hickman et al. 2021). In light of these trends, universities have a critical role to play in adapting education to the demands of the 21st century, ensuring that students are equipped with the knowledge and skills necessary to address pressing global challenges (Lozano et al. 2013).

The integration of sustainability into the curriculum at EPFL has been a participatory effort driven by both students and institutional leadership. The combination of a bottom-up approach through advocacy from students and student associations prompting calls for sustainability education, and the top-down backing from the direction within our institution provided the groundwork for the realization of the sustainability course.

2 SET UP AND LEVERAGES

2.1 Institutional leverage

Context Efforts to address sustainability within EPFL were primarily coordinated through the Sustainability Task Force, which included a subgroup focused on education. In 2019 and 2020, this task force had been actively engaged in identifying opportunities to enhance sustainability education within the institution. Challenges such as the COVID-19 pandemic, lack of sustainability representative at the direction level, and limited collaborative actions have slowed down these efforts.

In 2021, our institution underwent a significant structural reorganization, establishing novel vice-presidencies to oversee various aspects of the institution's operations. A dedicated vice-presidency was created with a focus on sustainability and equality initiatives on campus. This strategic decision underscored the institution's commitment to integrating sustainability principles into its core mission, operations and academic duty. With the institution of a dedicated vice-presidency, a more centralized approach to sustainability initiatives emerged at our institution.

Teach4Sustainability Working Group Under the guidance of the associate vice-president for education, who maintained a strong link with the institution's leadership, the Teach4Sustainability Working Group (T4S) aimed at integrating sustainability into EPFL's educational offer, with the intention on implementing major actions by the academic year 2024/25. Coordination assistance was provided by project leaders from the sustainability focused vice-presidency, who offered valuable support and ensured that deadlines were met in the process.

T4S created a framework consisting of three parallel action areas, or pillars (see Figure 1): Pillar 1 involves the introduction of a new school-wide first year course providing a foundation in sustainability, Pillar 2 focuses on linking specific study plans with sustainability topics, and Pillar 3 entails integrating sustainability-related content into individual courses.

The new sustainability course, focus of this paper, falls under Pillar 1 and has the objective to align first year bachelor students on a scientific knowledge of sustainability applicable to bachelor students studying at a technical university. The course, currently piloted with 150 students, is slated for implementation in the study plans for the academic year 2024/25.

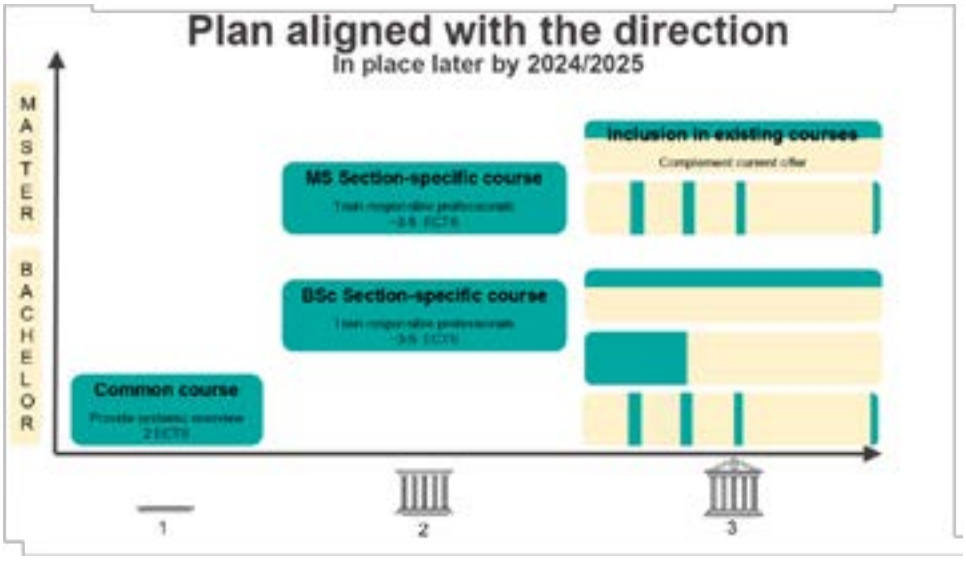

Figure 1: Illustration of the three pillars

Students engagement The collaboration between our institution and students associations, especially the ones advocating for urgent and ambitious action, underscores a unique partnership in addressing sustainability challenges within the academic community.

The participatory approach to integrating sustainability into EPFL's educational offer facilitated the dialogue between different stakeholders and therefore allowed to have a more consistent alignment of goals despite the challenges that such endeavour may entail.

3 PEDAGOGICAL STRUCTURE

3.1 Collaborative course design

In the process of designing of the sustainability course logistical aspects played a crucial role.

Following the joint demand from the education and sustainability focused vice-presidencies, numerous units from our institution were consulted and involved in the setup. These include the Teaching Support Center, which provided pedagogical advice for teachers

and teaching assistants, the Center for Transversal Skills and Career, which supports student learning of transversal skills, and the Center for Digital Education. The sustainability course is furthermore the result of the joint endeavour between the Program of Social

and Human Sciences and the Section of Science and Environmental Engineering, which contributed by facilitating the engagement of teachers from the respective structures in the sustainability course, establishing an interdisciplinary perspective from the inception. This collaborative effort among faculties, units, departments and centers ensured a comprehensive and well-coordinated logistical setup, laying the foundation for a sound and resilient institutional and pedagogical structure.

3.2 Piloting phases

The final format of the course is a 2 ECTS course across two faculties, taught by a teaching team of 14 teachers and lecturers, 6 teaching assistants and one coordinator. Two pilot courses are therefore planned: the first edition in 2024 with approximately 150 students, which we will hereafter refer to as "2024 pilot", followed by a larger pilot in 2025 with approximately 2000+ students, hereafter "2025 pilot". The former is intended to test the scientific content, while the latter to validate the logistics.

It is worth knowing that each bachelor study plan at EPFL demands students to take a 2 ECTS course from the *global issues* program in their first year of bachelor which includes courses on climate, communication, energy, food, health and mobility. Given this context, the pilot 2024 was integrated within this existing framework. However, in order to fit the sustainability course in the study plan for all bachelor students (pilot 2025), *global issues* will shift to the second year, ensuring the space for the sustainability course in the first year of studies at EPFL and guaranteeing a continuity and deepening of the topics related to global issues. This significant restructuring in all study plans at EPFL freed up 2 ECTS in the first year specifically for the sustainability course.

Outline of the course The content of the sustainability course has been defined and divided into three main parts: firstly, students are introduced to the theoretical background of planetary boundaries (Richardson et al. 2023), encompassing climate, biosphere integrity, hydrosphere, and a historical approach to sustainability. This foundational knowledge is complemented by an exploration of social, technological, political, and economic levers, followed by a systems thinking course and a project requiring a systemic approach to case studies (see Table 1).

Table 1: Outline of the course

Crisis, Planetary Boundaries and Social Needs	Week 1: Crises, Climate
	Week 2: External conference
	Week 3: Planetary boundaries, biosphere integrity
	Week 4: Hydrosphere and water cycle
	Week 5: Historical approach to sustainability
Potential Levers and Limits	Week 6: Technological, political and economical levers
	Week 7: 3 horizons and new narratives
	Week 8: Social levers and local transition examples
Intermediate Exam	Week 9: Multiple choice exam
Systems Thinking Study Case	Week 10: Systems thinking, examples of study case
	Week 11: Managing information search + prepare study case
	Week 12: Preparation for study case
	Week 13: Deadline for study case and poster
	Week 14: Poster presentation

In the initial stages of the course, students engage in ex-cathedra lectures followed by workshops to validate their theoretical understanding through experience following an active learning approach. While only three workshops were tested in the 2024 pilot, an additional four new ones will be developed for the 2025 pilot.

3.3 Pedagogical considerations

The pedagogical structure of the sustainability course aims at providing students with an interdisciplinary approach to sustainability science. The course is taught by an academically diverse team of 14 teachers, including experts from University of Lausanne and EPFL, and external professionals from the sustainability office of the city council, offering insights from the local context. The process of the content creation (modules, common thread and approach) has been the result of discussions between an initial group of teachers and students, and subsequently validated by the direction. It is important to note that the initial group of teachers partially differ from the ones involved

in the implementation of the course, demonstrating the non-dependency of the sustainability course to the group who initiated the project. To ensure coherence and avoid overlaps,

the teaching team has met monthly in the six months preceding the start of the semester. During this period, teachers have been supported in familiarizing themselves with the logistical constraints, including the assessment method for the 2024 pilot, in the conception of a concept map of each module and the whole course following (Lanares, Laperrouza, and Sylvestre 2023)'s approach, as well as an offer of pedagogical coaching and individual support when deemed necessary.

The course is supported by five master students working as teaching assistants and one PhD student, who have been following several training sessions (coaching skills, teaching with questions, facilitating group work, dealing with eco-emotions) aimed at providing them with the necessary tools to facilitate students' group work. Their main responsibilities include the facilitation of workshops, providing feedback related to the third part of the course (group projects applying systems thinking to a case study), and help to grade the students projects.

To accommodate the large number of students expected in 2025, the ex-cathedra lectures will transition to a flipped classroom model. This will require students watching a 45' video before attending class, where they meet with the teacher for 45' in large groups to delve deeper into the material by tackling common misconceptions, errors and potential questions arising from the first interaction with the theoretical content. Teachers can also take time to explain their own research work related to sustainability to give students ideas about their different professional futures. In the next period of 45', students will participate in weekly workshops designed to put into practice what they have previously learned in a more interactive setting.

Assessment method The 2024 pilot has taken place within the *global issues* program and consequently respect its evaluation method. It consisted of a 30% individual grade on a multiple choice mid-term to assess students' understanding of the content (first part), and 70% group work report and poster on a case study of their choice related to a sustainability challenge, that they will analyse and illustrate using the systems thinking approach based on (Meadows and Wright 2008). The evaluation criteria have been transparently communicated to the students as follows:

Sustainability	The link between the studied system and sustainability elements
Big picture	The definition, description of the context and limits of the studied system
Inter-dependencies	How the elements are connected to each other, cause-effect chains, feedback loops, etc
Leverage points	An action that would bring about a desirable effect, but can generate both wanted and unwanted consequences
Diagram of the system	Visual representation of the system
Language and structure	Quality of the report
Poster coherence	Logic, common thread with the report
Oral presentation	Vocabulary, time management, logical flow between group members

During the group work, students are requested to fill-in two intermediary reports aimed at scaffolding their analysis via guiding questions, and supporting their group work

While these two assignments are not graded, students are strongly advised to discuss them with the students assistants to receive feedback on the progression of their work.

4 FIRST RESULTS AND FOLLOW-UP

4.1 Preliminary feedback

Students intermediate survey A first feedback obtained after five weeks of course highlights positive aspects as well as areas for improvement. Considering a response rate of 47%, 79% of students *agree* or *strongly agree* that the course allows them to learn in an appropriate class climate [1]. The workshops are generally well-received, with students finding them enjoyable and valuable for their practical understanding. However, some students calls for a greater balance between workshops and ex-cathedra lectures. While the theoretical content is praised for its interesting and diverse nature, concerns are expressed about the depth of information provided and the frequent changes in topics and instructors. Some students suggest focusing more on practical sustainability solutions and reducing repetitions. Regarding organization and logistics, students highlight the need for improved classroom logistics and clearer communication regarding course requirements and evaluation methods. Considering this as a pilot, these observations constitute a valuable learning experience to the team involved in the teaching and design of the course.

Teaching Assistants' feedback The team of five student assistants provides weekly feedback that contribute to the improvement of the content for the 2025 pilot. While much of their feedback pertains to specific classes, several overarching themes emerge. Firstly, they highlight the importance of clarification and good organization of course material, the need for clear definitions and key concepts to guide students' understanding of the learning objectives. They also advocate for the inclusion of more examples illustrating local sustainability solutions to enhance relevance and engagement.

Regarding the workshops, students assistants noticed an active participation from students. We acknowledge nonetheless that the enthusiasm may be biased due to the fact that students who choose to partake in the 2024 pilot did it on a voluntarily basis. As the course expands to accommodate a larger cohort, we anticipate challenges in maintaining engagement and participation, stressing the need for innovative pedagogical approaches and logistical support.

5 CONCLUSION AND FUTURE DEVELOPMENTS

While the preliminary feedback for the 2024 pilot are promising, the limitations and constraints for the 2025 pilot are challenging. Teaching 2000+ students with limited human resources calls the need for innovative pedagogical methods and coordination with several services of our institution. To prepare the 2025 pilot, videos for the flipped classes will be recorded in the following months. We aim to digitalize most of the course's content with help from the Center for Digital Education and other school's services. Finally, a new Master course about teaching sustainability will start in the Fall of 2024. This new course will aim at training the team of teaching assistants to facilitate the workshops of the sustainability course and develop the

[1] Answer to the question "The running of the course enables my learning and an appropriate class climate"

specific skills required by the pedagogy of sustainability education. Once the courses will be running operationally, the goal is to obtain a virtuous cycle, where course Alumni will become assistants, both contributing to the continuous improvement of the course and deepening their sustainability competences by learning **and** teaching them.

REFERENCES

Børsen, Tom, Yann Serreau, Kiera Reifschneider, André Baier, Rebecca Pinkelman, Tatiana Smetanina, and Henk Zandvoort. 2021. "Initiatives, experiences and best practices for teaching social and ecological responsibility in ethics education for science and engineering students" [in en]. *European Journal of Engineering Education* 46, no. 2 (March): 186–209. ISSN: 0304-3797, 1469-5898, accessed April 4, 2024. https://doi.org/10.1080/03043797.2019.1701632. https://www.tandfonline.com/doi/full/10.1080/03043797.2019.1701632.

Duvillard, Laureline. "EPFL will train students on sustainability" [in en]. EPFL News. 2022. https://actu.epfl.ch/news/epfl-will-train-students-on-sustainability/

Engineering Technology, The Institution of. 2023. *International green skills 2023 survey* [in en]. December. Accessed 2024. https://doi.org/10.3390/su9101889.theiet.org/greenskills.

Guerra, Aida, and Fernando Rodriguez-Mesa. 2021. "Educating engineers 2030 – PBL, social progress and sustainability" [in en]. *European Journal of Engineering Education* 46, no. 1 (January): 1–3. ISSN: 0304-3797, 1469-5898, accessed April 4, 2024. https://doi.org/10.1080/03043797.2020.1828678. https://www.tandfonline.com/doi/full/10.1080/03043797.2020.1828678.

Haase, S. 2014. "Engineering students' sustainability approaches" [in en]. *European Journal of Engineering Education* 39, no. 3 (May): 247–271. ISSN: 0304-3797, 1469-5898, accessed April 4, 2024. https://doi.org/10.1080/03043797.2013.858103. http://www.tandfonline.com/doi/abs/10.1080/03043797.2013.858103.

Hickman, Caroline, Elizabeth Marks, Panu Pihkala, Susan Clayton, Eric R. Lewandowski, Elouise E. Mayall, Britt Wray, Catriona Mellor, and Lise Van Susteren. 2021. "Young People's Voices on Climate Anxiety, Government Betrayal and Moral Injury: A Global Phenomenon" [in en]. *SSRN Electronic Journal,* ISSN: 1556-5068, accessed April 4, 2024. https://doi.org/10.2139/ssrn.3918955. https://www.ssrn.com/abstract=3918955.

Lanares, Jacques, Marc Laperrouza, and Emmanuel Sylvestre. 2023. *Design pédagogique.* February. ISBN: 9782832322000. https://doi.org/10.55430/8015VA01.

Lozano, Rodrigo, Rebeka Lukman, Francisco J. Lozano, Donald Huisingh, and Wim Lambrechts. 2013. "Declarations for sustainability in higher education: becoming better leaders, through addressing the university system." *Journal of Cleaner Production,* Environmental Management for Sustainable Universities (EMSU) 2010, 48 (June): 10–19. ISSN: 0959-6526, accessed April 8, 2024. https://doi.org/10.1016/j.jclepro.2011.10.006. https://www.sciencedirect.com/science/article/pii/S0959652611003775.

Lozano, Rodrigo, Michelle Merrill, Kaisu Sammalisto, Kim Ceulemans, and Francisco Lozano. 2017. "Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal" [in en]. *Sustainability* 9, no. 10 (October): 1889. ISSN: 2071-1050, accessed April 6, 2024. https://doi.org/10.3390/su9101889. http://www.mdpi.com/2071-1050/9/10/1889.

Mann, Llewellyn, Rosemary Chang, Siva Chandrasekaran, Alicen Coddington, Scott Daniel, Emily Cook, Enda Crossin, et al. 2021. "From problem-based learning to practice-based education: a framework for shaping future engineers" [in en]. *European Journal of Engineering Education* 46, no. 1 (January): 27–47. ISSN: 0304-3797, 1469-5898, accessed April 4, 2024. https://doi.org/10.1080/03043797.2019.1708867. https://www.tandfonline.com/doi/full/10.1080/03043797.2019.1708867.

Martin, Diana Adela, Eddie Conlon, and Brian Bowe. 2021. "A Multi-level Review of Engineering Ethics Education: Towards a Socio-technical Orientation of Engineering Education for Ethics." *Science and Engineering Ethics* 27, no. 5 (August): 60. ISSN: 1471-5546. https://doi.org/10.1007/s11948-021-00333-6. https://doi.org/10.1007/s11948-021-00333-6.

Meadows, Donella H., and Diana Wright. 2008. *Thinking in systems: a primer.* OCLC: 225871309. White River Junction, Vt: Chelsea Green Pub. ISBN: 9781603580557.

Richardson, Katherine, Will Steffen, Wolfgang Lucht, Jørgen Bendtsen, Sarah E. Cornell, Jonathan F. Donges, Markus Drüke, et al. 2023. "Earth beyond six of nine planetary boundaries." Publisher: American Association for the Advancement of Science, *Science Advances* 9, no. 37 (September): eadh2458. Accessed April 8, 2024. https://doi.org/10.1126/sciadv.adh2458. https://www.science.org/doi/10.1126/sciadv.adh2458.

Smith, Jeremy, Anh L. H. Tran, and Paul Compston. 2020. "Review of humanitarian action and development engineering education programmes" [in en]. *European Journal of Engineering Education* 45, no. 2 (March): 249–272. ISSN: 0304-3797, 1469-5898, accessed April 4, 2024. https://doi.org/10.1080/03043797.2019.1623179. https://www.tandfonline.com/doi/full/10.1080/03043797.2019.1623179.

Intended Learning Outcomes on Process Level in an Engineering Course with Knowledge-Based Learning Outcomes

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ABSTRACT

This practice paper introduces an approach to learning outcomes within the context of the Innovation Space Bachelor End Project (ISBEP), which underscores the transition from traditional outcome-focused education to a process-level learning paradigm at a Technical University in the Netherlands. At the core of ISBEP's methodology is competence development through challenge-based learning, encouraging interdisciplinary collaboration and engagement with societally relevant challenges. The paper discusses the effectiveness of process-level learning outcomes, highlighting the importance of reflection, self-awareness, and iterative learning in fostering a growth mindset among students.

We then outline the application of this process-oriented approach to knowledge-based learning outcomes, an area traditionally dominated by outcome-based

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assessments. By segmenting educational progress into distinct stages—beginning, emerging, proficient, and advanced—this approach facilitates a more engaged and reflective learning process. It encourages students to actively participate in their knowledge acquisition, applying critical thinking and synthesis to complex problems.

The proposed methodology is set to be tested in the "Automotive Societal Factors" course within the Master program in Automotive Technology, a course that focuses on the societal impacts of autonomous driving. This course will assess students' self-reflection on personal development, aiming to foster intrinsic motivation and a growth mindset that may extend to other areas of their education. This exploration into process-level learning outcomes represents a significant shift in educational philosophy, offering a comprehensive framework for enhancing learning engagement and understanding in various settings.

1 DEFINING LEARNING OUTCOMES ON PROCESS LEVEL

The Innovation Space Bachelor End Project (ISBEP) stands at the vanguard of educational innovation, embodying the principles of challenge-based learning (CBL) (Doulougeri et al., 2024). This approach is encapsulated in the course's core characteristics: interdisciplinary collaboration (i.e., different disciplinary backgrounds, such as mechanical engineering and electrical engineering), focus on societally relevant challenges, and partnership with a broad spectrum of stakeholders.

ISBEP promotes both skill and (disciplinary) knowledge development. Assessment of disciplinary knowledge is performed by specialists from each student’s own department. Assessment of skills is performed through a set of individual and team-based learning outcomes. Individually, students strive to understand the nuanced needs of stakeholders, to dissect interdisciplinary problems into manageable components, and to navigate the murky waters of situations with no clear answers while applying or deepening their respective disciplinary knowledge. Collectively, their goal is to synthesize their findings into a cohesive, experiential demonstrator, showcasing their ability to apply knowledge across disciplines and to collaborate effectively.

1.1 Skill-Based Learning Outcomes on Process Level

Central to ISBEP's educational philosophy is the transition from traditional outcome-focused metrics to an approach that emphasizes process-focused metrics. In other words, the focus is less on showcasing abilities at the end of the course, and more on guiding students in the process that leads them to acquire the necessary skills.

This philosophy underlines the understanding that learning is an iterative journey, unfolding over time and across various stages of comprehension and competence (i.e., skills, knowledge, attitudes) development. By articulating these process-level outcomes, ISBEP offers students guidance along their educational journey, enhancing their engagement with the learning activities and facilitating a deeper understanding of the challenges and successes they can expect in the interdisciplinary collaboration. It encourages a growth mindset, which is shown to enhance intrinsic motivation to learn (Ng, 2018). Fostering a growth mindset encourages the development of new talents (Dweck, 2009), and as such empowers students to take charge of their own learning progress. It also encourages students to set goals for themselves, and in the field of academic performance, studies show that self-based goals are associated with higher motivation and engagement (Martin & Elliot, 2016; Yu & Martin, 2014).

This methodology proves particularly effective for several reasons. First, it provides students with clear milestones in their learning progression, helping them identify their current stage in the development of learning outcomes and the steps needed to advance further. This clarity is crucial for fostering awareness among students regarding their learning process, enabling them to seek appropriate support and resources as they progress. Furthermore, by delineating the stages of learning, students are encouraged to engage in reflective practices, (self-)assessing their strengths and areas for improvement in relation to the defined learning outcomes.

The organization of ISBEP thus facilitates a learning environment where reflection (i.e. actively thinking about one's own learning), iterative learning (i.e. continuous improvement through small steps), collaborative learning, and practical application have become the cornerstone of the educational experience. Students are not merely passive recipients of knowledge; they are active participants in a learning journey that emphasizes growth, development, and the practical application of skills.

1.2 The Role of Self-Reflection

Reflection plays a pivotal role in ISBEP, serving as a mirror for students to examine their learning processes, both as individuals and within their teams. Through coaching sessions, guided reflection, and self-assessment, they gain insights into their growth, challenges, and achievements. A digital platform serves as a canvas for their self-reflection, offering graphical overviews of their growth in individual learning outcomes and a holistic view of their competencies through spider diagrams.

ISBEP delineates four stages of process orientation: beginning, emerging, proficient, and advanced. Each stage represents a milestone in the student's journey towards becoming engineers who are more aware of their interdisciplinary competencies. At the start of the course, students carry out a first self-assessment in relation to their overall development and gain awareness of their starting point in the learning journey within ISBEP.

- **Beginning**: This initial stage is characterized by foundational learning, where students are introduced to new concepts and begin to engage with the learning activities and their project. The expectation at this level is foundational knowledge and basic application.
- **Emerging**: At this stage, students start to display an increased understanding of the competencies they are developing, their role within the team, and contribution to the challenge. Moreover, they can apply concepts in more varied contexts. Expected outcomes include a deeper engagement with the project and the beginning of critical thinking regarding the subject matter.
- **Proficient**: Proficiency is marked by a significant level of mastery over the project, with students demonstrating the ability to apply knowledge in complex situations and engage in higher-level thinking and problem-solving.
- **Advanced**: The advanced stage signifies a deep and comprehensive understanding of the subject matter, with the ability to engage in creative problem-solving, contribute original ideas, and synthesize information across various contexts.

ISBEP places a strong emphasis on reflection as a mechanism for learning. Reflection, both guided and self-driven, allows students to internalize their experiences, understand their thought processes, and critically evaluate their own work. This approach is structured in several layers:

- **Team / Individual Work**: Encourages collaborative learning as well as individual study, providing a balanced environment for knowledge acquisition.
- **Coaching Sessions**: These sessions offer personalized guidance, helping students navigate challenges and gain deeper insights into their learning process.
- **Guided Team Reflection**: Facilitated by process coaches, guided reflection helps students identify key learnings, challenges, and areas for improvement.
- **Self-Assessment**: Students engage in a personal review of their learning journey, fostering self-awareness and personal growth.

2 APPLICATION IN AN ENGINEERING COURSE

The process approach to intended learning outcomes has shown to be successful when applied to a course with only skill-based learning outcomes. Most of the courses at our university do not (only) contain skill-based learning outcomes, but are designed to help students obtain knowledge-based learning outcomes. Knowledge-related learning outcomes are those through which knowledge acquisition is being assessed.

2.1 From Skill-based to Knowledge-based

Expanding the principle of process-level learning beyond broader competence (i.e., skills, knowledge, attitudes) development and into the realm of knowledge-related learning outcomes, marks a significant evolution in educational philosophy. This extension involves reimagining traditional content acquisition as an exploratory, iterative process. The segmentation of the educational process into stages would suppose the enhancement of students' ability to engage with complex problems, but knowledge acquisition also becomes an active, engaged process that emphasizes critical thinking, reflection, and synthesis.

Despite the advantages of a process-oriented approach (as experienced in ISBEP), its implementation, particularly within the context of knowledge-based learning outcomes, is met with several challenges. Traditional educational frameworks often prioritize outcome-based assessments and discipline-specific knowledge, presenting obstacles to the adoption of process-oriented strategies.

When relying on self-reports to assess learning gains, there are some limitations to consider. For instance, Rogaten et al. (2019) highlight that students may exhibit overconfidence in their knowledge. This tendency tends to amplify over time (Mathabathe and Potgieter, 2014; Rogaten and Rienties, 2021; Varsavsky et al., 2014). Additionally, scholars emphasize that self-reported measures constantly compare students' perceived learning gains against their subjective "feeling" of learning or "feeling of knowing" (Rogaten and Rienties, 2021). Self-reflections thus are inherently subjective, as they represent individual students' perceptions of their learning experiences and progress. This subjectivity poses a difficulty in evaluating self-reflections against standardized criteria, as interpretations of learning progress can vary widely among students.

One potential solution to this challenge is taking a learning analytics approach, where linguistic indicators of personal development could be examined in reflective writing (Kovanović et al., 2018). Another approach is integrating self-reflections with other types of evidence in course deliverables. By comparing the elaborations in self-reflections to tangible outcomes and artifacts produced during the course, educators can achieve a more comprehensive and objective assessment of student learning. This comparative analysis allows for a triangulation of evidence, wherein self-reflections provide insights into the students' self-perceived growth and learning processes, while course deliverables offer concrete evidence of their skills and knowledge application. This method not only enhances the reliability of assessments but also encourages students to consistently align their reflective practices with their practical work, fostering a holistic approach to learning.

2.2 Context of the Engineering Course

This approach will be put to the test by applying it in an engineering course that has knowledge-based learning outcomes. The course is a core course in the first quartile of the Master program Automotive Technology; Automotive Societal Factors. The course addresses the relation between a car or other vehicle, its human driver, and its dynamic environment. It is especially concerned with technological, social, and legal perspectives of autonomous driving. Apart from lectures students will work in groups on an assignment that incorporates many of the topics of the course: societal dimensions of autonomous driving, future mobility and traffic, user perception, legal issues, and ethics.

2.3 Knowledge-Based Learning Outcomes on Process Level

The intended learning outcomes of the course are based on four levels of Bloom's (1956) taxonomy and are the following:

After completion of the course, students are able to

- **Apply** human-centred design methods and evaluation metrics within an automotive context
- **Analyse** a driving task in terms of perceptual, attentional, environmental and societal processes
- **Analyse** connections between key theories and principles within the automotive context
- **Evaluate** their own personal development on the learnings outcomes throughout the course
- **Create** a (VR) simulation/experience showing automated driving in context

These learning outcomes are then each split into the four process-levels. For the learning outcome "Analyse a driving task in terms of perceptual, attentional, environmental, and societal processes", this leads to the following:

- **Beginning**: Students recognize the components of driving tasks but cannot articulate how perceptual, attentional, environmental, and societal factors influence these tasks.

- **Emerging**: Students can describe how each of the specified factors affects driving tasks but struggle to integrate this understanding into a coherent analysis.
- **Proficient**: Students provide a thorough analysis of driving tasks, clearly explaining the interplay between perceptual, attentional, environmental, and societal factors. They can predict task performance outcomes based on these analyses.
- **Advanced**: Students offer deep insights into the driving task analysis, incorporating cutting-edge research and theoretical frameworks. They are adept at forecasting the implications of these factors on future automotive technologies and societal impacts.

3 IMPLEMENTATION IN THE COURSE

The Automotive Societal Factors course starts in September 2024, and this will be the first rendition in which students' self-reflection on personal development is assessed. The design of the assessment itself (the assessment criteria and descriptors of the different levels) will look as follows: at the end each week, all groups submit a new part of their assignment to Canvas (the Learning Management System used by TU/e). At the same time, students individually complete an assignment in which they reflect on their personal development. They indicate for each ILO which level they have achieved, and elaborate on their choices by answering one open question. Assessment of the reflection will be based on two components. The first is the extent to which the indicated levels on individual level correspond with the quality of the work on group level. The second is the quality of the elaboration on the reflection itself (i.e. showing a deeper understanding of one's own capabilities and what is needed to reach the next step would make a student get a more positive assessment).

Our expectations are that students will become intrinsically motivated to study for the course, as the process focus will nudge them into obtaining a growth mindset. This will be evaluated by measuring students' mindset several times throughout the course (at the start and at the end, and one or two more times in between). We expect that the educational approach of the course will foster more growth mindsets, which ultimately could spill over into other courses in the program, preparing students for a successful educational path.

REFERENCES

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., and Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals. *Handbook 1: Cognitive domain* (pp. 1103-1133). New York: Longman.

Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education*.

Dweck, C. S. (2009). *Mindsets: Developing talent through a growth mindset*. Olympic Coach, 21(1), 4-7.

Kovanović, V., Joksimović, S., Mirriahi, N., Blaine, E., Gašević, D., Siemens, G., & Dawson, S. (2018, March). Understand students' self-reflections through learning analytics. In *Proceedings of the 8th international conference on learning analytics and knowledge* (pp. 389-398).

Martin, A. J., & Elliot, A. J. (2016). The role of personal best (PB) and dichotomous achievement goals in students' academic motivation and engagement: A longitudinal investigation. *Educational Psychology, 36*(7), 1285-1302.

Mathabathe, K. C., & Potgieter, M. (2014). Metacognitive monitoring and learning gain in foundation chemistry. *Chemistry Education Research and Practice, 15*(1), 94-104.

Ng, B. (2018). The neuroscience of growth mindset and intrinsic motivation. *Brain sciences, 8*(2), 20.

Rogaten, J., & Rienties, B. (2021). A critical review of learning gains methods and approaches. *Learning Gain in Higher Education*, 17-31.

Rogaten, J., Rienties, B., Sharpe, R., Cross, S., Whitelock, D., Lygo-Baker, S., & Littlejohn, A. (2019). Reviewing affective, behavioural and cognitive learning gains in higher education. *Assessment & Evaluation in Higher Education, 44*(3), 321-337.

Varsavsky, C., Matthews, K. E., & Hodgson, Y. (2014). Perceptions of science graduating students on their learning gains. *International Journal of Science Education, 36*(6), 929-951.

Yu, K., & Martin, A. J. (2014). Personal best (PB) and 'classic' achievement goals in the Chinese context: their role in predicting academic motivation, engagement and buoyancy. *Educational Psychology, 34*(5), 635-658.

THE EFFECTIVENESS OF VIRTUAL REALITY IN ENGINEERING EDUCATION: A SEMI-EXPERIMENTAL STUDY AT CASE COMPANY

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ABSTRACT

This article deals with research focused on exploring the efficacy of virtual reality (VR) in maintenance training within a large mechanical engineering company. It highlights the research collaboration in pedagogical issues between a technical university of applied sciences (UAS), a pedagogical university, and an industrial company, marking a departure from traditional research topics focused mainly on technical problems and processes. The study involved BSc engineering students from the UAS as participants in an experimental pedagogical research project conducted at the Case Company during academic year 2023-2024, with the primary researcher affiliated with a pedagogical university. Three groups of students were

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trained each with a different instructional method, one being the VR training. Data collection encompassed both qualitative and quantitative methods, with subsequent analysis aimed at assessing the effectiveness of VR in facilitating learning of technical maintenance tasks. The preliminary results of the semi-experimental study at Case Company showed that overall, the VR learning group (8.00 $p \leq 0.05$) had better practical skills learning outcomes in overhauling engine pistons compared to the distance learning group (3.00 $p \leq 0.05$) with the hands-on learning group (13.00 $p \leq 0.05$) getting the best results. Nevertheless, the quantitative data analysis also revealed that the VR group performed equal or worse in some practical skills variables compared to the distance learning group. The qualitative assessment revealed the potential reasons for the underperformance of VR group compared to the other groups, where students' feedback highlighted the strengths and weaknesses of VR complemented by suggestions for improvement.

1 INTRODUCTION

With the continuous development in technology, we are also facing a new era in education. Nowadays, there are different forms of immersive technologies that can make learning more engaging. As shown in Figure 1 on this page, Extended Reality (XR) is a label commonly used to categorize different types of such digital experiences. In this domain, there exists Virtual Reality (VR), a technology generating interactive virtual surroundings, Augmented Reality (AR), a technology overlaying virtual data onto the real world, and Mixed Reality (MR), blending aspects of VR and AR in one interface. Interest in XR has surged in Higher Education (HE) recently. Engineering stands out as the primary area within HE utilizing this technology for research, with 24% of research papers focusing on it. Various disciplines in engineering benefit from XR applications, such as manufacturing training, workshop safety, fluid dynamics, electrical principles, and chemical/biological simulations. XR has gained significant attention in higher education due to the numerous advantages it provides to the learning process, including enabling individuals to explore knowledge and surroundings using unconventional approaches not typically available through traditional means (Bangert et al. 2023).

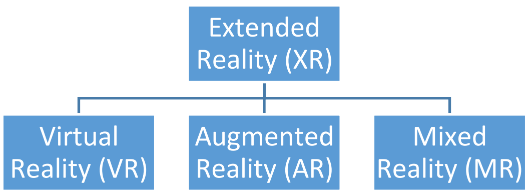


Fig. 1. Immersive technologies

In this study, we are focused on VR and not other forms of similar immersive technologies. VR is a virtual environment that is created using computer technology and is designed to simulate real-world experience. This technology allows users to interact with and explore a 3-dimensional environment, enhancing the learning experience. It has been widely used in a variety of fields including gaming, entertainment, healthcare, and education. VR in engineering education has gained significant attention in recent years due to its potential to improve the teaching and learning experience (Soliman et al. 2021).

VR technology allows students to immerse themselves in realistic and interactive virtual environments, providing them with hands-on experience and practical training (Marougkas et al. 2023). VR offers a dynamic and immersive learning environment for students in engineering education. It enables them to visualize complex concepts, simulate real-world scenarios, and manipulate virtual objects, fostering deeper understanding and problem-solving skills. Additionally, VR can enhance collaboration and communication among students, as they can interact and work together in the virtual environment. Furthermore, VR provides a safe and cost-effective alternative to traditional hands-on training methods.

Instruction with VR lies on various theoretical frameworks, learning theories, and educational approaches (Marougkas et al. 2023) with constructivism learning, experiential learning and gamification of learning being probably the most dominant ones. For instance, constructivism posits that individuals construct their own understanding and knowledge of the world through experiences and interactions with their environment. In the context of VR, this theory suggests that learners can construct their own knowledge and understanding of a subject by interacting with a virtual environment. This type of learning experience can be particularly effective, as it allows learners to engage with the material in a hands-on and immersive way, which can lead to deeper understanding and retention. In addition, experiential learning in VR can provide opportunities for trial and error without the consequences that might be associated with real-world mistakes. This can be especially beneficial in high-stakes or potentially dangerous situations, where the cost of failure is high. As such, this risk-free environment allows individuals to push their boundaries and explore new challenges with confidence. Furthermore, gamification of learning can make the learning process more engaging and enjoyable. It can also promote healthy competition and collaboration among learners. As a result, it can lead to improved knowledge retention and a greater sense of accomplishment.

This study aims to investigate the effectiveness of VR in engineering education, specifically focusing on a semi-experimental study conducted at Case Company. The special training center in the Case Company that conducted the study delivers training to its employees and customers. The Case company produces different types of marine and power plant engines. Two of its engines designed for marine applications called W20 and W25 were used in this study.

More specifically, this research aims to evaluate the effectiveness of VR for learning the technical task of overhauling engine piston. The participants will be taught with the following delivery methods: 1) Instructor-led Distance Learning via Teams 2) Instructor-led Hands-on Learning at Training Center 3) Instructor-led VR Learning at Training Center. The purpose is to see which works best in which areas. The researcher will evaluate students based on the following research questions:

RQ(1): To what extent is virtual reality efficient in terms of transferring theoretical knowledge? (understanding and remembering components, understanding the process of overhauling an engine)
RQ(2): To what extent is virtual reality efficient in terms of transferring practical skills knowledge?
Several other studies (Ma, Zhang, and Wu 2022; Amin et al. 2022; Athik Nagappan and Shobithraj 2022; Mojica-Irigoyen et al. 2023; Taghian et al. 2023; Sánchez-López et al. 2024; Wong and Humayoun 2022; Jalil et al. 2022; Kumar et al. 2021; Bhatia and Hesse 2023; Ivanova, Ivanov, and Zdravkov 2023; Asham, Bakr, and

Emadi 2023; Ghazali et al. 2024; Han 2023) in this area have shown positive outcomes, suggesting the effectiveness of VR in engineering education. However, to the best of our knowledge, no dedicated study has done such a comparative experiment. We aim to fill this research gap by comparing teaching with VR to two other traditional ways of maintenance training. As the results related to the first research question are not ready yet, we are reporting only the results of the second research question in this article.

2 METHODOLOGY

2.1 Study Design

The research uses mixed methods approach. As shown in Figure 2 on this page, the participants answered surveys both before and after the training received in the delivery methods. Some of the participants were also interviewed and qualitative data was collected.

The research has a semi-experimental design. There is no random assignment, or control of other variables that might affect the experiment.

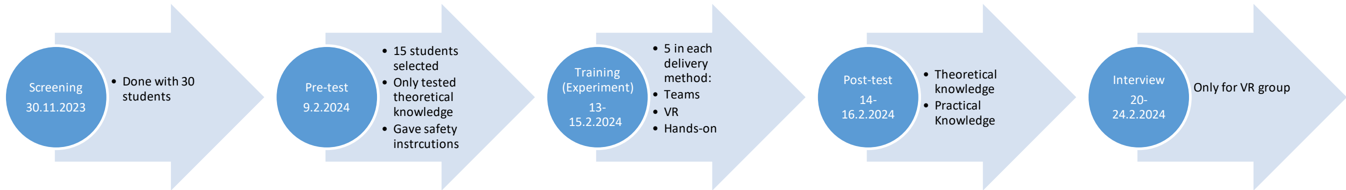


Fig. 2. Five main stages of study

The independent variables in the study are instructional methods: virtual reality (VR), face-to-face and distance teaching mode. The dependent variables are theoretical knowledge and hands-on skills on an engine maintenance task which was chosen to be overhauling the engine piston. The training content was based on the engine W20 for those coming to the hands-on facility for face-to-face session. For the VR group, the engine W25 was the only option for the training as that is the one which has been modelled for the virtual reality. For the distance group, the instructor used the available videos of some older engines from the video database of the Case Company. Still, all the face-to-face activities for the evaluation phase was based on the W20, purely for the safety reasons.

The collecting tools (screening survey and pre/post-test survey) was a researcher-made instrument. The process of designing, developing, and validation was as follow: first, the tools were made with collaboration of a research team consisted of the researcher, the expert/instructor from the company with extensive knowledge and experience about the engine, and an expert in research methods and pedagogical studies. Second, in line with the research questions, the relevant dimensions of practical and theoretical knowledge necessary for the training were identified by the expert of the engine and the researcher. Third, the identified elements were transformed to the tools for collecting data with the collaboration of methodological and pedagogical expert. Fourth, for the content validity of the tools, they were assessed by the exerts from the company to see if the tools measure what (theoretical and practical knowledge about engine) they claim. Fifth, for the face validity, and before the main administration, the tools were given to a few students from the same population (not the same sample) to see if they fully understand the questions in surveys. The final recommendations were integrated into the tools to be used for the study.

As shown in Figure 2, this research has five stages: 1) Screening 2) Pre-test 3) Experiment 4) Post-test 5) Interview.

In screening, measuring the background of students in terms of main dependent variables was necessary. The researcher screened the students with the help of a screening survey and put them in different groups based on their answers. To that end, students answered a survey on Microsoft Forms based on theoretical knowledge and practical skills of overhauling engine piston. The practical skills have only been inquired theoretically and students were not required to perform their skills. The purpose of the screening was to rule out any students who had too much or too little knowledge about the engines. The first phase of data collection (screening data) was completed with thirty BSc engineering students visiting the Case Company on 30.11.2023.

In pre-test phase, students were tested for theoretical knowledge on overhauling engine piston. The post-test was the same as the pre-test and it was given after the training was completed. To that end, they have answered a standardized level test on Microsoft Forms. For testing practical skills knowledge, pre-test could not be used. It was unsafe and would influence the actual test results. The expectation was that there is zero practical skills knowledge as the topic was Case Company specific and the test persons were students.

In the experiment phase, there was training for both theoretical and hands-on skills knowledge on overhauling engine piston.

In the post-test, students were tested for both theoretical and hands-on skills knowledge on overhauling engine piston to see the effect of the training. There was only one instructor to deliver the training. However, for evaluating practical skills knowledge, we had to have at least two mechanical instructors to ensure safety and more valid results. The practical skills knowledge was scored based on a rubric designed within the Case Company. It has gone through validation by at least two mechanical instructors.

In addition, some qualitative test data was also collected when the researcher interviewed the VR group after their training. The interview questions addressed the quality and effectiveness of the VR instructional method.

2.2 Study Population

Thirty students studying BSc degree in Energy Technology at a UAS have participated in this study. They were screened to fifteen students in the screening phase. In the experiment, there were five students per instructional method. The inclusion criterion was that students should not have completed any training related to the engines of the Case Company or worked in the Case Company before. The ideal scenario was that the participants did not have extensive background knowledge or experience about engines or piston overhaul to evaluate the effect of the delivery methods. Similarly, field service workers were not suitable participants either since they had been working already with engines.

Even though students were above eighteen, we had to consider these steps for following research ethics: First, we provided honest information about the purpose of the study; Second, we informed the participants that participation is voluntary; Third, we provided information about anonymity; Finally, we gave information on how we plan to store the data during the study.

2.3 Method

The researcher has evaluated the screening survey results with SPSS. Homogenous sampling was used to attain a sample of similar cases in the screening phase. The screened participants have similar characteristics so that the group that is the representative sample can be researched in depth. The participants were screened based on their average scores for the five theoretical knowledge and two practical skills assessment questions (See Appendix 1 for part of the survey).

After screening the population, the participants have gone through the training as the intervention in this research. This research is semi-experimental since we could obtain post-test results only. The researcher has further analyzed the data set using SPSS. The data set mainly consists of analyzing ten theoretical knowledge questions (See Appendix 2), and eight practical skills knowledge questions (See Appendix 3). The results of the first research question are yet to come and, in this paper, we only report the results of the second research question. Overall, we reported eight variables based on the practical skills knowledge and we also computed a new variable based on their average score. The researcher analyzed the data using the Kruskal-Wallis test. It is a nonparametric (distribution free) test and evaluates data ranks. It is used when the assumptions of one-way ANOVA are not met.

2.4 Procedure

In the pre-test, some students attended in person, while others participated online. The instructor provided safety instructions on the same day. The actual research happened in 2024 (See Figure 2). There was preparation, training and then testing of students. The training sessions for each group, and theoretical and hands-on tests were at least around four hours each including the breaks. The tests happened on one day with the practical test following the theoretical test. The distance learning group followed their training remotely and they only came for the tests to the Case Company.

The instructor from the Case Company gave the technical training using three different delivery methods: 1) Distance Learning via Teams 2) Hands-on Learning at Training Center 3) VR Learning at Training Center. The researcher was not the instructor, but she was present when the instructions were delivered. Students were divided in three different groups, and they were receiving training with these delivery methods. Only one group was trained with VR since we wanted to see the effectiveness of VR compared to other methods.

As shown in Figure 3, after the training, on the next day, there were tests to see how well students performed the tasks which were about overhauling engine piston. The researcher was monitoring the theoretical tests that were given to the students.

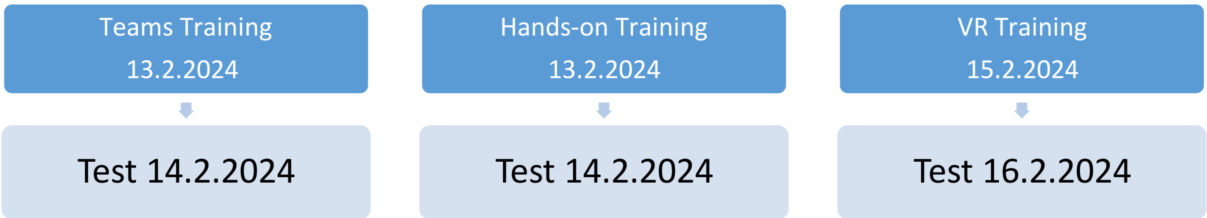


Fig. 3. Training and post-test schedule

The practical skills knowledge test was conducted by the Case Company instructor. Like the instruction phase, the researcher was present in the testing situation.

3 RESULTS

In this chapter, we have analyzed data in line with the second research question we posed. The results are organized in two sections: 1) Inferential Analysis Report 2) Interview Results.

In the inferential analysis, the main goal was to see how effective the intervention, teaching with VR, was in enhancing students' learning about engine overhauling compared to distance and hands-on groups. As such, we analyzed the practical skills knowledge of students after training (post-test).

3.1 Inferential Analysis

Our second research question (RQ2) aimed to evaluate the extent to which virtual reality is efficient in terms of transferring practical skills knowledge.
As shown in Table 1, we have summarized the results based on the nine variables that we had for measuring the effectiveness of instructional methods in terms of transferring practical skills knowledge.

We hypothesized that there were no significant differences among three groups in terms of the nine variables in engine overhauling after experiment (H0). A Kruskal-Walli's test was performed on the scores of the three groups (VR, Teams, Hands-on). The differences between the rank totals of the three groups were statistically significant, H (2, n = 15) = 14.000 p ≤0.05. This means that the null hypothesis was rejected. In other words, there was a significant difference between the three groups in terms of the nine variables in engine overhauling after experiment.

Table 1. Instructors' practical skills knowledge evaluation

Variables	Instructional methods	Mean rank	Sample size (n)
Correct selection of parts	Teams	8.00	5
	VR	3.00	5
	Hands-on	13.00	5
Correct selection of tools	Teams	5.50	5
	VR	5.50	5
	Hands-on	13.00	5

Job safety analysis	Teams	3.00	5
	VR	8.00	5
	Hands-on	13.00	5
Work safety	Teams	5.50	5
	VR	5.50	5
	Hands-on	13.00	5
Process executed in correct order	Teams	3.00	5
	VR	8.00	5
	Hands-on	13.00	5
Applying the use of manual	Teams	8.00	5
	VR	3.00	5
	Hands-on	13.00	5
Work done autonomously	Teams	5.50	5
	VR	5.50	5
	Hands-on	13.00	5
Timing of the work	Teams	3.00	5
	VR	8.00	5
	Hands-on	13.00	5
Practical skills knowledge average score	Teams	3.00	5
	VR	8.00	5
	Hands-on	13.00	5

3.2 Interview Results

We summarized the interview results based on the following five interview questions:

1) What do you think about the quality (effectiveness) of the teaching method you experienced?

2) What were the strengths of the teaching method you experienced? What was good about it?

3) What were the weaknesses of the teaching method you experienced? What were the inefficiencies/problems?

4) Did the training method you experienced meet your expectations?

5) Do you have any suggestions for the improvement of the teaching method you experienced?

Here, we have explored the key takeaways:

- Interviewee one found the visual and interactive nature of VR learning was effective for understanding complex concepts like engine components, although she experienced discomfort after prolonged use. She suggested more training time.
- Interviewee two also had a positive experience with VR, improving awareness of complex systems but faced challenges like headaches. He suggested making the training easier to use and recommended taking regular breaks.
- Interviewee three appreciated the immersive experience of VR training for machine assembly but noted the potential for dizziness with prolonged use. He also suggested more training time.
- Interviewee four praised the interactive learning process with VR but pointed out issues with tool handling, teleporting objects, and connection issues when collaborating with multiple team members in the VR setting.
- Interviewee five highlighted the detailed view and ease of use in VR training and its time-saving benefit. However, he also noted the difficulty translating VR experience to hands-on tasks, especially tool selection, as real-world situations involve more detailed knowledge and complexity. He suggested adding more instruments to simulate specific tools for specific tasks in the program and emphasized the need for pre-training on using VR tools to avoid time constraints during actual sessions.

4 CONCLUSION

This study collected both qualitative and quantitative data to evaluate how effectively VR facilitates learning of technical maintenance tasks. Unlike conventional research, this study emphasized collaboration between a UAS, a pedagogical university, and an industrial company. Based on our experience, we suggest more of these types of collaborations for future studies in similar topics.

The qualitative findings of this study align with previous research in this area, emphasizing the potential of VR to create a dynamic and immersive learning environment for engineering students. The ability to visualize and interact with 3-dimensional models, simulate real-world scenarios, and collaborate with peers in a virtual space has been shown to enhance the overall learning experience.

The quantitative findings of this study, however, showed that the VR group performed the same in practical skills variables like correct selection of tools, work safety, and work done autonomously compared to the Teams group. In some other cases like correct selection of parts and applying the use of manual, the VR group had even a poorer performance compared to the other groups. The hands-on group did the best in all the practical skills variables. Based on these results, we suggest a combination of different instructional methods for better learning results. Future studies could work on finding the optimal combination.

This study had a few limitations that can be a basis for further research and should be considered by other researchers. First, we had limited time to be able to test all the participants for practical skills knowledge and give individual scores, so we could only give group scores. Second, we should point out that the engine type for VR intervention was different from other training types and this could be one possible factor that affects our sample's learning performance. We suggest, for further research, the researcher use the same engine type for all training types to control this issue. More specifically, the only engine type available in the VR was W25. With further development, more engines can be simulated in the VR environment. There is a chance that engine design might affect the difficulty level of maintenance task. The engine type affects the results, but it is hard to tell how much the design for W20 and W25 affects the results since this study was the first one done with the VR in the Case Company. Third, the intervention (the training type administration) was too short, and the sample may not fully have experienced the learning environment of each training type, particularly teaching with VR. A longer intervention is required to scientifically study and compare the learning environment of each training type and its effects on practical knowledge of the students.

For engineering education, our results indicate that both virtual and practical skills training need to be included while virtualizing engineering labs. Laboratory courses can be virtualized, but we still need to keep the hands-on training to some extent. In the higher education, the extent to which laboratory courses can be virtualized should be further researched. In summary, this study has provided us with useful insights into using different types of training in engineering, however we need to be careful about generalizing the results to other contexts because this study relied on one Case Company and its VR technology. More research is required to deal with the above-mentioned limitations.

REFERENCES

Amin, Isma Widiaty, Cica Yulia, and Ade Gafar Abdullah. "The Application of Virtual Reality (VR) in Vocational Education." In *Proceedings of the 4th International Conference on Innovation in Engineering and Vocational Education (March 2022)*, 112–20. Atlantis Press. https://doi.org/10.2991/assehr.k.220305.024.

Sánchez-López, Angélica Lizeth, Jesús Antonio Jáuregui-Jáuregui, Nancy Anabel García-Carrera, and Yocanxóchitl Perfecto-Avalos. "Evaluating Effectiveness of Immersive Virtual Reality in Promoting Students' Learning and Engagement: A Case Study of Analytical Biotechnology Engineering Course." *Frontiers in Education* 9 (Feb 2024). https://doi.org/10.3389/feduc.2024.1287615.

Ghazali, Anith Khairunnisa, Nor Azlina Ab. Aziz, Kamarulzaman Ab. Aziz, and Neo Tse Kian. "The Usage of Virtual Reality in Engineering Education." *Cogent Education* 11, no. 1 (2024). https://doi.org/10.1080/2331186X.2024.2319441.

Asham, Youssef, Mohamed H. Bakr, and Ali Emadi. "Applications of Augmented and Virtual Reality in Electrical Engineering Education: A Review." *IEEE Access* 11 (Nov 2023): 134717-134738. https://doi.org/10.1109/ACCESS.2023.3337394.

Bangert, Krys, Edward Browncross, Matteo DI Benedetti, Harry Day, and Andrew Garrard. "Comparing XR and Digital Flipped Methods to Meet Learning Objectives." In *Proceedings for the 51st Annual Conference of the European Society for Engineering Education*, Dublin, October 2023, 126-36. https://doi.org/10.21427/VJVG-V478.

Bhatia, Dinesh, and Henrik Hesse. "Enhancing Student Engagement in Engineering and Education Through Virtual Reality: A Survey-Based Analysis." In *TENCON 2023*

- *2023 IEEE Region 10 Conference (TENCON), Thailand,* 2023, 170–75. IEEE. https://doi.org/10.1109/TENCON58879.2023.10322377.

Han, Yunmeng. “Virtual Reality in Engineering Education.” *SHS Web of Conferences* 157, no. 2001 (2023). https://doi.org/10.1051/shsconf/202315702001.

Ivanova, G., A. Ivanov, and L. Zdravkov. “Virtual and Augmented Reality in Mechanical Engineering Education.” In *2023 46th MIPRO ICT and Electronics Convention (MIPRO)*, Croatia, 2023: 1612–17. IEEE. https://doi.org/10.23919/MIPRO57284.2023.10159965.

Jalil, José Manuel Nieto, Aaron Castro Bazua, Luis Carlos Félix Herrán, Francisco Isaías Gutiérrez Castillo, Dionisio Othón Katase, and Oscar Alberto González Valenzuela. “The Virtual Reality as a Flexible Resource to Improve Engineering Education.” In *2022 IEEE Global Engineering Education Conference (EDUCON)*, Tunisia, 2022: 579–85 IEEE. https://doi.org/10.1109/EDUCON52537.2022.9766624

Kumar, Vinod Vijay, Deborah Carberry, Christian Beenfeldt, Martin Peter Andersson, Seyed Soheil Mansouri, and Fausto Gallucci. “Virtual Reality in Chemical and Biochemical Engineering Education and Training.” *Education for Chemical Engineers* 36 (July 2021): 143–53. https://doi.org/10.1016/j.ece.2021.05.002.

Ma, Yan, Lu Zhang, and Min Wu. “Research on the Influence of Virtual Reality on the Learning Effect of Technical Skills of Science and Engineering College Students: Meta-Analysis Based on 32 Empirical Studies.” *International Journal of Digital Multimedia Broadcasting* (2022): 1–9. https://doi.org/10.1155/2022/6202370.

Marougkas, Andreas, Christos Troussas, Akrivi Krouska, and Cleo Sgouropoulou. “Virtual Reality in Education: A Review of Learning Theories, Approaches and Methodologies for the Last Decade.” *Electronics* 12, no. 13 (2023): 2832-2853. https://doi.org/10.3390/electronics12132832.

Mojica-Irigoyen, Mauricio, J. Obedt Figueroa-Cavazos, Ana Gabriela Rodriguez-Mendoza, M. Ileana Ruiz-Cantisani, and Vianney Lara-Prieto. “The Effect of a Virtual Reality Resource on the Engagement and Learning Experience of First-Year Engineering Students.” In *Proceedings of the 7th International Conference on Education and Multimedia Technology*, New York, 2023, 1–7. NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3625704.3625717.

Athik Nagappan.V, and S.S. Shobithraj. “Virtual and Augmented Reality in Production Engineering.” *International Journal of Engineering Applied Sciences and Technology* 6, no. 11 (March 2022): 84-7. https://doi.org/10.33564/ijeast.2022.v06i11.018.

Soliman, Maged, Apostolos Pesyridis, Damon Dalaymani-Zad, Mohammed Gronfula, and Miltiadis Kourmpetis. “The Application of Virtual Reality in Engineering Education.” *Applied Sciences* 11, no. 6 (March 2021): 2879-93. https://doi.org/10.3390/app11062879.

Taghian, Aya, Mohammed Abo-Zahhad, Mohammed S Sayed, and Ahmed H Abd El-Malek. “Virtual and Augmented Reality in Biomedical Engineering.” *Biomedical Engineering Online* 22 (July 2023). https://doi.org/10.1186/s12938-023-01138-3.

Wong, Jenna, and Shah Rukh Humayoun. "Expanding Structural Engineering Education through Virtual Reality." In *2022 ASEE Annual Conference & Exposition Proceedings,* USA, August 2022. https://doi.org/10.18260/1-2--40725.

APPENDIX 1: SCREENING SURVEY

Theoretical Knowledge Assessment

This is added in Microsoft Forms as a subtitle: ***Instruction on the scaling system:*** *On a scale from 1-5, please rate your experience with engines (theoretical knowledge and practical skills) from questions 6 to 13. A score of 1 indicates no experience, while a score of 5 signifies extensive experience as follows:*

1. *I have no knowledge or skills about engines.*
2. *I know a few basic facts or skills about engines.*
3. *I have a fair amount of knowledge or skills about engines, but there's more I could learn.*
4. *I have a strong understanding or skills of engines and how they work.*
5. *I have a comprehensive understanding or skills in engines, including complex concepts and mechanics.*

Q1: How would you rate your theoretical knowledge about engines?

Q2: How would you rate your knowledge of the four-stroke engine working principle?

Q3: How would you rate your knowledge of main engine components?

Q4: How would you rate your knowledge of engine piston function?

Q5: How would you rate your knowledge of the process of engine piston overhauling?

Practical Skills Assessment

Q6: How would you rate your practical skills of assembling engine components?

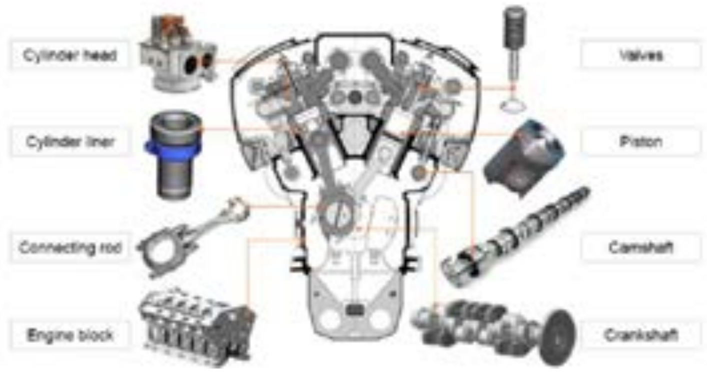
This is added in Microsoft Forms as a subtitle: On a scale of 1 to 5, a score of 1 indicates no experience, while a score of 5 signifies extensive experience.

Q7: Have you ever fixed or repaired any type of engines?

1. Never
2. I have only seen how it is done or watched videos of it.
3. I have done it only once or twice.
4. I have done it a couple of times.
5. Fixing engines is my hobby/work.

APPENDIX 2: THEORETICAL KNOWLEDGE SURVEY

#	Questions	Answers
1	Identify following main components:	(picture of engine from engine course at Case Company)

		
2	What type of an engine Case Company engines are?	Case Company engines are reciprocating (piston) engines.
3	What three things are needed to create a flame/combustion?	Fuel, air (oxygen), heat (spark)
4	What happens inside Case Company diesel engine cylinder?	Fuel is mixed with hot air, fuel and air reacts chemically and due to the presence of high temperature, the mixture ignites creating combustion. Combustion causes heat, exhaust gases and generates pressure, all of which are different form of energies. Piston is being pushed down via the pressure, some of the heat radiates out and most of the heat is delivered out via exhaust gases. Hot exhaust gases are directed (pushed out) and fresh air is taken in to start the combustion process from the beginning.
5	What are the four main events of an 4-stroke engine working cycle?	Intake (stroke) Compression (stroke) Power (stroke) exhaust (stroke)
6	How are Case Company engines named?	Engine name comes from the cylinder bore. Example: W20 engine means cylinder bore/diameter is 20 centimeters.
7	How do you call the side of an engine where flywheel is located?	Driving end (Flywheel end)
8	What is the function of a flywheel in Case Company engine?	Flywheels are used to provide continuous power output in systems where the energy source is not continuous. For example, a flywheel is used to smooth the fast angular velocity fluctuations of the crankshaft in a reciprocating engine. In this case, a crankshaft flywheel stores energy when torque is exerted on it by a firing piston and then returns that energy to the piston to compress a fresh charge of air and fuel.

9	What are the initial steps to start the engine overhaul process (describe as many as you can, and in correct order!):	1) Stop the engine and let it cooldown. Cooldown duration depends totally on the size of the engine. 2) Engage the turning device. => Make sure engine cannot be restarted. (mechanical and electrical safety aspect) 3) Set engine to service mode from automation system. 4) Drain the cooling water line. 5) Block the fuel delivery line (mechanical isolation) 6) Mechanical lever to "stop" position to block the movement of the fuel rack line. 7) Main starting air valve to be blocked and isolated
10	Arrange following items to correct removal order: Cylinder Liner, Cylinder head, piston, Fuel pipes, Hob box cover, Cylinder head hydraulic connections, Connecting rod hydraulic connections,	1) Remove hotbox covers 2) Remove fuel pipes 3) Remove cylinder head hydraulic connections 4) Remove cylinder head 5) Remove connecting rod hydraulic connections 6) Remove piston 7) Remove cylinder liner

APPENDIX 3: PRACTICAL SKILLS KNOWLEDGE SURVEY

	Group	Outcomes not reached	Outcomes partially reached	Outcomes reached	Outcomes reached beyond expectation	Points	Evaluating instructor:
1	**Parts + Tools**					**10 max**	
1.1	Correct selection of parts	**0-1**	**2**	**3**	**4-5**	**5**	
		Do not know which parts to pick up	Picked up right parts but not in right order	Picked up correct parts and in correct order	Picked up correct parts in the correct order with surety and speed		Instructor 1
							Instructor 2
1.2	Correct selection of tools	**0-1**	**2**	**3**	**4-5**	**5**	
		Do not know which tools to pick up	Picked up right tools but not in right order	Picked up correct tools and in correct order	Picked up correct tools in the correct order with surety and speed		Instructor 1
							Instructor 2
2	**Process + Safety**					**35 max**	
2.1	Job safety analysis	**0-1**	**2**	**3**	**4-5**	**5**	
		Job safety analysis was not done	Job safety analysis was done but was inadequate	Job safety analysis was done correctly	Job safety analysis was done correctly and with sureness		Instructor 1
							Instructor 2
2.2	Work safety	**0-1**	**2**	**3**	**4-5**	**5**	
		Process was not done in safe way	Process was initially not done safe but student corrected it	Process was done safely	Process was done safely with speed and sureness		Instructor 1
							Instructor 2

2.3	Process executed in the correct order	**0-2**	**2-5**	**6-8**	**9-10**	**10**	
		Process was not in correct order	Process was initially not in right order but student corrected it	Process was in right order	Process was in right order with speed and sureness		Instructor 1
							Instructor 2
2.4	Applying the use of manual	**0-1**	**2**	**3**	**4-5**	**5**	
		Student did not check the manual	Student did not check the manual but after starting to the apply pressure did check	Student did check the manual	Student checked the manual immediately and was fast and efficient		Instructor 1
							Instructor 2
2.5	Work was done autonomously	**0-1**	**2**	**3**	**4-5**	**5**	
		Student could not proceed without continuously asking help or confirmation from the instructor.	Student could work autonomously most of the time but had to rely on instructor expertise sometimes.	Student did not need to rely on the instructor expertise and help	Student did not need to rely on the instructor expertise and they worked with speed and sureness.		Instructor 1
							Instructor 2
2.6	Timing of the work	**0-1**	**2**	**3**	**4-5**	**5**	
		Student did not pay attention to the duration of the work, didn't not focus on the elapsed time,	Students did somewhat understood the time limit and limitations but was far for reaching the time target.	Students understood the time limit well but did not reach the time limit.	Work was finished in time and correct and safe manner.		Instructor 1
		and could not finish the work within the time limit.					Instructor 2

WRITING-TO-ENGAGE: AN APPROACH TO ENHANCING CREATIVE PROBLEM-SOLVING THROUGH WRITING PROMPTS IN ENGINEERING COURSES

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ABSTRACT

While traditional engineering education emphasizes linear problem-solving techniques, this practice piece offers the “writing-to-engage” method for engineering educators to incorporate writing and design instruction to develop students’ creativity, essential for navigating complex engineering situations. This approach to educating the whole engineer integrates writing and creativity into the engineering curriculum to support the teaching of technical content.

1 INTRODUCTION

1.1 Project context and need

This paper presents writing and design instruction in a sustainability-focused 10-week course required for senior environmental engineering majors at California Polytechnic State University, San Luis Obispo (Cal Poly). Engineering students need to develop creative problem-solving skills when linear problem-solving techniques (well-established

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in Cal Poly students' previous engineering classes) are inadequate for addressing engineering problems. The pedagogical approach shared in this work-in-progress may inspire discussion among engineering educators, as it emphasizes the writing process itself as a problem-solving technique useful for navigating challenging engineering design situations.

Teaching writing as a problem-solving technique aligns with calls to educate the whole engineer. Engineers need to "understand the social, ethical, cultural, political, and environmental contexts of their work" and begin to develop that understanding in context of their engineering classes (Hitt et al. 2023, p. 457). Engineering programs take many approaches to educating the whole engineer, from hosting guest speakers from liberal arts departments, to hiring faculty with interdisciplinary backgrounds, to encouraging engineering majors to pursue liberal arts minors (Hitt et al. 2023, p. 465). These approaches can be resource-intensive, leading the authors to consider ways to educate the whole engineer within the constraints of an engineering course, and teaching writing and creativity in ways that support the learning of technical content. This work-in-progress piece may inspire engineering educators to experiment with pedagogical approaches to integrating engineering, writing, and creativity.

1.2 Defining writing

For our purposes, writing involves the entire process, from idea generation to production. Writing process activities (e.g., conversations, notes, lists, drawings, etc.) count as writing, as do written products (e.g., reports and proposals). This definition reflects a threshold concept in writing studies: writing is a cognitive (thinking) process that "extends before and after the moment of text production " (Dryer et al. 2015, p. 72). This means that writing is more expansive than "transcribing thought while avoiding error " (Dryer et al, 2015, p. 72). Writing is also a metacognitive process, meaning that writers must "think about their mental processes" (Dryer et al. 2015, p. 76). Since writing requires both cognition and metacognition, we designed activities that would develop both areas for students.

1.3 Defining creative thinking

We offer the following definition of creative thinking that aligns with our focus on environmental engineering and sustainability. Creativity is "the ability to generate new or unique and effective ideas in conjunction with other members of a community to challenge unjust status quos and tackle wicked social justice problems" (Sarraf 2023, p. 3). As Caratozzolo et al. (2019) note, creative thinking is a "metacognitive process" that enables "complex problem solving" and facilitates "a high degree of innovation" (p. 2). As such, developing creative thinking skills and writing skills (as defined above) are complementary activities.

1.4 Relationship between writing and creativity in engineering education

The pedagogical approach offered here is inspired by the Writing as Creative Praxis (WaCP) model of writers' creativity, developed by Sarraf (2020) from their study of workplace professionals' use of writing as a tool to move from reflection to action about wicked communication and disciplinary problems. Essentially, WaCP positions writing itself as a tool to move from creative reflection to creative action, deepening interdisciplinary understandings of the relationship between writing and creativity. WaCP adapts the notion of "critical digital praxis [...] as a form of critical reflection and action in digital media" (Vetter & Sarraf, 2020, p. 5). Praxis involves combining reflection and action to intervene in problems in meaningful ways.

In praxis, reflective writing enhances metacognitive awareness. To exercise creativity, engineering students need to have metacognitive awareness about their own creative thinking processes. Several studies have demonstrated that writing activities promote metacognition, enhance creativity, and improve students' engineering skills (Ford et al. 2021; Gardiner 2020; Gorzelsky et al. 2016; Langer and Applebee 1987; McVeigh et al. 2023; VanKooten and Berkley 2016). Foundational texts such as Emig's (1977) article and Langer and Applebee's (1987) book demonstrated that writing helps students to engage with and integrate course information. Born from this research, the writing across the curriculum (WAC) and writing in the disciplines (WID) global movements have led educators to integrate informal and formal writing in engineering classes.

However, it is important to note that the writing across the curriculum (WAC) and writing in the disciplines (WID) movements take three approaches to the writing/disciplinary-knowledge connection. First, the-writing-to-learn approach prioritizes the use of informal, ungraded writing exercises to help students memorize and understand course concepts. Second, the writing-in-the-disciplines approach teaches students to communicate like disciplinary-experts and write clear technical communication (Andrews et al. 2021; Fleming et al. 2023; Jalali et al. 2022; Londner et al. 2023). Unfortunately, writing-in-the-disciplines requires a large investment of instructor time to teach disciplinary-writing practices. Thus, more recently, a third approach has developed called "writing-to-engage." Writing-to-engage uses both informal and formal writing assignments to help students develop their thinking about a discipline.

Writing-to-engage provides a middle way for instructors (Palmquist 2020). It uses a spectrum of formal and informal writing activities to promote students' cognitive development. Importantly, writing-to-engage activities ask students to "draw on critical thinking skills such as reflecting, applying, and analyzing," engaging in "knowledge transforming" (Palmquist 2020, p. 16). Students reflect, apply, and analyze scenarios, using writing to bridge lower-order skills (like remembering/understanding) and higher-order skills (like evaluating and creating) (Palmquist 2020).

Thus, we explored a writing-to-engage approach to enact the Writing as Creative Praxis model, in which writing is a tool to teach creative problem-solving, communication, and engineering design. The potential innovation is our use of writing-to-engage to enhance *creativity* in engineering. Our writing activities include freewriting and brainstorming, which "records" the thinking process and moves it forward, helping students to "discover, develop, and clarify" their ideas (Bean 2011, p. 120). We also used integrated reflective writing prompts, as reflection promotes metacognition and transfer. As Sheppard et al. (2018) wrote, "Reflective practice is essential for the ability of emerging engineering practitioners to nimbly meet the ever-changing needs they encounter while tackling the world's complex problems" (p. 125). Thus, given that reflective practices help engineers address complex problem-solving, we also integrated reflective activities into our writing prompts. The activities presented in the next section draw on the writing-to-engage movement, bringing this pedagogical approach to the engineering classroom. Further, the activities presented may inspire readers seeking to explicitly connect writing-to-engage to creativity in an engineering context.

2 METHODOLOGY

2.1 Section Overview

Here, we offer our experiences developing writing-to-engage activities that aim to promote creative thinking about environmental engineering problems. Specifically, we describe co-author Outlon's implementation of the co-authored pedagogical approach in their sustainability-focused 10-week course. As this paper's goal is to provide inspiration for teaching and directions for future research, we present the teaching activities that occurred over five weeks as a sampling of possible approaches to writing–to-engage methods. The authors plan to develop a mixed-methods study based on this work-in-progress to further examine the efficacy of these pedagogical approaches in comparison to previous years without these activities.

2.2 Assignment and activity overview

The authors first met to adapt the exercises from an assignment Sarraf designed for her technical and professional writing courses, which included both science, technology, engineering, and math (STEM) and liberal arts majors. Then, to help develop students' creative problem-solving skills, Oulton incorporated a series of writing and design exercises into the engineering course.

The engineering course was structured to develop and apply creativity skills, teamwork skills, communication skills, and technical skills simultaneously. In this way, the course epitomizes the goal of "educating the whole engineer." Essential to this goal is reinforcing with students the understanding that engineering is not just a technical profession, but a creative and communicative one as well. At its core, engineering is about creating and communicating solutions, and there may be myriad valid approaches to develop, optimize, and amplify those solutions. Embracing creativity, teamwork, and communication are necessary for developing innovative technical solutions.

With those goals in mind, the culminating experience of the course is preparation of a technical report and presentation for a real world client to provide recommendations to improve an existing process. Students work in groups over the entire ten-week quarter to prepare their project. Creativity exercises were incorporated throughout the quarter to scaffold students' creative thinking processes as they worked on their projects.

While most of the creativity exercises were not explicitly related to the project or engineering, each lab ended with a writing reflection and/or a talk back with the class, to emphasize the relevance of the exercise and its application to students' engineering development and creative thinking skills. Thus, students made explicit connections between creativity, writing, and engineering. The objective was that these individual and/or group metacognitive writing reflections would facilitate skill development through explicit reflection.

The writing-to-engage exercises described below were intended to progressively develop creative thinking and problem-solving skills through group activities and individual or group writing assignments. These initial creativity exercises were conducted during a three-hour laboratory class each week for five weeks. Other creativity exercises were offered throughout the quarter; we limit the present focus to five weeks for illustrative purposes and to meet the constraints of this particular practice piece.

- Week 1: The creativity exercises began with a divergent thinking exercise in which students played improvisational games where they were limited to using only one communication skill: verbal, visual, or body language. This low stakes activity was designed to build teamwork and emphasize the value of combining verbal, visual, and other means to communicate ideas in engineering. Students reflected individually on their experiences with the games to increase their metacognitive awareness. They also reflected via a class talk back about the importance of varied communication skills in engineering.
- Week 2: Students engaged in a series of storytelling activities in which they collaborated in different ways (linear, non-linear, and convergent) to build a story inspired by work of art. The intention of this activity was to develop team cohesion and collaboration skills while using various modes of "design" to create a group outcome. A post-activity reflection focused on the value of storytelling to engage nontechnical audiences when communicating engineering ideas.
- Week 3: This week, exercises started to connect more explicitly to course content: students worked in small groups to develop educational materials to explain an aspect of the wicked problem of climate justice to a group of younger students (first-year college students through elementary/primary students, at the group's choice) and inspire those younger students to engage with and think critically about the issue.
- Week 4: Students worked in small groups to propose conceptual stormwater infrastructure improvements for selected locations on campus. Again, the challenge combined technical considerations with creative thinking to reconceptualize an existing and familiar location to achieve a specific goal, and communication skills to present their conceptual design effectively.
- Week 5: This series of exercises culminated in a Design Charette intended to facilitate creative problem solving focused on their team design project (culminating experience) for the course. The Design Charette is discussed further below.

Similar creative engagement activities continued throughout the course; generally focused on specific class topics. While games and storytelling may at first seem irrelevant to engineering, they help build essential engineering skills such as communication skills and team building while taking minimal time from class. Primarily, these introductory creativity exercises established the class as one that will challenge students to take risks and helped students build comfort with non-traditional approaches to problem solving in a low-stakes environment. Further, each exercise combined creativity with communication and asked students to make explicit connections to engineering practice.

2.3 Activity Spotlight: Design Charette

Here, we highlight the Week 5 activity, a Design Charette, offering it to readers for its integration of writing, design, and creativity skills focused on a specific engineering design challenge.

Design Charrettes are long standing practice in both Architecture and City Planning, though the two fields practice charrettes differently. In City Planning, and increasingly in related fields such as Civil and Environmental Engineering, Design Charrettes are intended to allow for multiple stakeholders from different fields to work together to develop potential project solutions. Design Charrettes typically involve some divergent thinking practices (such as brainstorming) to develop a large number of ideas, followed by convergent thinking practices (such as ranking or grouping ideas from the brainstorming session) to hone the ideas to those most feasible for a solution.

Engineering students completed the Design Charette during Week 5's lab. By this time in the course, students had become familiar with the background of the project and had developed a solid technical understanding of the client's challenges. The goal of the Design Charette was to develop ideas for solutions to those challenges that the student groups would develop for the remainder of the quarter.

The Design Charette for the class followed established Charette practices, though with an accelerated time scale to fit into the class period:

- Divergent Thinking Activity. First, student project teams were directed to spend 30 minutes on a series of visioning or brainstorming activities to generate ideas without judgment. Each team used a white board to record ideas, and they were instructed to rotate recorder responsibilities at least every ten minutes.
- Research Activity. During the second phase (1 hour), students worked in pairs to research the feasibility of the proposed ideas. Groups were tasked to decide collaboratively, while keeping an open mind, which ideas were worth researching. If even one member of the group felt an idea was worth further investigation, the group included the idea in their research activities.
- Convergent Thinking Activity. The final phase was a discussion (45 minutes) for groups to refine their list of ideas to no more than six, with the ultimate goal to include three well-developed proposals in the final report. The Design Charette ended with an individual commitment to "next steps" by each team member.

3 INSTRUCTOR TAKEAWAYS

Here, we share instructor takeaways from implementing these activities, with the goal to provide inspirational value for future project iterations.

3.1 Hold short brainstorming sessions

Time constraints can encourage rapid-fire brainstorming and help reduce inhibitions. During the Design Charrette, the engineering students struggled with the extensive length of time required for continued brainstorming. Several groups were ready to move onto research after approximately ten minutes, when the easy ideas started lagging. They were encouraged to use all thirty minutes and to lean into creative or even ridiculous suggestions, and let that process inspire more reasonable options. All of the groups successfully continued to develop ideas for the requisite time period, though it became a struggle for most groups by the end. Instead of a single, long brainstorming session, instructors can encourage students to engage in short, sprint-like brainstorming sessions to reduce fatigue and enhance ideation.

3.2 Conduct research to move from divergent to convergent thinking

The engineering students were more comfortable with the research phase, as this is familiar territory for senior-level engineering students. The research informed their group convergent thinking as they were able to merge or hone their list. While most student groups focused on honing to those most practical or most feasible, some groups retained at least one “creative” idea that they thought was worth further development.

3.3 Showcase rejected ideas

Convergent thinking necessarily requires students to select the most effective and feasible idea from a list of many possible ideas. However, convergent thinking is limited by students’ notions of effectiveness and feasibility. Incidentally, sometimes students may embrace an idea that is practical but less novel than rejected ideas. Thus, we recommend that instructors give students space to showcase and share the ideas that their teams rejected during the convergent thinking phase. For example, in Oulton’s class, students wrote a Design Report based on the ideas that their team selected from the initial brainstorming and research phases. Oulton asked students to include team-rejected ideas in an appendix to their reports. Interestingly, it was these creative ideas housed in the appendix that the real-world clients were most interested in when students presented their work. Despite the apparent infeasibility of the rejected ideas to the students, the clients drew inspiration from the unique solutions, rather than the more traditional solutions presented by most teams.

4 CONCLUSION

Engineering is a creative and communication-based profession, in addition to being a technical one. Integrating a writing-to-learn approach that uses low-stakes creativity exercises such as the Design Charrette allows students to learn technical material while they develop their communication, creativity, and broader critical thinking skills in the context of their engineering courses. Rather than considering writing and creativity as practices relegated to their GE classes, students may learn to recognize that these are essential skills for their engineering practice as well. Educators may use the ideas presented in this paper to develop their own writing-to-engage activities. Future research will examine the efficacy of these and other writing-to-engage activities in engineering classrooms.

REFERENCES

C. D. M. Andrews, M. Mehrubeoglu, and C. Etheridge, "Hybrid Model for Multidisciplinary Collaborations for Technical Communication Education in Engineering," *IEEE Transactions on Professional Communication*, vol. 64, no. 1, pp. 52–65, Mar. 2021, doi: 10.1109/TPC.2020.3047313.

D. B. Dryer, C. Bazerman, H. Tinberg, C.M. Anson, and K. Taczak. "Writing Is (Also Always) a Cognitive Activity." In L. Adler-Kassner and E. Wardle (Eds.), *Naming What We Know: Threshold Concepts of Writing Studies*,pp. 71–82. University Press of Colorado, 2015. http://www.jstor.org/stable/j.ctt15nmjt7.12

J. Bean, *Engaging ideas: The professor's guide to integrating writing, critical thinking, and active learning in the classroom*, 2nd ed. San Francisco, CA: Jossey-Bass, 2011.

P. Caratozzolo, Á. Álvarez-Delgado, Z. Gonzalez-Pineda, and S. Hosseini, "Enhancing Interdisciplinary Skills in Engineering with the Cognitive Tools of Storytelling," presented at the SEFI, Budapest, 2019.

J. Emig. "Writing as a mode of learning." *College Composition and Communication*, vol. 28, no. 2, pp. 122-128, May 1977.

G.C. Fleming, M. Borrego, and D. Knight. "Engineering Graduate Education in the United States" in the *International Handbook of Engineering Education Research*. Edited by A. Johri. 1st edition. Routledge, pp. 263-285, 2023.

J.D. Ford, M. Paretti, D. Kotys-Schwartz, S. Howe, and R. Ott. New Engineers' Transfer of Communication Activities From School to Work. *IEEE Transactions on Professional Communication*, vol. 64, no. 2, pp. 105–120, 2021. https://doi.org/10.1109/TPC.2021.3065854

P. Gardiner, "Learning to think together: Creativity, interdisciplinary collaboration and epistemic control," *Thinking Skills and Creativity*, vol. 38, pp. 100749, Dec. 2020, doi: 10.1016/j.tsc.2020.100749.

G. Gorzelsky, D. L. Driscoll, J. Paszek, E. Jones, and C. Hayes, "Cultivating constructive metacognition: A new taxonomy for writing studies," *Critical transitions: Writing and the question of transfer*, pp. 217–249, 2016.

J.S. Hitt, A. Banzaert, and O. Pierrakos, "Educating the Whole Engineer by Integrating Engineering and the Liberal Arts," in *International Handbook of Engineering Education Research*, 1st ed., New York: Routledge, 2023, pp. 457–476. doi: 10.4324/9781003287483-25.

Y. Jalali, H. Kovacs, S. Isaac, and J. Zufferey. "Bringing visibility to transversal skills in engineering education: towards an organizing framework." In Conference: *SEFI 50th Annual Conference of The European Society for Engineering Education*, Barcelona. Pps. 1252-1259, 2022, doi 10.5821/conference-9788412322262.1251.

J. A. Langer and A. N. Applebee, *How writing shapes thinking: A study of teaching and learning*. Urbana, IL: National Council of Teachers of English, 1987. [Online]. Available: https://wac.colostate.edu/books/landmarks/langer-applebee/

E. Londner, M. Dabkowski, I. Kloo, and J. D. Caddell, “The Communication Coefficient Method: A New Faculty Grading Tool Designed to Help Engineering Students Improve Their Technical Communication,” *IEEE Trans. Profess. Commun.*, vol. 66, no. 2, pp. 202–219, Jun. 2023, doi: 10.1109/TPC.2023.3260479.

M. McVeigh, A. Valquaresma, and M. Karwowski, “Fostering Creative Agency through Screenwriting: An Intervention,” *Creativity Research Journal*, vol. 0, no. 0, pp. 1–14, Feb. 2023, doi: 10.1080/10400419.2023.2168341.

M. Palmquist. A Middle Way for WAC: Writing to Engage. *The WAC Journal,* vol. 31 no. 1, 2020. https://doi.org/10.37514/WAC-J.2020.31.1.01

K. S. Sarraf, “Tying Creative Problem-Solving to Social Justice Work in Technical and Professional Communication,” *Technical Communication Quarterly*, pp. 1–12, 2023, doi: 10.1080/10572252.2023.2194340.

C. VanKooten and A. Berkley, “Messy Problem-Exploring through Video in First-Year Writing: Assessing What Counts,” *Computers and Composition*, vol. 40, pp. 151–163, Jun. 2016, doi: 10.1016/j.compcom.2016.04.001.

A ROLES-BASED COMPETENCY FRAMEWORK FOR INTEGRATING ARTIFICIAL INTELLIGENCE (AI) IN ENGINEERING COURSES

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ABSTRACT

In this practice paper, we propose a framework for integrating AI into disciplinary engineering courses and curricula. The use of AI within engineering is an emerging but growing area and the knowledge, skills, and abilities (KSAs) associated with it are novel and dynamic. This makes it challenging for faculty who are looking to incorporate AI within their courses to create a mental map of how to tackle this challenge. In this paper, we advance a role-based conception of competencies to assist disciplinary faculty with identifying and implementing AI competencies within engineering curricula. We draw on prior work related to AI literacy and competencies and on emerging research on the use of AI in engineering. To illustrate the use of the framework, we provide two exemplary cases. We discuss the challenges in implementing the framework and emphasize the need for an embedded approach where AI concerns are integrated across multiple courses throughout the degree program, especially for teaching responsible and ethical AI development and use.

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1 INTRODUCTION

Computing and computing education have become an integral component of the engineering profession and engineering education. Topics such as programming, data analysis, and computational sciences are now commonly taught in the engineering curricula (Malmi and Johri 2023; Raj et al. 2019). In recent times, the field of artificial intelligence (AI), encompassing domains like data mining, machine learning, natural language processing, large language models, and transformers, has also begun to impact engineering (Broo, Kaynak, and Sait 2022; Johri 2020; Mustapha, Yap, and Abakr 2024). Consequently, in addition to computing literacy or computational thinking skills, it has become necessary to integrate these topics within engineering curricula and pedagogy (Magana, Falk, and Reese Jr 2013).

Given the expansiveness and ever-evolving nature of AI as a field with diverse applications, comprehending the specifics of AI education, including what and how they should be taught, is a challenging task for educators. Recently, there have been several efforts towards defining AI literacy as a basic set of competencies integral to for acting in an AI-driven professional environment (Long and Magerko 2020; Laupichler et al. 2022). Several studies have proposed generic competencies in AI (Laupichler et al. 2022; Ng et al. 2021) that cut across disciplines but increasingly there is an emphasis towards a more discipline-based approach. For instance, Stolpe and Hallström (2024) proposed AI literacy for technology education, Knoth et al. (2024) outlined an assessment matrix spanning from generic to domain-specific AI literacy and Schleiss et al. (2022) proposed an interdisciplinary competence profile for AI in engineering, that highlights the intersection of disciplinary and AI knowledge and skills.

While several teaching approaches and implementations have been proposed and tested (Isaac Flores-Alonso et al. 2023; Singelmann and Covarrubias 2023; Ng et al. 2023), the adoption of AI literacy in engineering education has not received much focus. Consequently, educators are challenged with identifying relevant competence constructs in the context of their disciplinary domain. Since AI in engineering is largely application-oriented, it is important for educators to understand the disciplinary and interdisciplinary contexts of these applications. At the same time, educators in engineering education do not always have a background in AI and their domain, making it difficult to identify the relevant competencies and building a barrier to integrating AI education into the disciplinary teaching offers.

To address the gap of clarity in relevant AI competencies, we propose a role-based approach that integrates AI literacy and competency to assist disciplinary faculty with identifying and implementing AI competencies within engineering curricula. In particular, we focus on the question of how to identify and select relevant AI competencies for discipline-specific AI education in engineering education. The paper builds on prior work related to AI literacy and competencies within the literature and on emerging research on the use of AI in engineering. To situate prior AI literacy frameworks within an engineering context, we take a roles-based approach. Our framework focuses on the use of AI by a specific actor within the engineering context and how this leads to the need for integration of a distinct AI competency within the curriculum. We inductively analyze case studies of the use of AI in engineering to understand emerging patterns and translate findings from literature into a practical and usable framework for educators.

Overall, this study aims to contribute to integrating AI education in engineering education across disciplines (Laupichler et al. 2022; Schleiss et al. 2023; Patel et al. 2021). In the following, we first introduce related work on AI literacy definitions and competencies and the roles-based approach that provide the base to our framework. Next, we describe the cases and inductively develop the **r**oles-based **c**ompetency for **AI** in **e**ngineering or RCAIE framework. Last, we discuss our findings and provide conclusions.

2 RELATED WORK

2.1 AI Literacy Definitions and Competencies

With the field of AI literacy being a novel and growing research field, there exist many definitions of AI literacy aiming at different target populations, purposes or from different disciplinary perspectives (Long and Magerko 2020; Laupichler et al. 2022; Ng et al. 2021; Stolpe and Hallström 2024; Knoth et al. 2024). Most prominent is the definition of Long and Magerko (2020) who define AI literacy as “a set of competencies that enables individuals to critically evaluate AI technologies, communicate and collaborate effectively with AI, and use AI as a tool online, at home, and in the workplace” (p.2). To bridge the gap between definitions of AI literacy to educating these competencies, several conceptual frameworks exist (Almatrafi, Johri, and Lee 2024). In their literature review, Almatrafi, Johri, and Lee (2024) identified six core constructs that form AI literacy: (1) *Recognize (Be Aware)* different types of AI applications as a basis to enable informed interactions, (2) *Know and Understand* fundamental concepts and techniques of AI, (3) *Use and Apply AI* applications and tools to solve tasks or achieve an objective, (4) *Evaluate* as the “ability to analyze and interpret the outcomes of AI applications critically”, (5) *Create* as the ability to design and code AI applications, (6) *Navigate ethically* refers to understand ethical and social implications and become a responsible user of AI. These categories form an understanding of the core constructs of AI literacy and can be used as an analysis lens as well as to identify disciplinary-specific AI literacy constructs. Given the extensive systematic review on which this list of constructs rests, we utilize them as a core part of our framework but extend them towards domain-specific competencies in the context of roles and use-cases in engineering education.

2.2 Roles-based Approach to Competencies

Roles-based approach, although new to engineering, has widespread acceptance within another professional field – medical education. The approach has been applied both to roles in the profession that students need to be prepared for and for better understanding roles played by faculty as educators. For example, Harden and Crosby (2000) argued that given the changing and complex role of teaching in medical education, it was important to categorize these roles so that teachers or educators could identify what kind of expertise they needed in the medical field and in their roles as teachers. Whitehead et al. (2014), further argue that although more work needs to be done, the use of roles to describe competencies and build competency-based frameworks is now the norm in medical education reflecting “a conceptual shift in understandings of medical education from a process representing one of knowledge acquisition and time-based clinical rotations, to one in which competence can be considered as the adequate performance of a set of professional roles" (pg. 786). Similarly, Cenkner et al. (2017) identify six roles for an educational technology expert and for each role describe the corresponding competencies and give examples of activities that someone playing that role engages in.

In summary, a roles-based approach makes it easier for those who are new to a topic or area to approach it and have a guide or mental model of what it looks like including the responsibilities and objectives. The encapsulation of the knowledge as a role makes it task based and thereby easier for a newcomer to grasp given the alignment with practice. For this paper, we have created roles as group-level constructs meaning that roles define or identify groups of professionals who are "guided in their domain of practice by an established set of heuristics for thought and action (McClarey 2004; pg. 4)."

Professionals performing a certain role require a specific set of knowledge or expertise. The knowledge needed to perform a given role is known as 'role knowledge' (McClarey 2004; pg. 12). We adopt this approach towards examining roles that professionals in the workplace can play in relation to AI and what this means for what students need to be taught to be prepared for the workforce. In this initial mapping, we develop a broad conceptualization that can be expanded and defined more precisely through future work.

Within the literature on AI literacy, a roles-based approach has found resonance. Faruqe, Watkins, and Medsker (2021) distinguish between four groups of users with different depth of contact and competency requirements: (1) consumers, the general public and policymakers, (2) co-workers and users of AI products, (3) Collaborators and AI Implementers, and (4) creators of AI. Similarly, Schüller et al. (2023) distinguish between (1) informed prosumer, (2) skilled user, and (3) expert creator and developer. These roles correspond with different skill profiles within the industry such as AI Management, ML Architect, Data Engineer, Data Governor, Product Owner, Data Analyst, Data Architect, Data Steward, Data Scientist and ML Engineer (Machado and Mynter 2024). Given that this is an emergent area and there has been no rigorous analysis of AI-related roles for engineers, we synthesized three broad roles that we believe can provide guidance for knowledge assessment and skills development: a) consumer; b) user; and c) creator and developer. These roles in conjunction with the AI literacy constructs stated above provide us with a framework to describe the knowledge needed for AI integration within engineering.

3 RCAIE Framework and Case Studies

Overall, the **R**oles-based **C**ompetency in **AI** for **E**ngineering (RCAIE) framework builds on three pillars of use cases, roles and competencies (see Figure 1) and acts as foundation to identify suitable learning experience.

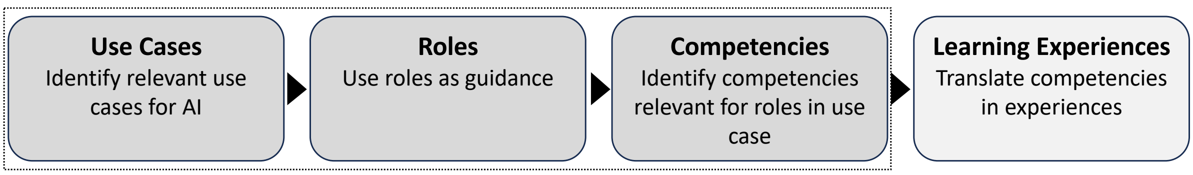

Figure 1: Process to identify competencies with the RCAIE framework

Given the wide application area for AI in engineering, we selected two exemplary case studies that help us explicate and describe the RCAIE framework in use. We have deliberately selected cases that are applied, in the sense that they are relevant to industrial applications, as opposed to AI research.

Case 1: Predictive Maintenance

Predictive Maintenance describes at its core the idea of optimizing the maintenance process by predicting and preventing machine failures proactively (Dalzochio et al. 2020; Lee et al. 2019; Hrnjica and Softic 2020). Found often in manufacturing environments but also in transportation or civil engineering, the goal of predictive maintenance is to minimize unplanned downtime, improve management of spare parts and repairs and enhance the overall equipment effectiveness (Dalzochio et al. 2020).

Different data sources can be used to bring the scenario to life. This can include machine condition data, historical maintenance records, real-time operational data from sensors or environmental factors like temperature or humidity. To use the thought frame introduced earlier, the goal is to infer and monitor the “health condition” of a machine by assessing different sensory inputs and historical data to anticipate and respond to potential problems (Lee et al. 2019). As the name suggests, predictive maintenance moves from reactive maintenance (“fix when it is broken”) and periodic, scheduled maintenance towards using AI capabilities to predict machine failures (Hrnjica and Softic 2020). From a data perspective, the theoretical underlying concepts include time-series data from log-data or even sensory inputs. From an AI perspective, multiple approaches might be useful, from statistical analysis to more advanced models working on time-series data.

Case 2: Quality Control and Testing

Often seen in manufacturing processes, quality control and testing with AI describes the idea of using AI-based solutions to automatically detect defects in an assembly line or inspect quality requirements at a scale. The goal is to increase the overall product quality and reduce defects through higher test coverage. Depending on the product and manufacturing process, various data sources can come into play, mapping to the steps a human inspector would test to ensure quality. Most commonly advanced computer vision algorithms are being used in visual inspection scenarios (Fahle, Prinz, and Kuhlenkötter 2020). Overall, the quality controls can also be embedded into a bigger picture using them as data inputs to predict the overall quality from design factors, manufacturing parameters, sensory data and quality checks (Tercan and Meisen 2022). Thus, the initial goal of quality control is assessing the quality or identifying defects but this can also be used to infer further actions.

RCAIE Framework

Table 1 depicts the elements of the RCAIE framework for both cases introduced above. For each case, it lists how each of the constructs translates into discrete AI knowledge relevant for each of the roles: consumer, user, and creator and developer. The constructs were derived by mapping the relevant knowledge and skills for the use case and the respective role, in consultation with prior work. As presented here, the framework is an initial proposal that can be adapted by educators as needed and further validated by experts trough e.g. a Delphi Study.

Table 1: The filled RCAIE framework with constructs for selected cases

#	Use Case	Roles	AI Literacy Constructs					
			Recognize	**Know/ Understand**	**Use/ Apply**	**Evaluate**	**Create**	**Navigate Ethically**
1	Predictive Maintenance	Consumer	Recognize that prediction relies on sensor data and AI systems	Understand the concept of predictive maintenance and how it supports the maintenance scheduling	Use maintenance recommendations to inform decision-making	Assess and compare predictions to own experiences and traditional approaches	-	Be aware of ethical implications and potential pitfalls in the use case
		User	Recognize different types of sensor signals and predictions	Understand the concept of prediction and its connection to data	Use time series prediction on sensor data	Assess the impact and performance of different prediction algorithms	-	Consider ethical implications in the decision-making
		Creator and Developer	Recognize different types of sensor signals and AI algorithms	Understand different types of sensor data and how they can be processed towards predictions using AI algorithms	Use different signal processing algorithms, build specific models using (physical) domain knowledge and deploy them	Test and validate different modelling approaches using multiple types of metrics	Develop new physical-based modelling approaches	Address and communicate ethical implications in the use case
2	Quality control and testing	Consumer	Recognize that automated quality control relies on sensor data and AI algorithms	Understand the difference between AI-based and traditional quality control	Use insights to make decisions about product rework or acceptance	Assess and compare quality control to own experiences and traditional approaches	-	Be aware of ethical implications and potential pitfalls in the use case
		User	Recognize that AI capabilities useful for quality control	Understand different data sources, algorithm approaches and their limitations	Select and apply AI-based quality control systems for different manufacturing processes	Evaluate the performance in use	-	Ensure ethical and responsible deployment of tools
		Creator and Developer	Recognize data potentials in manufacturing processes useful for quality control	Understand underlying data and model requirements for development and deployment	Use different AI capabilities based on the data requirements	Evaluate the effectiveness of models and overall solution with various metrics	Create new solutions and models for quality control	Advocate for responsible development and deployment

4 DISCUSSION AND CONCLUSION

In this practice paper, we illustrate one approach for disciplinary engineering faculty to understand and integrate AI into their curriculum. As the description for each of the constructs in Table 1 shows, based on the area of application, different levels of knowledge need to be developed. From a basic and generic recognition of AI capabilities to an advanced understanding of models and training for a specific function, a range of options are available for learners. Their inclusion in curriculum depends on instructor expertise and training, as well as the level of course, and critically, students' prior knowledge.

Application of the Framework for Educators

Given the increasingly broad and dynamic developments in AI, we argue that a roles-based approach to competency allows instructors to develop a mental model that provides them with an anchor such that they can start integrating AI aspects in a useful but simple manner. They can then keep building on constructs of competencies while keeping in mind the potential role of how an engineer would use AI and what additional knowledge they would need. Thus, educators can use the RCAIE framework as an approach to define and identify relevant competencies given identified use cases and future roles of their students. Moreover, a collection and synthesis of filled RCAIE frameworks in a domain can inform future development of curricula.

Limitations and Outlook

Although we only use two case studies, it is easy to use the framework we have advanced to look at other disciplines or applications. The developed framework opens new avenues for research and has direct implications for the practice of engineering educators interested in integrating AI competencies in their studies.

We recognize that the framework has certain limitations. First, it is currently inductively developed from case studies only and, thus, not yet validated in use with educators. Second, the selection of case studies might have biased the development of the framework. In the future, these limitations can be overcome through a more thorough analysis of use cases, especially those that build on expert interviews to validate and deepen the insights into the domain-specific AI competencies. This approach can form the basis to identify domain-specific AI competencies and constructs that can be recognized across different engineering disciplines as well as other similarities and differences among the competencies. A collaborative approach with other educators so that they can share their identified competencies through an open repository will also help make this work stronger. Finally, competencies build the base for pedagogical approaches and this work can also be extended towards systemizing and analyzing the effectiveness of pedagogical approaches for different target groups or specific competencies.

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REFERENCES

Almatrafi, Omaima, Aditya Johri, and Hyuna Lee. 2024. “A Systematic Review of AI Literacy Conceptualization, Constructs, and Implementation and Assessment Efforts (2019-2023).” *Computers and Education Open*, 100173.

Broo, Didem Gürdür, Okyay Kaynak, and Sadiq M Sait. 2022. “Rethinking Engineering Education at the Age of Industry 5.0.” *Journal of Industrial Information Integration* 25:100311.

Cenkner, Michael, Lyn Kathryn Sonnenberg, Patrick Von Hauff, and Clarence Wong. 2017. “Integrating the Educational Technology Expert in Medical Education: A Role-Based Competency Framework.” *MedEdPublish* 6:79. https://doi.org/10.15694/mep.2017.000079.

Dalzochio, Jovani, Rafael Kunst, Edison Pignaton, Alecio Binotto, Srijnan Sanyal, Jose Favilla, and Jorge Barbosa. 2020. “Machine Learning and Reasoning for Predictive Maintenance in Industry 4.0: Current Status and Challenges.” *Computers in Industry* 123:103298. https://doi.org/10.1016/j.compind.2020.103298.

Fahle, Simon, Christopher Prinz, and Bernd Kuhlenkötter. 2020. “Systematic Review on Machine Learning (ML) Methods for Manufacturing Processes – Identifying Artificial Intelligence (AI) Methods for Field Application.” *Procedia CIRP*, 53rd CIRP Conference on Manufacturing Systems 2020, 93 (January):413–18. https://doi.org/10.1016/j.procir.2020.04.109.

Faruqe, Farhana, Ryan Watkins, and Larry Medsker. 2021. “Competency Model Approach to AI Literacy: Research-Based Path from Initial Framework to Model.” *arXiv:2108.05809 [Cs]*. http://arxiv.org/abs/2108.05809.

Harden, Ronal M, and JR Crosby. 2000. “The Good Teacher Is More than a Lecturer–the Twelve Roles of the Teacher. AMEE Medical Education Guide No 20.” *Medical Teacher* 22 (4): 334–47.

Hrnjica, Bahrudin, and Selver Softic. 2020. “Explainable AI in Manufacturing: A Predictive Maintenance Case Study.” In *Advances in Production Management Systems. Towards Smart and Digital Manufacturing*, edited by Bojan Lalic, Vidosav Majstorovic, Ugljesa Marjanovic, Gregor von Cieminski, and David Romero, 66–73. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-57997-5_8.

Isaac Flores-Alonso, Santiago, Noemi V. Mendoza Diaz, Joseph Kapphahn, Olivia Mott, David Dworaczyk, Rene Luna-García, and Ana Sofia Rangel Paredes. 2023. “Introduction to AI in Undergraduate Engineering Education.” In *2023 IEEE Frontiers in Education Conference (FIE)*, 1–4. https://doi.org/10.1109/FIE58773.2023.10343187.

Johri, Aditya. 2020. “Artificial Intelligence and Engineering Education.” *Journal of Engineering Education* 109 (3): 358–61. https://doi.org/10.1002/jee.20326.

Knoth, Nils, Marie Decker, Matthias Carl Laupichler, Marc Pinski, Nils Buchholtz, Katharina Bata, and Ben Schultz. 2024. “Developing a Holistic AI Literacy

Assessment Matrix – Bridging Generic, Domain-Specific, and Ethical Competencies.” *Computers and Education Open* 6 (June):100177. https://doi.org/10.1016/j.caeo.2024.100177.

Laupichler, Matthias Carl, Alexandra Aster, Jana Schirch, and Tobias Raupach. 2022. “Artificial Intelligence Literacy in Higher and Adult Education: A Scoping Literature Review.” *Computers and Education: Artificial Intelligence* 3:100101. https://doi.org/10.1016/j.caeai.2022.100101.

Lee, Wo Jae, Haiyue Wu, Huitaek Yun, Hanjun Kim, Martin B. G. Jun, and John W. Sutherland. 2019. “Predictive Maintenance of Machine Tool Systems Using Artificial Intelligence Techniques Applied to Machine Condition Data.” *Procedia CIRP*, 26th CIRP Conference on Life Cycle Engineering (LCE), 80:506–11. https://doi.org/10.1016/j.procir.2018.12.019.

Long, Duri, and Brian Magerko. 2020. “What Is AI Literacy? Competencies and Design Considerations.” In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–16. Honolulu HI USA: ACM. https://doi.org/10.1145/3313831.3376727.

Machado, Alexander, and Max Mynter. 2024. “ML Skill Profiles: An Organizational Blueprint for Scaling Enterprise ML.” Munich: appliedAI. https://www.appliedai.de/en/insights/ml-skill-profiles.

Magana, Alejandra J, Michael L Falk, and Michael J Reese Jr. 2013. “Introducing Discipline-Based Computing in Undergraduate Engineering Education.” *ACM Transactions on Computing Education (TOCE)* 13 (4): 1–22.

Malmi, Lauri, and Aditya Johri. 2023. “A Selective Review of Computing Education Research.” In *International Handbook of Engineering Education Research*, 573–93. New York: Routledge. https://doi.org/10.4324/9781003287483.

McClarey, Bryan Schulze. 2004. *Role-Based Learning: Considering Identity and Practice in Instructional Design*. Vanderbilt University.

Mustapha, Khameel B., Eng Hwa Yap, and Yousif Abdalla Abakr. 2024. “Bard, ChatGPT and 3DGPT: A Scientometric Analysis of Generative AI Tools and Assessment of Implications for Mechanical Engineering Education.” *Interactive Technology and Smart Education* ahead-of-print (ahead-of-print). https://doi.org/10.1108/ITSE-10-2023-0198.

Ng, Davy Tsz Kit, Min Lee, Roy Jun Yi Tan, Xiao Hu, J. Stephen Downie, and Samuel Kai Wah Chu. 2023. “A Review of AI Teaching and Learning from 2000 to 2020.” *Education and Information Technologies* 28 (7): 8445–8501. https://doi.org/10.1007/s10639-022-11491-w.

Ng, Davy Tsz Kit, Jac Ka Lok Leung, Kai Wah Samuel Chu, and Maggie Shen Qiao. 2021. “AI Literacy: Definition, Teaching, Evaluation and Ethical Issues.” *Proceedings of the Association for Information Science and Technology* 58 (1): 504–9. https://doi.org/10.1002/pra2.487.

Patel, Amit R, Kashyap K Ramaiya, Chandrakant V Bhatia, Hetalkumar N Shah, and Sanket N Bhavsar. 2021. “Artificial Intelligence: Prospect in Mechanical Engineering Field—a Review.” *Data Science and Intelligent Applications: Proceedings of ICDSIA 2020*, 267–82.

Raj, Rajendra K., Allen Parrish, John Impagliazzo, Carol J. Romanowski, Sherif G. Aly, Casey C. Bennett, Karen C. Davis, Andrew McGettrick, Teresa Susana Mendes Pereira, and Lovisa Sundin. 2019. “An Empirical Approach to Understanding Data Science and Engineering Education.” In *Proceedings of the Working Group Reports on Innovation and Technology in Computer Science Education*, 73–87. ITiCSE-WGR ’19. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3344429.3372503.

Schleiss, Johannes, Michelle Bieber, Anke Manukjan, Lars Kellner, and Sebastian Stober. 2022. “An Interdisciplinary Competence Profile for AI in Engineering.” In *Proceedings of 50th Annual Conference of the European Society for Engineering Education (SEFI)*, 1601–9. https://doi.org/10.5821/conference-9788412322262.1288.

Schleiss, Johannes, Matthias Carl Laupichler, Tobias Raupach, and Sebastian Stober. 2023. “AI Course Design Planning Framework: Developing Domain-Specific AI Education Courses.” *Education Sciences* 13 (9): 954. https://doi.org/10.3390/educsci13090954.

Schüller, Katharina, Florian Rampelt, Henning Koch, and Johannes Schleiss. 2023. “Better Ready than Just Aware: Data and AI Literacy as an Enabler for Informed Decision Making in the Data Age.” In *INFORMATIK 2023 - Designing Futures: Zukünfte Gestalten.*, 425–30. Gesellschaft für Informatik e.V. https://doi.org/10.18420/inf2023_49.

Singelmann, Lauren, and Jacob Covarrubias. 2023. “A Framework For Teaching Machine Learning For Engineers.” https://doi.org/10.21427/3Z16-YM65.

Stolpe, Karin, and Jonas Hallström. 2024. “Artificial Intelligence Literacy for Technology Education.” *Computers and Education Open* 6 (June):100159. https://doi.org/10.1016/j.caeo.2024.100159.

Tercan, Hasan, and Tobias Meisen. 2022. “Machine Learning and Deep Learning Based Predictive Quality in Manufacturing: A Systematic Review.” *Journal of Intelligent Manufacturing* 33 (7): 1879–1905. https://doi.org/10.1007/s10845-022-01963-8.

Whitehead, Cynthia, Veronica Selleger, José van de Kreeke, and Brian Hodges. 2014. “The ‘Missing Person’in Roles-based Competency Models: A Historical, Cross-national, Contrastive Case Study.” *Medical Education* 48 (8): 785–95.

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INTEGRATING AI EDUCATION IN DISCIPLINARY ENGINEERING FIELDS: TOWARDS A SYSTEMS AND CHANGE PERSPECTIVE

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ABSTRACT

Building up competencies in working with data and tools of Artificial Intelligence (AI) is becoming more relevant across disciplinary engineering fields. While the adoption of tools for teaching and learning, such as ChatGPT, is garnering significant attention, integration of AI knowledge, competencies, and skills within engineering education is lacking. Building upon existing curriculum change research, this practice paper introduces a systems perspective on integrating AI education within engineering through the lens of a change model. In particular, it identifies core aspects that shape AI adoption on a program level as well as internal and external influences using existing literature and a practical case study. Overall, the paper provides an analysis frame to enhance the understanding of change initiatives and builds the basis for generalizing insights from different initiatives in the adoption of AI in engineering education.

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1 INTRODUCTION

The use of AI has become increasingly relevant across domains (Broo, Kaynak, and Sait 2022; Patel et al. 2021). The rise of generative AI tools in particular is an example of how the use of AI-based tools, such as ChatGPT, has found high use, especially by students, while their conceptual understanding of how these tools work is limited (Weidener and Fischer 2024; Tsoeu et al. 2023). Thus, the digital transformation accelerated by AI increases the need for AI education in the disciplinary context so that students can make responsible judgments about the use of tools, the outputs they get, and so that they are workforce-ready (Dignum 2021; Cevik Onar et al. 2018).

Positioning AI Education

AI education is a complex undertaking as the field can be positioned from multiple perspectives. First, it describes *teaching about AI* rather than the use of AI tools in teaching (Zawacki-Richter et al. 2019). Second, it can address different target groups, distinguishing between *general, (basic) AI literacy* that builds foundations for the broad public, *domain-specific AI literacy* that aims to build competencies in the context of a disciplinary field, and *expert AI literacy*, which might target Computer Science majors (Schleiss, Laupichler, et al. 2023; Long and Magerko 2020; Laupichler et al. 2022). Third, AI education in engineering education can be seen as a subset of Computer Science (CS) education, similar to the role of programming, which is a basic skill but applicable across disciplines, which requires a greater understanding of how it can be integrated into curricula (Malmi and Johri 2023).

Integration of AI Education in Disciplinary Engineering Fields

With the premise that the use of AI tools and applications will become more dominant across different engineering use cases, it is necessary to address the integration of related AI competencies in the engineering curricula and create systematic research-based understanding. This aligns with the call for interdisciplinarity in engineering education aimed at integrating multiple disciplines to solve a problem (Van den Beemt et al. 2020; Spelt et al. 2009) as well as the continuation of efforts towards digital engineering and use of data and computation in engineering (Cevik Onar et al. 2018).

In the context of engineering education, Kolmos, Hadgraft, and Holgaard (2016) advanced three different curriculum change strategies: first, an *add-on strategy*, referring to including additional courses or components in a curriculum but not changing the overall educational paradigm; second, an *integration strategy*, which involves modifications of programs, and third, a *re-build strategy* which refers to a fundamental change of the educational paradigms of the curricula. These can be used as an analysis lens for the type and depth of curricular change.

The applicability of either of these strategies depends on the context as curricular change does not take place in a vacuum and a range of factors shape curricular reform, especially in interdisciplinary efforts (Knight et al. 2013; Klein 2018). One conceptual framework that helps to understand the factors that influence design decisions on curriculum and course planning is the *Academic Plan Model* (Lattuca and Stark 2009). The model proposes that the development of curricula and courses while being conducted by faculty is also influenced by external and internal forces in a sociocultural context.

In this paper we build upon the three curriculum response strategies proposed by Kolmos, Hadgraft, and Holgaard (2016), the *Academic Plan Model* (Lattuca and Stark 2009), and perspectives from change theory to create practical insights for integrating AI in engineering education. Our approach is guided by the question: *what factors – external, internal, and program level – influence the integrating AI knowledge in engineering education?* We combine findings from literature and a case study of curricular development to provide an analytical frame for integrating AI education in disciplinary engineering fields.

We first review prior work relevant to understanding curriculum change in engineering before moving on to a practical case study that will help us exemplify change by integrating theoretical perspectives. Our move from the concrete to the analytical is deliberate so that the practical insights we generate are theoretically grounded in an integrated manner. Overall, this paper contributes to a system perspective on the integration of AI education in the engineering domain and supports educational strategy development in engineering education.

2 RELATED WORK

2.1 Transformation towards AI Education in Education

There already exists some work on transformation processes towards AI education that can be used to identify important drivers. Cantú-Ortiz et al. (2020) described a case study of the AI education strategy and programs at the Tecnologico de Monterrey that builds on five strategic initiatives of (1) developing *academic programs*, (2) building up *research capabilities*, (3) *dissemination* through conferences and training seminars, (4) *outreach* through industry-university collaboration and (5) *internationalization* to enhance the exchange. As influencing factors for the program, the paper mentions internationalization and internships, employability, entrepreneurship, academic competitions, growth plans, funding from industry and public sector, AI conferences, and industry partners. Similarly, Southworth et al. (2023) described the “AI Across the Curriculum” initiative at the University of Florida. The initiative is built on pillars of (1) *investment towards compute* and *adding AI-focused faculty*, (2) *developing AI pedagogy* and including *measures* towards it in the quality enhancement plan, and (3) *developing an understanding of AI literacy* in the university and *targeting curriculum development* and development of new academic programs, pathways, research experiences and career development. The complexity and multidisciplinarity of developing AI programs are also highlighted by the experiences of Utrecht University’s AI master program (Janssen et al. 2020) and the design of AI education offers for K-12 target groups (Chiu and Chai 2020).

2.2 Models for Interdisciplinary Engineering Education

Approaches in interdisciplinary engineering education have the vision to focus on complex real-world problem-solving, the social awareness and entrepreneurial competencies of engineers as well as the improvement of disciplinary programs (Van den Beemt et al. 2020). Thus, related work on change processes and related change efforts do exist, and two recent efforts that can be a good model for AI are the integration of ethics education and sustainability education in engineering curricula. For example, Weiss, Barth, and von Wehrden (2021) analysed 131 case studies of curriculum change towards integrating sustainability and identified six *implementation patterns* ranging from (1) collaborative paradigm change, (2) bottom-up, evolving institutional change, (3) top-down, mandated institutional change, (4) externally driven initiatives, (5) isolated initiatives, and (6) limited institutional change. Also in the context of sustainability, the *curriculum response strategies* of (Kolmos, Hadgraft, and Holgaard 2016) are inspired by responses to sustainable education proposed by (Sterling 2001): making adjustments in the existing system such as improvements or restructuring and changing the educational paradigm as in redesigning the system and institutions. Similarly, Lambrechts (2010) analysed how and to what extent sustainability-related competencies were integrated in Bachelor programs at their university. Next to sustainability, engineering ethics is another topic of curriculum change processes. In this context, Martin, Conlon, and Bowe (2021) analysed literature through four different analytical levels: individual teaching practices, institutional (programs, departments, implementations), policy (accreditation, funding) and culture (paradigms of practice). This suggests that similar to ethics, AI should be integrated across modules, needs to be put into practice and is shaped from different disciplinary domains (Hitt, Holles, and Lefton 2020).

3 Case Study

Next to looking at curriculum change from a theoretical perspective, we describe the case of a curricular development of a Bachelor program of AI engineering to understand practical factors of influence in the context of engineering education. The program (210 ECTS (European Transfer Credit System) credits) at the Otto von Guericke University Magdeburg aims at integrating both disciplines, AI and engineering. The interdisciplinary curriculum, situated between AI and engineering, has been developed in a collaborative and participatory process using the method of curriculum workshops (Schleiss, Manukjan, et al. 2023). As a newly developed curriculum, it follows the re-build strategy and recreates educational experiences on a green field. The purpose of the program and vision is to bridge the gap between engineering and AI and train so-called AI engineers who can develop data-driven solutions for engineering use cases. This interdisciplinary skillset focuses on competencies to responsibly work with data and (AI) models as well as having a domain understanding of underlying engineering processes, data and requirements. Moreover, it requires a high level of systematic problem-solving skills and the ability to communicate effectively across disciplines. As a re-build curriculum, about half of the modules are newly developed targeting different educational experiences, for example, projects, flipped-classroom settings, or hackathons. Additionally, a focus lies on developing and using Open Educational Resources (OER) in teaching and collaboration with industry.

The program structure roughly consists of six different elements: fundamental courses, specialisation courses, projects, electives, internship and thesis. The first semesters target the fundamentals in engineering and computer science with a focus on working with data and AI, and related subjects such as maths or working with sensors. After the fundamentals, students select a specialisation of one engineering application area and focus on working with data and AI solutions in this application context. Throughout the program, students have projects that aim to integrate the different knowledge components and bring them into practice. In the higher semesters, the students have three electives allowing for going deeper in some directions. Moreover, in their last semester, students have a 12-week internship and complete the program with a thesis.

The program development was influenced by multiple internal and external drivers. From the external side, AI education is currently high on the political agenda and funding has been provided to establish the study program. Moreover, the content and implementation are shaped through interactions with industry partners. Internally, the program is influenced mostly by the educators who designed the program and secured the funding for its establishment. While acknowledging the need for such a program on the faculty and institutional level, the development was not driven top-down or part of strategic initiatives for further development. Moreover, the program in its form is only possible through the availability of resources, especially concerning faculty staff (mostly financed by external funding) and existing computing resources for the students. The culture at the institution and faculty was initially resisting change, especially concerning novel approaches to teaching and the structure of the curriculum. At the same time, the external funding and governmental support were perceived as validation of the ideas and acceptance of the proposed curriculum. Next, we use this case to exemplify how AI can be integrated into engineering programs and curricula.

4 INTEGRATED PERSPECTIVES FOR AI EDUCATION IN ENGINEERING FIELDS

4.1 Academic Plan Model for AI Education in Engineering

To move towards a system perspective on integrating AI education in disciplinary engineering fields, we integrate the findings from theory and practice towards a system model that highlights external and internal influences. The abstract model (Figure 1) builds upon the *Academic Plan Model* (Lattuca and Stark 2009) and frames the context that is used to understand and describe how change might occur towards adopting AI education. In the following, we describe the different contexts in more detail and highlight how these behave specific to AI education.

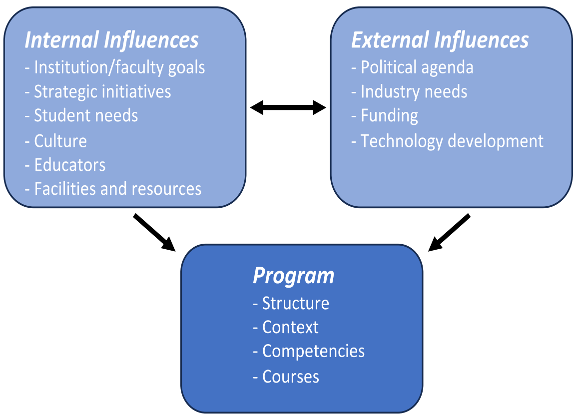

Figure 1. System perspective on influences of curriculum change inspired by (Lattuca and Stark 2009)

4.1.1. Program Level for AI Education in Engineering

Within the context of an educational environment, the central element is the *program* with its structure, context, competencies, and content such as instructional resources, processes and assessment and evaluation. A program includes content aspects (curriculum) and organizational aspects (regulations). A curriculum is usually described through the goal, purpose, content and sequence of how different modules work together. Different modules might consist of one or more courses and include instructional resources, processes, assessment and evaluation, all targeted to build out competencies for learners. As introduced earlier, when looking at changes in curricula, response strategies can be roughly distinguished into an add-on, integration and re-build strategy (Kolmos, Hadgraft, and Holgaard 2016). Thus, we can use these perspectives for integrating AI in engineering education.

Following this structure, it becomes clear that we need to understand how to develop (interdisciplinary) curricula that integrate AI and different engineering domains including aspects of what competencies and content are relevant and in what sequence it should be taught. This can lead to adding new competencies, integrating them into existing curricula and courses or re-building them. More specifically, from a course perspective, there is the need to understand what our learners need in their interaction with AI, what relevant instructional resources are, how we can structure instructional processes and how we can assess and evaluate the learning.

A few curricula and course development efforts exist in the literature. Work in the context of curricula, development has been focused on the idea of multi- and interdisciplinary design highlighting the diverse nature of AI (Janssen et al. 2020; Southworth et al. 2023). The research on understanding relevant AI competencies is still in development (Tenório and Romeike 2024; Almatrafi, Johri, and Lee 2024; Wolters, Arz Von Straussenburg, and Riehle 2024). Regarding course development, there have been efforts to provide structure for educators, e.g. the AI course design planning framework (Schleiss, Laupichler, et al. 2023). Moreover, there have been multiple efforts in the definition of AI literacy assessment instruments (Hornberger, Bewersdorff, and Nerdel 2023; Laupichler, Aster, and Raupach 2023).

Exemplary Core Questions

- What is the purpose of integrating AI in the program?
- What AI competencies are targeted and should be integrated?
- Does the adoption of curricula or courses towards AI follow an add-on, integration and re-build strategy?
- What learning activities and assessment strategies are suitable for AI education?

4.1.2. Internal Influences on AI Education in Engineering

Within the socio-cultural context, we find internal and external forces. Concerning internal influences Lattuca and Stark (2009) distinguish between institutional such as the objectives of the institution, resources or governance, and unit-level influences such as educators in faculty, discipline culture and student characteristics. From the perspective of adopting AI education in engineering education, it is important to understand internal drivers in the institution. These can be roughly distinguished as focusing on people and focusing on organizational structures. People are central to change, especially in education. In adopting AI education, one key challenge is the readiness of faculty for change, be it the level of expertise and skills in AI, the needed support structures, or the potential resistance to change (Stark et al. 1988). Moreover, aspects such as governance structures are important to consider. For example, Knight et al. (2013) highlighted the importance of organizational features, such as the appointment of a program director and faculty appointment within the interdisciplinary field. Additionally, in the context of AI, computational resources are needed for deployment, experiments and teaching. Thus it is important to consider what resources are available on a faculty and institutional level.

Exemplary Core Questions

- Who is driving the integration of AI education? Is it led by leadership (top-down) or by faculty/educators/students (bottom-up)?
- How well embedded is AI education in the faculty goals or strategic initiatives?
- How well-equipped are educators to teach AI topics?
- What governance structures can support the integration of AI in curricula?
- How is the funding and resource situation, e.g. for compute at the institution?

4.1.3. External Influences on AI Education in Engineering

Next to internal influences, the educational environment is influenced by external forces. These can include market forces, political agenda and initiatives, accrediting agencies, disciplinary associations, technology advancements, funding or industry needs. Concerning AI education, we can highlight five major forces from theory and practice. First, AI development has mostly accelerated due to technological advancements in computing and model architectures in recent years, leading to new market forces and industry demand for AI talent. This creates a demand for more AI education at universities. Second, the need for AI talent and research is also picked up by governments and supported through funding or political initiatives, which create an opportunity for universities to create new programs or research initiatives. Third, new competencies are also picked up by accrediting bodies, even though a recent article highlighted that currently AI is not yet broadly integrated into engineering accreditation (Tsoeu et al. 2023). Fourth, the use of AI systems has ethical, legal and social implications and is also a topic of regulatory aspects. Regulations like the EU AI Act influence the possible use of AI systems but in a broader sense also what should be taught in the context of AI education to educate responsible engineers. Fifth, there exists the challenge of a high volatility of skills due to technology advancements. Identifying the relevant skills and adopting courses and curricula at the required speed remains challenging for higher education.

Exemplary Core Questions

- How important is the topic of AI considered on the current political agenda?
- What is the need for AI skills in the industry? Who are potential partners?
- How much funding is available to develop new programs?
- How is the constant technology change in AI influencing relevant skills, adoption in programs and in courses?

4.2 Change Theory Perspective for AI Education in Engineering

Curriculum change can be viewed from three dimensions: (1) *triggers* of change, (2) *drivers and barriers* of change, and (3) the *type and content* of change. *Triggers of change* refer to the impetus of change, from forces within the institution or from external sources (Lattuca and Stark 2009), and it can be normative or goal-oriented

(Fumasoli and Lepori 2011). *Drivers and barriers of change* can again be external or internal influences (Gruba et al. 2004). Internally, questions about the institutional goals, resource availability, governance structures, and readiness of faculty for integrating and changing (Gruba et al. 2004; Roberts 2015). Moreover, student needs and interests as well as their characteristics and abilities might drive or hinder change (Gruba et al. 2004). Externally, the market forces, the political agenda, accreditation agencies or disciplinary associations or change in other institutions might influence the change process (Gruba et al. 2004). Finally, the *type and content of change* vary and can be linked to different response strategies, e.g. adding new degrees or course work, new subjects or integrating aspects in core or electives (Gruba et al. 2004; Kolmos, Hadgraft, and Holgaard 2016). From a content perspective, there is the question of what competencies are relevant and categorizing their integration, e.g. in vertical integration (explicit mentioning of competency), horizontal integration (competency implicitly integrated across the curriculum), and a combination of both (Lambrechts 2010). For an overview, the system and the change perspective are summarized in Table 1.

Table 1. Integrated Systems and Change Perspective towards integrating AI education in EE

Change Dimensions	**System Elements**		**Program Level Changes for integrating AI education in engineering education**
	Internal	*External*	
Trigger	Faculty interests and motivation Strategic initiatives from leadership Student demands for integration of AI	Accreditation processes Funding from industry and government Market demands for AI graduates Risks of the use of AI	Awareness and training in AI for faculty and leadership as well as new faculty hires can trigger change Loop between market demands and student needs for AI related competencies and new learning experiences Responsible and ethical use of AI is key for engineers
Drivers and Barriers	Institutional goals Available resources Governance structure Readiness of faculty	Accreditation processes Funding from industry and government Internationalization Exchange with others Change in other HEIs	Faculty AI skills, motivation and time as well as related governance structures relevant for program level change Funding and accreditation accelerates the change process towards integrating AI in EE AI technology advancement driven through industry - Industry collaboration more important Student demands accelerates AI adoption
Type and Content	Curricular regulations Agility of faculty administration	Availability of competence frameworks Accreditation	Identification of relevant competencies and their integration across curricula as main challenge Selecting adequate change response strategy and integration strategy and related teaching approaches

5. DISCUSSION AND IMPLICATIONS

We have introduced a system perspective on integrating AI education in disciplinary engineering fields building upon literature and a practical case study. Connecting to other transformation processes, this work contributes towards an improved understanding of the required change processes for integrating AI competencies in disciplinary engineering fields. It can serve as a thinking frame for educators and faculty leaders to see where they stand and how to develop a change strategy towards integrating AI into their educational offers. We recognize that the paper has certain limitations. First, the system perspective as an analysis frame is inductively developed from a case study and literature only and not yet validated in use. Moreover, the selection of the case might have biased the development. These limitations can be overcome in future through analysis of further use cases and integration of expert feedback, in particular with comparison to previous integration efforts of other cross-ranging aspects such as sustainability and ethics. From the analysis frame, we can also identify implications for further research. First, more case studies should be collected and analysed within the analysis frame to build a foundation for transferring local best practices to more general contexts. Second, more research is needed to understand program structures and ways to integrate AI competencies in engineering education in a disciplinary and interdisciplinary way. Third, internal and external drivers of AI education can benefit from more research, in particular to map change theories to the drivers (Reinholz and Andrews 2020). Fourth, the analysis frame could be further enhanced with metrics, e.g. a readiness scale, to support the change processes at universities and allow for comparisons on a faculty, institutional, national or international level.

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REFERENCES

Almatrafi, Omaima, Aditya Johri, and Hyuna Lee. 2024. “A Systematic Review of AI Literacy Conceptualization, Constructs, and Implementation and Assessment Efforts (2019-2023).” *Computers and Education Open*, 100173.

Broo, Didem Gürdür, Okyay Kaynak, and Sadiq M Sait. 2022. “Rethinking Engineering Education at the Age of Industry 5.0.” *Journal of Industrial Information Integration* 25:100311.

Cevik Onar, Sezi, Alp Ustundag, Çigdem Kadaifci, and Basar Oztaysi. 2018. “The Changing Role of Engineering Education in Industry 4.0 Era.” In *Industry 4.0: Managing The Digital Transformation*, edited by Alp Ustundag and Emre Cevikcan, 137–51. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-57870-5_8.

Chiu, Thomas K. F., and Ching-sing Chai. 2020. “Sustainable Curriculum Planning for Artificial Intelligence Education: A Self-Determination Theory Perspective.” *Sustainability* 12 (14): 5568. https://doi.org/10.3390/su12145568.

Dignum, Virginia. 2021. “The role and challenges of education for responsible AI.” *London Review of Education* 19 (1). https://doi.org/10.14324/LRE.19.1.01.

Fumasoli, Tatiana, and Benedetto Lepori. 2011. “Patterns of Strategies in Swiss Higher Education Institutions.” *Higher Education* 61 (2): 157–78. https://doi.org/10.1007/s10734-010-9330-x.

Gruba, Paul, Alistair Moffat, Harald Søndergaard, and Justin Zobel. 2004. “What Drives Curriculum Change?” In *Proceedings of the Sixth Australasian Conference on Computing Education*. Vol. 30.

Hitt, Sarah Jayne, Cortney E. P. Holles, and Toni Lefton. 2020. "Integrating Ethics in Engineering Education through Multidisciplinary Synthesis, Collaboration, and Reflective Portfolios." *Advances in Engineering Education*. https://eric.ed.gov/?id=EJ1279776.

Hornberger, Marie, Arne Bewersdorff, and Claudia Nerdel. 2023. "What Do University Students Know about Artificial Intelligence? Development and Validation of an AI Literacy Test." *Computers and Education: Artificial Intelligence* 5 (January):100165. https://doi.org/10.1016/j.caeai.2023.100165.

Janssen, Christian P., Rick Nouwen, Krista Overvliet, Frans Adriaans, Sjoerd Stuit, Tejaswini Deoskar, and Ben Harvey. 2020. "Multidisciplinary and Interdisciplinary Teaching in the Utrecht AI Program: Why and How?" *IEEE Pervasive Computing* 19 (2): 63–68. https://doi.org/10.1109/MPRV.2020.2977741.

Klein, Julie Thompson. 2018. "Current Drivers of Interdisciplinarity: The What and the Why." In *Promoting Interdisciplinarity in Knowledge Generation and Problem Solving*, 14–28. IGI Global. https://doi.org/10.4018/978-1-5225-3878-3.ch002.

Knight, David B., Lisa R. Lattuca, Ezekiel W. Kimball, and Robert D. Reason. 2013. "Understanding Interdisciplinarity: Curricular and Organizational Features of Undergraduate Interdisciplinary Programs." *Innovative Higher Education* 38 (2): 143–58. https://doi.org/10.1007/s10755-012-9232-1.

Kolmos, Anette, Roger G. Hadgraft, and Jette Egelund Holgaard. 2016. "Response Strategies for Curriculum Change in Engineering." *International Journal of Technology and Design Education* 26 (3): 391–411. https://doi.org/10.1007/s10798-015-9319-y.

Lambrechts, Wim. 2010. "The Integration of Sustainability in Competence Based Higher Education." In *ERSCP-EMSU Conference*.

Lattuca, Lisa R., and Joan S. Stark. 2009. *Shaping the College Curriculum: Academic Plans in Context*. John Wiley & Sons.

Laupichler, Matthias Carl, Alexandra Aster, and Tobias Raupach. 2023. "Delphi Study for the Development and Preliminary Validation of an Item Set for the Assessment of Non-Experts' AI Literacy." *Computers and Education: Artificial Intelligence* 4 (January):100126. https://doi.org/10.1016/j.caeai.2023.100126.

Laupichler, Matthias Carl, Alexandra Aster, Jana Schirch, and Tobias Raupach. 2022. "Artificial Intelligence Literacy in Higher and Adult Education: A Scoping Literature Review." *Computers and Education: Artificial Intelligence* 3:100101. https://doi.org/10.1016/j.caeai.2022.100101.

Long, Duri, and Brian Magerko. 2020. "What Is AI Literacy? Competencies and Design Considerations." In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–16. Honolulu HI USA: ACM. https://doi.org/10.1145/3313831.3376727.

Malmi, Lauri, and Aditya Johri. 2023. "A Selective Review of Computing Education Research." *International Handbook of Engineering Education Research*, 573–93.

Martin, Diana Adela, Eddie Conlon, and Brian Bowe. 2021. “A Multi-Level Review of Engineering Ethics Education: Towards a Socio-Technical Orientation of Engineering Education for Ethics.” *Science and Engineering Ethics* 27 (5): 60. https://doi.org/10.1007/s11948-021-00333-6.

Patel, Amit R, Kashyap K Ramaiya, Chandrakant V Bhatia, Hetalkumar N Shah, and Sanket N Bhavsar. 2021. “Artificial Intelligence: Prospect in Mechanical Engineering Field—a Review.” *Data Science and Intelligent Applications: Proceedings of ICDSIA 2020*, 267–82.

Reinholz, Daniel L., and Tessa C. Andrews. 2020. “Change Theory and Theory of Change: What’s the Difference Anyway?” *International Journal of STEM Education* 7 (1): 1–12. https://doi.org/10.1186/s40594-020-0202-3.

Roberts, Pamela. 2015. “Higher Education Curriculum Orientations and the Implications for Institutional Curriculum Change.” *Teaching in Higher Education* 20 (5): 542–55. https://doi.org/10.1080/13562517.2015.1036731.

Schleiss, Johannes, Matthias Carl Laupichler, Tobias Raupach, and Sebastian Stober. 2023. “AI Course Design Planning Framework: Developing Domain-Specific AI Education Courses.” *Education Sciences* 13 (9): 954. https://doi.org/10.3390/educsci13090954.

Schleiss, Johannes, Anke Manukjan, Michelle Ines Bieber, Philipp Pohlenz, and Sebastian Stober. 2023. “Curriculum Workshops As A Method Of Interdisciplinary Curriculum Development: A Case Study For Artificial Intelligence In Engineering.” https://doi.org/10.21427/XTAE-AS48.

Southworth, Jane, Kati Migliaccio, Joe Glover, Ja’Net Glover, David Reed, Christopher McCarty, Joel Brendemuhl, and Aaron Thomas. 2023. “Developing a Model for AI Across the Curriculum: Transforming the Higher Education Landscape via Innovation in AI Literacy.” *Computers and Education: Artificial Intelligence* 4:100127. https://doi.org/10.1016/j.caeai.2023.100127.

Spelt, Elisabeth J. H., Harm J. A. Biemans, Hilde Tobi, Pieternel A. Luning, and Martin Mulder. 2009. “Teaching and Learning in Interdisciplinary Higher Education: A Systematic Review.” *Educational Psychology Review* 21 (4): 365–78. https://doi.org/10.1007/s10648-009-9113-z.

Stark, Joan S., Malcolm A. Lowther, Michael P. Ryan, and Michele Genthon. 1988. “Faculty Reflect on Course Planning.” *Research in Higher Education* 29 (3): 219–40. https://doi.org/10.1007/BF00992924.

Sterling, Stephen. 2001. “Sustainable Education: Re-Visioning Learning and Change. Schumacher Briefings.”

Tenório, Kamilla, and Ralf Romeike. 2024. “AI Competencies for Non-Computer Science Students in Undergraduate Education: Towards a Competency Framework.” In *Proceedings of the 23rd Koli Calling International Conference on Computing Education Research*, 1–12. Koli Calling ’23. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3631802.3631829.

Tsoeu, Mohohlo, Rendani Maladzi, Nomcebo Mthombeni, Katleho Moloi, Tebogo Mashifana, and Fulufhelo Nemavhola. 2023. “Engineering, the Profession in Trouble: Lack of Programme Development Standards That Support the AI Chatbot? A System View.” In *2023 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC)*, 1–6. https://doi.org/10.1109/WEEF-GEDC59520.2023.10343985.

Van den Beemt, Antoine, Miles MacLeod, Jan Van der Veen, Anne Van de Ven, Sophie van Baalen, Renate Klaassen, and Mieke Boon. 2020. “Interdisciplinary Engineering Education: A Review of Vision, Teaching, and Support.” *Journal of Engineering Education* 109 (3): 508–55. https://doi.org/10.1002/jee.20347.

Weidener, Lukas, and Michael Fischer. 2024. “Artificial Intelligence in Medicine: Cross-Sectional Study Among Medical Students on Application, Education, and Ethical Aspects.” *JMIR Medical Education* 10 (1): e51247. https://doi.org/10.2196/51247.

Weiss, Marie, Matthias Barth, and Henrik von Wehrden. 2021. “The Patterns of Curriculum Change Processes That Embed Sustainability in Higher Education Institutions.” *Sustainability Science* 16 (5): 1579–93. https://doi.org/10.1007/s11625-021-00984-1.

Wolters, Anna, Arnold F Arz Von Straussenburg, and Dennis M Riehle. 2024. “AI Literacy in Adult Education-A Literature Review.”

Zawacki-Richter, Olaf, Victoria I. Marín, Melissa Bond, and Franziska Gouverneur. 2019. “Systematic Review of Research on Artificial Intelligence Applications in Higher Education – Where Are the Educators?” *International Journal of Educational Technology in Higher Education* 16 (1): 39. https://doi.org/10.1186/s41239-019-0171-0.

Rule-based access to learning materials in a Flipped class in embedded programming

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ABSTRACT

This empirical study explores the effectiveness of the Flipped Classroom (FC) model combined with blended learning in the context of Electrotechnical Bachelor of Engineering education in a digital electronics and programming course on 2nd semester. It particularly focuses on the use of a Learning Management System (LMS) to facilitate pre-class, in-class, and post-class activities, emphasizing the role of quizzes, video materials, and slide presentations in enhancing student engagement and preparation. The research was conducted over several semesters, comparing student engagement metrics and assignment quality before and after the implementation of rule-based access to learning materials. Data were gathered from the LMS, including quiz participation rates and access to pre-class slide presentations and correlated with the quality of students' assignment submissions.

The findings indicate a mixed impact of rule-based access on student preparation, with some improvement in quiz participation and slide access but less engagement with video materials. However, the quality of assignment submissions did not significantly correlate with the enforced pre-class activities, suggesting that motivation and engagement might be influenced by factors beyond the structured access to learning materials. The study also highlights the challenges of encouraging consistent student preparation and the potential of LMS tools to tailor the learning experience to individual needs.

The research contributes to the ongoing discussion about the flipped classroom (FC) model's effectiveness, offering insights into how digital tools and structured access rules can enhance or hinder student learning in programming courses. It calls for further investigation into the motivational factors driving student engagement in blended learning environments.

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1 INTRODUCTION

In this empirical work, we will study and analyze if students uses of materials reflects the quality of assignment and if a rule based setup in the learning management system improves the uses of material compared to year without any rule set. The rule-based access to the lesson slide presentations was introduced in fall 2023 and also used in spring 2024. The rule is: The quiz must be scored before getting access to the in-class slide presentations. The paper introduces the concept of the flipped class, drawing from relevant literature and providing motivation for the research questions. The course used is introduced. Details about data collection and results are presented. The paper concludes with a discussion and conclusion.

1.1 Introduction flipped classroom

Programming involves various skills to learn. The Flipped Classroom (FC) creates a new learning environment with practical programming sessions and enhances

students' learning experiences (Siripongdee, Pimdee, & Tuntiwongwanich, 2020).

The main advantages of FC are providing students with knowledge before class and preparing them to spend extra time in class for active and collaborative learning (Eusoff, Salleh, Mohd, 2021). The FC principle typically covers 3 parts of activity: pre-class, in-class, and post-class. Our course Digital electronics and Programming (62734) on 2nd semester electro technology Bachelor of Engineering used for research here uses pre-class activity: video, slides, quiz and in class activity use slides and assignment programming as well as post-class work on the assignment and report for documentation.

This paper written by Eusoff, Zin, Salleh(2022) shows literature review and it reveals in-class activity hands-on experiences are most used, whereas only 21% use assignments. Moreover, they find mostly pre-class videos to convey knowledge and quizzes. When using FC, learning is individualized, and students must be able to learn at their own pace and ask questions to the facilitators in the class. (Rasheed A. et al. 2020). The teacher's role is changed to support, guide, and facilitate the students towards learning from different perspectives.

The teacher is responsible for materials available online due to the FC being a 24/7 classroom. The FC model also effectively enhances students' engagement, interaction, self-efficacy, and attitudes (Eusoff, Zin, Salleh, 2022), But in practice, one of the challenges educators face is ensuring students' participation in learning activities in pre-class (Eusoff, Salleh, Zin, 2021). Our previous work (Schultz, & Blaszczyk, 2023).) reveals that 25 – 30% percent of the students don't use the pre-class materials.

Motivation is the most important element when using the FC method. In addition, Lopes et al. (2019) have analyzed data regarding students' affective perception of flipped classrooms and write that the statistical analysis indicates, especially in the 3rd and 4th semesters, semesters in e-learning and classroom classes present a significantly higher affective perception. A motivation factor for the students could be quizzes - a kind of gamification, a competition. Many research articles ex (Eusoff, Zin, Salleh, 2022)(Baig, Yadegaridehkordi 2023)(Sobral, 2021) present data from research and literature reviews. The course (62734) activity in-class programming could also motivate the students as the program can do specific tasks in a microcontroller with a visible result. Lio (2024) has done an evaluation of the flipped classroom used in programming and one of the findings is “the motivated students aggressively accessed the course materials and obtained a better score”. Founded on above studies and own experiences it is relevant to raise these two research questions: **1st research question:** Does a rule-based setup in the LMS system for access to in class slide-materials improve the amount of students answering the quizzes before class as well as uses of the pre class video and pre-class slides?

2nd research question: Is the solution to assignments dependent on the students' engagement with the in-class materials in the LMS?

In the next section the course in the LMS delivering data is described

1.2 The course Digital Electronics and Programming for research

As in general, programming learning software-development for embedded platforms (microcontroller) is pretty much the same. The main difference is the program runs in a small processor (microcontroller), not a PC. The course has been taught, during the last 8 years, as FC or semi-flipped. The course content is both about understanding the hardware and in parallel programming/configuring the controller to perform different tasks on the input-output, serial ports, etc. We use a Learning Management System (LMS), Learn, developed by Brightspace. At Learn the materials are sorted in different folders.

Preparation materials are available in a subfolder to the specific lesson folder and contain a slide series, a video presentation of the slide series, and a quiz and sometimes a demo to exemplify how to write a small program. The quiz questions are questions in the digital electronic, but there are also programming questions ex. true/false or select a correct program-statement among four opportunities about a program statement ex. read a signal level on a physical port or turn on a Light Emitting Diode (LED).

The quiz(es) results are used as an introduction to the lesson where we go through some of the answers at the beginning of the lesson. The video length is between 10 and 15 minutes as suggested in the literature (Baig, Yadegaridehkordi, 2023). Due to the time limitation, there are sometimes 2 or 3 videos for preparation.

We use Discord as a 24/7 online communication tool therefore students can always reach out for help or use it for internal discussion.

Students work in pairs-groups up to three students on four different assignments. The groups hand in a small report documentation for the program and a program. The teacher/supervisor correct each assignment report and the program. Moreover, an example solution will be available for students who have handed in the assignment. The course is evaluated through an oral individual exam. Students answer six general questions related to the curriculum, with 5 minutes to explain a randomly drawn topic. Afterward, additional questions assess program knowledge and understanding. The grade reflects documentation quality, program proficiency, and demonstrated understanding during the exam

2 METHOD AND DATA

For answering the questions raised above, we use empirical data from the LMS system and evaluation of two assignments. We extract a record of data for each student enrolled in the course. The record includes access/clicks on all topics, encompassing access/clicks to the lesson slides, pre-class slides, quiz scores, hand-ins of assignments.

The Table 1, next page, shows year, semester and number of students enrolled and groups in spring semesters. In principle, all enrolled students should access all materials. From the LMS we use the records of data for answering the first question: Does a rule-based setup in the LMS system for access to in class slide-materials improve the amount of students answering the quizzes before Class, as well as uses of the pre class video and pre-class slides? The students in the fall semester are from a winter intake by February and are more diverse, and not everyone is just coming from high school but have been in work before the study started.

Table 1: Data size 2nd semester students enrolled into course 62734

Year	Fall - enrolled	Spring - enrolled	Groups of students
2022	28 students		
2023	29 students	48 students	21 with 43 stud.
2024		68 students	25 with 63 stud.

Whereas the spring semester students are from a fall intake by September and most students are continuing from their high school. In spring 2024, there are 68 students (IT-electronics students together with electro technology students).

The second question: Is the solution to assignments dependent on the students' engagement with the in-class materials in the LMS? This question is answered using two assignments (Assignment 2 and Assignment 3) handed in in week 4 and 6 respectively in spring 2023 and spring 2024. Fulfillment of an assignment requires having a program running on the microcontroller and acceptable quality of documentation. Evaluation data is created as: The quality of documentation is given a rating from 2 for good, 1 for poor, and 0 for not handed in. The program is rated -1 for not running, 0 for not handed in, and 1 for running. As data is not Gaussian distributed, Spearman’s correlation coefficient (named for Charles Spearman) summarizes the strength between the two data samples. For kind of falsification of correlation, data used in this analysis is only from students in groups either lacking a working program or adequate documentation, and those with satisfactory documentation but no working program, as well as groups that have not handed in a program, documentation, or both. Nevertheless, all students access data to in-class slide presentations is correlated with completed hand-in of report and program.

In the following result section, we conduct the data analyses and later in the discussion section we discuss the results.

3 RESULTS

Here, data records extracted from the LMS and data from correcting the tasks are analyzed.

3.1 Preparation by pre-class activity

For answering the first question, we use plots of students’ completeness to pre-class materials in histograms for the first 8 lessons.

Figure 1 on next page shows students' pre-class activity during week 1 to week 8.

On the X-axis, the Module is the lesson in week 1 to 8. The Y scale is the percentage of students who have completeness/accessed the materials listed in the categories shown by the legends.

The legends shown by color for each bar. The color changes for each legend and the first two colored bars are the video, the next two are the quiz, and the last two are the pre-class slide presentation.

- The figure to the left is for fall 2022 (F22) and fall 2023 (F23) covering: video_F23, quiz_F23, and sl_pr_F23 (pre-class slide presentation).
- The figure to the right is for the years: spring 2023 (S23) and spring 2024 (S24).

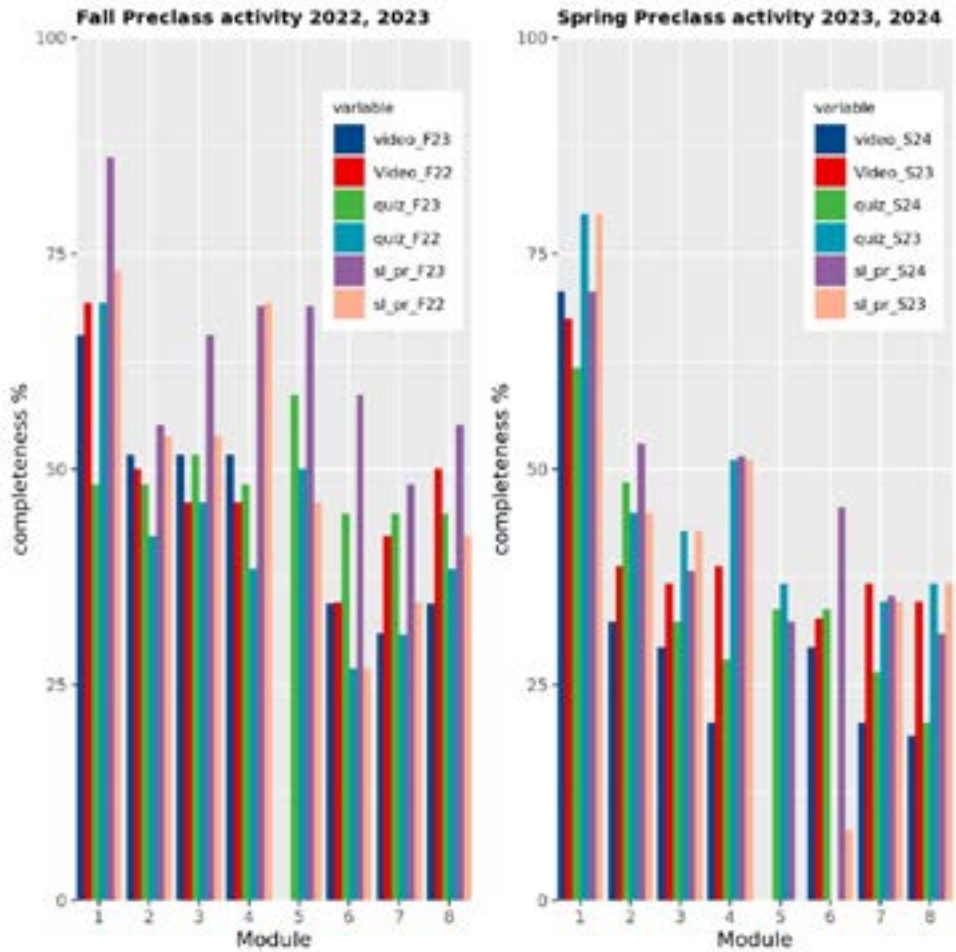

Figure 1: Pre-class activity in fall 2022, 2023, spring 2023, 2024.

The Average value for access for each kind of material is:

- **Video**: video_S24 2024: 29.14 % and for 2023: 38.78% so a decrease by 10%.
- **Quiz**: quiz_S24 2024: 31.25 % and for 2023: 36.36 % a decrease by 5%
- **Pre-class slide series**: sl_pr_S24 2024: 39.81% and for 2023 36.36% an increase by 3%.

Overall, students accessed the pre-class slide presentations improved from S23 to S24 except for lessons: 1,3,8. While video access and quiz scores for all semesters have mixed results depending on the module.

Looking at the left figure for fall 2023 compared to fall 2022; the same picture pre-class slides are used more in 2023 than the previous year. The pre class slide series is together with the video mend as the foundation for the quiz. This is also confirmed by the figure both quiz and pre class slides is accessed more in fall 2023. But in the spring 2024, with some exceptions, it is the opposite picture. Students in 2024 are not complete the quizzes as much as in spring 2023. Looking on the video access, the students in spring 2024 use the video more for preparing than in spring 2023. That could of course be the reasons for not accessing the pre-class slides. Exactly opposite to spring 2023, where the students access the video less. The rule about the quiz to be completed seems not to motivate the students to do more quizzes in spring 2024 compared to spring 2023 where there was no rule. However, in fall 2023 the rule could have an impact on the uses of the materials compared to fall 2022, where there were no rules applied.

3.2 The Slide materials

The figure 2 shows how the students access the in class slides (sl_les22/23/24) and pre class slides (sl_pre22/23/24) in years: 2022, 2023, and 2024. Again, a pair of colors address the two types of slides and the related semesters. The semester term and year is headline for each sub-figure in figure 2. In addition, on the x-axes Module is the lesson from 1 to 8. The slides used in the lesson are used most which also is found by (O. Schultz and T. 2023).For Spring 2024 there is small difference between the slides for preparation (sl_pre24) and slide ls_les24 used in the lesson. Whereas in spring 2023 the difference between access in class and pre class slides, is more than 10%

On average, 42% have accessed the preparations slide presentations in spring 2024, and in spring 2023 only 31% accessed, so an increase of 11%, and for the slide presentations used in the lesson, the average access is 57% in spring 2024 and in spring 2023 78.6%, so a decrease of 21% - reflected in the outstanding purple bars in figure 2 to the right. So, with the rule use less access to the slide presentations and less quiz completed.

Therefore, the rule about the quiz must be done, does not in 2024 motivate students to take the quiz and watch the pre-class slide presentations nor the in-class slide presentations, but in Fall 2023 with the rule used, it results in higher completeness. It could be explained with rules that motivates students.

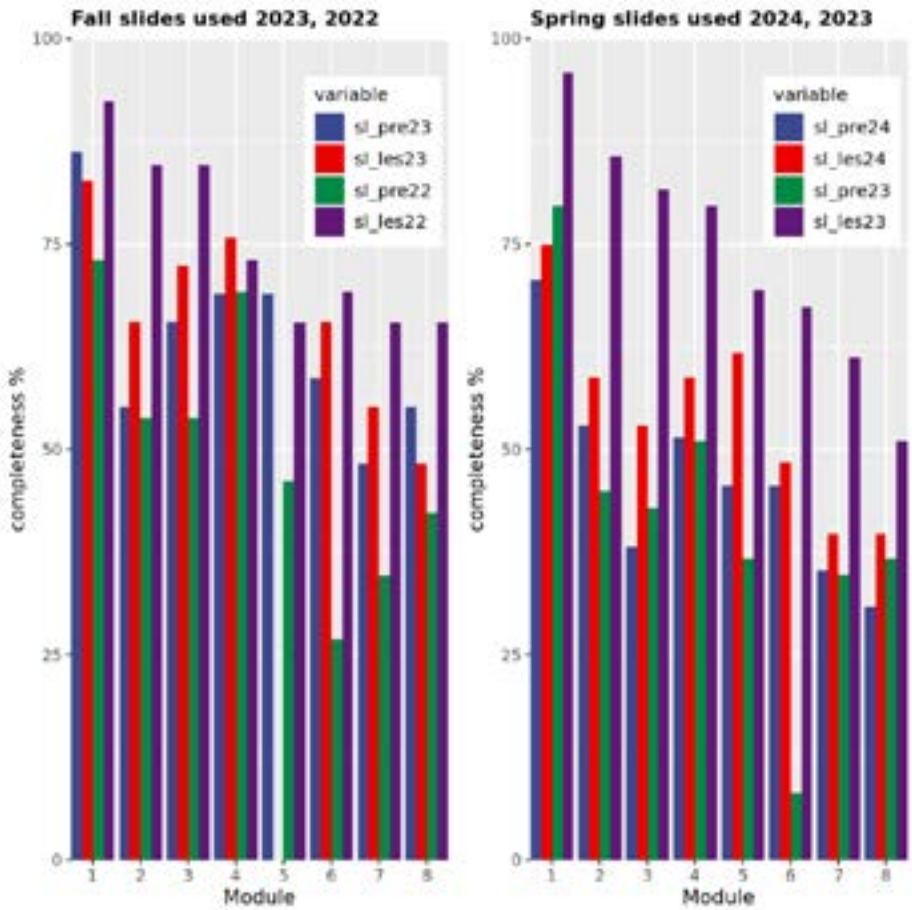

Figure 2: In-class and pre-class slide activity in fall 2022, 2023, spring 2023, 2024.

3.3 Quality of assignment work

Table 2 shows the documentation evaluation data correlated to slide presentations (doc_sl) for lessons, and slide presentations for preparation (doc_psl) and quizzes before class (doc_q). And the program evaluation-data correlation to slides used in class (pro_sl) and slide presentations for preparation (pro_psl). Data is from students not completely full fill assignments as explained in section 2. Spring 2023 no rule for getting access to in class slide presentations. Spring 2024 we use the rule: quiz must be scored before access to in class slide presentations.

Table 2. Correlation coefficients scoring assignments in relation to activity

year	assign	doc_sl	doc_psl	doc_q	pro_sl	pro_psl
Spring 2023	2	0.58	0.51	0.23	-0.27	-0.26
Spring 2024	2	-0.47	-0.16	0.12	0.33	0,21
Spring 2023	3	0.44	0,22	0,36	0,19	-0,36
Spring 2024	3	-0,22	0,073	-0,045	0,015	-0.13

Assign column is referring to assignment 2 and 3 by number.

- Rows spring 2023 -in blue:, there seems to be a weak correlation between the use of slides (doc_sl for lessons, doc_psl slides for pre-class) and the quality of documentation. But the program and slides (columns: pr_sl, pro_psl) does correlate weak negative – confirming programs quality is poor due to not using the hints in the slides.

- Rows spring 2024 – in black, with the rule for accessing slides introduced, there is a weak to none and negative correlation for the quality of documentation. Whereas for the program quality there is a weak correlation 0.33 to the slides for assignment 3 and for assignment 2 correlation of 0.33, which contradicts with the results in spring 2023.In spring 2024 Quality of documentation for assignments has a weak negative correlation to the slide presentations, that can be explained by less uses of the slides confirmed by figure1 and 2.

When using all students' **access data (slide presentations in-class and preparation slide presentation) for spring 2024** correlated to the hand-in of program and journal (for assignment 2) in correlation to the slides used in class it shows correlation by 0.40 and for assignment 3 hand-in correlated to in class slides by 0.28. In addition, **data for spring 2023** for assignment 2 close to zero correlation 0.060 whereas assignment 3 has a correlation to slides in class by 0.35. This confirms using the materials helps students to fulfill hand-in of assignments.

4 Discussion

The results shown in Figures 1 and 2, where we compare two different semesters in fall 2023 and 2022, and spring 2023 and 2024, indicate that, in general, there is less activity in 2024 compared to 2023, particularly for pre-class material in Figure

1. The rule setting, where a quiz must be scored before access to the lesson slides, does not seem to have any significant effect on activity in the Spring semester.

However, in the fall, there are up to 20% more students scoring on quizzes, and the pre-class slides series is more frequently visited. However, in spring 2024, where the rule is active, even the quiz scores are less than in spring 2023, except for lesson 2.

Figure 2 illustrates the difference between slides used for preparation and those used in the lesson. The rule for accessing the lesson slide series in spring 2024 does not motivate the students to do the quiz before class. However, opposite in the fall 2023 where activity was 10 to 20% higher compared to fall 2022 without any rule. Therefore, perhaps there is a motivation factor by the rule. That could lead to the conclusion on first question: "Does a rule-based setup in the LMS system for access to in class slide-materials improve the amount of students answering the quizzes before class as well as uses of the pre class video and pre-class slides". For the fall 2023, rule-based access improves the access to quizzes and materials, whereas in 2024 it seems not to have much influence. Conclusion on the points to the rule based assess can have an impact for some kind of students.

The other question: "Is the solution to assignments dependent on the students' engagement with the in-class materials in the LMS?". From table 2 we find there is in the positive correlation between the documentation quality and slides used in class for the spring 2023 and for spring 2024 a negative correlation between documentation quality and access to the slides used in class. In addition, the program quality has a positive correlation to the slides used in class for spring 2024 and opposite for the spring 2023.

When we look at completeness of assignment 2, 3 spring 2024, and correlated with completeness/access for slide presentations used in class there is a positive correlation between hand-in of the assignment and access to slide presentations.

When relate that to the first question then we must conclude the rule does not help all students, but the more students use the slide presentations, the better quality of the assignments and completeness.

Regarding these results, one challenge with the pre-class activity and the programming assignment is that students are evaluated on the assignment report and the program running in the microcontroller, and there is not any tight coupling with the content on Learn. Ex. the material mainly for pre-class activity is about the digital electronics part and the general concept of the microcontroller not about programming. The assignment can be completed using resources like ChatGPT, which are accessible without login. This allows students to get immediate assistance with their tasks. The quizzes mirror the oral exam's theoretical questions, making them good practice. However, Schultz & Blaszczyk (2023) found no link between quiz performance and final grades. Similarly, quiz usage did not correlate with the quality of programming or documentation in the evaluated tasks (see table 2).

5. Conclusions

The research questions regarding whether a rule setup can motivate students to be more prepared by doing quizzes and thereby using the supplied materials are addressed in the work presented here, drawing on data from the LMS system. There is a tendency to suggest that the rule could motivate to do the quiz before class; however, it also presents challenges for students who haven't scored on the quiz and are thereby unable to access the slides for hints, consequently affecting their ability to fulfill the assignment. A correlation analysis between individual students' data from the LMS and the scores of assignments shows a weak correlation between the program running in the microcontroller and the use of slide presentation in the lesson. Students can complete the quiz by using the pre-class slide presentations, but the videos are not utilized as much. Nonetheless, the changes observed are minor. Therefore, other ways to motivate the students should in the future be tried in this course.

REFERENCES

Journal Article with DOI

Baig M. I, Yadegaridehkordi E.. "Flipped classroom in higher education: a systematic literature review and research challenges", International Journal of Educational Technology in Higher Education. 20:61. (2023) DOI: https://doi.org/10.1186/s41239-023-00430-5

Gabryella Rodrigues, Ana Francisca Monteiro,António Osório "Introductory Programming in Higher Education (2022) A Systematic Literature Review".Openaccess Series in Informatics, Volume 102, pp. 4 (2018).

DOI: https://doi.org/10.4230/OASIcs.ICPEC.2022.4

Gökçe Akçayıra, Murat Akçayırb. "The flipped classroom: A review of its advantages and challenges". Computers & Education 126, p 334–345

He, Wenliang; Holton, Amanda;Farkas, George;Warschauer, Mark."The effects of flipped instruction on out-of-class study time, exam performance, and student perceptions". Learning and Instruction, volume 45. p. 61-71. (2016)

DOI: 10.1016/j.learninstruc.2016.07.001

He,Wenliang ; Holton ,Amanda ; Farkas, George ; Warschauer, Mark “The effects of flipped instruction on out-of-class study time, exam performance, and student perceptions”. Learning and Instruction Volume 45, October 2016, Pages 61-71

Hendrik, H. Hamzah, Almed. “Flipped Classroom In Programming Course: A Systematic Literature Review”.International Journal of Emerging Technologies in Learning. Volume 16, Issue 2, pp. 220-236. (2020) DOI: https://doi.org/10.3991/ijet.v16i02.15229

Lopes, Sergio Francisco Sargo Ferreira; Gouveia, Luís Manuel Borges Reis, Pedro Alexandre da Cunha.” The Flipped Classroom and Higher Education - Experiences with Computer Science Students”.International Journal of Advanced Engineering Research and Science. Volume 6.p 13-18. (2019) DOI: 10.22161/ijaers.610.3

Lundin, Mona; Bergviken, Rensfeldt, Annika; Hillman, Thomas; Lantz-Andersson, Annika; Peterson, Louise. “Higher education dominance and siloed knowledge: a systematic review of flipped classroom research”International Journal of Educational Technology in Higher Education. Volume 15, Issue 1, pp. 20. (2018)

Rasheed A. K., Amirrudin A., Nor A. K., Habeebah A. A., Auwal S. M., Ahmad S. Yahaya A. S..“Self-Regulated Learning in Flipped Classrooms: A Systematic Literature Review”. International Journal of Information and Education Technology Volume 10, Pages 848-853. (2020) DOI: 10.18178/ijiet.2020.10.11.1469

Rosnizam Eusoff, Abdullah Mohd Zin, Syahanim Mohd Salleh. “A Flipped Classroom Framework for Teaching and Learning of Programming”. International Journal on Advanced Science, Engineering and Information Technology. Volume 12, Issue 2, pp. 539-549. (2022) DOI: 10.18517/ijaseit.12.2.14909

Rosnizam Eusoff, Syahanim Mohd Salleh, Abdullah Mohd Zin. “Implementing Flipped Classroom Strategy in Learning Programming”. International Journal of Advanced Computer Science and Applications, Vol. 12, No. 10. (2021)

Sobral, S. R.. Flipped classrooms for introductory computer programming courses. International Journal of Information and Education Technology, 11(4), 178–183. (2021) DOI: https://doi.org/10.18178/ijiet.2021.11.4.1508

Siripongdee, K., Pimdee, P., & Tuntiwongwanich, S.. A blended learning model with IoT-based technology: Effectively used when the COVID-19 pandemic? Journal for the Education of Gifted Young Scientists, 8(2), 905–917. (2020) DOI: https://doi.org/10.17478/JEGYS.698869

Conference paper with DOI:

Schultz, O., & Blaszczyk, T.. Generation Z and their use of learning management system in programming. In G. Reilly, M. Murphy, & B. V. Nagy (Eds.), Book of Proceedings for the 51st Annual Conference of the European Society for Engineering Education (pp. 2852-2860). European Society for Engineering Education (SEFI). (2023) DOI: 10.21427/3X3S-YV20

Proceedings: Lio, J.. An Evaluation of the Flipped Classroom Approach Toward Programming Education. Journal of Information Processing, 32, 159–165. (2024) DOI: https://doi.org/10.2197/ipsjjip.32.159

chatGBT4 has been used for spelling and grammar correction.

ENHANCING STUDENT ENGAGEMENT AND DEEP LEARNING THROUGH INNOVATIVE LEARNING STRATEGIES IN ENGINEERING EDUCATION: POINT-BASED GAMING (PBG) FRAMEWORK

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ABSTRACT

Gamification in a learning environment can positively impact student engagement, commitment, motivation, and deep learning. Conventional teaching methods have shown a deficiency in actively engaging students with their learning and helping them gain a profound and lasting understanding of the contents. This practice paper introduces a learning innovation framework for implementing point-based gaming (PBG) to improve student engagement and learning in the apprenticeship advanced mechanical engineering modules. The effectiveness of this pedagogy is evaluated based on the mark of their final individual assessment compared to the outcome achieved through the traditional teaching method. Previous evaluations have shown that more than 90% of students actively engage with the activities and find them fun and engaging. Based on the results, an increase in academic performance was observed compared to the previous delivery model, which did not incorporate these active methods, with the fail rate reduced by 28% and the number of students achieving a first-class mark increased by over 35%. Implementing PBG also helped achieve a high-quality education based on the Ofsted lesson observation model. This approach can be applied to other engineering courses, empowering instructors to enhance students' experiences by engaging them to think, feel, and act.

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1 INTRODUCTION

Conventional lectures in higher education are based on a teacher-centred approach, with the lecturer primarily responsible for delivering and transmitting knowledge to students. The large cohort sizes (100+ students) typical of Science, Technology, Engineering and Mathematics (STEM) courses often mean that teaching sessions are heavily reliant on a lecture-based format (Cho et al. 2021). In this traditional classroom setting, students play a passive role in their learning, where limited opportunities exist for students to ask questions (van Alten et al. 2019) or to interact with the lecturer or their peers, thus hindering opportunities to develop higher-order critical thinking and transferable skills. Moreover, lectures are considered ineffective in catering to different student needs and learning styles (Howell 2021; Lax et al. 2017).

The lack of motivation and engagement from students has been linked to poor academic achievement, demonstrating the crucial roles that engagement plays in student learning (Metzger and Langley 2020). The lack of social and intellectual stimulation within the traditional classroom setting can result in academic boredom (Sharp et al. 2020). It leads students to believe the topic is tedious and challenging. Students can quickly become disengaged in the class and lose interest in the subject matter entirely.

Various works have explored a shift from this teacher-centred approach to student-centred learning over the last decade to overcome these challenges. (Freeman et al. 2014). Using student-centred strategies such as *Active learning* has reported increased academic performance, particularly within the engineering field, where hands-on activities are crucial in applying theoretical concepts to real scenarios and developing the soft skills required by graduates (Garcia et al. 2020).

However, transitioning to a student-centred approach requires an initial time investment from the lecturer. The amount of work needed to plan and design such activities is more significant than traditional approaches (Howell 2021), and lecturers are required to develop the technical and pedagogical competencies needed to implement such learning environments effectively (Das Neves et al. 2021).

1.1 Active Learning

In active learning (AL) approaches, the student takes a proactive role in their learning, and the teacher now acts as a facilitator rather than the sole transmitter of knowledge. AL activities promote higher-order thinking, student interaction with their peers, creativity and reflection. These activities include case studies, team-based exercises, simulations, games, practical labs and flipped classrooms. Engaging students in these cognitive activities allows them to retain at a higher level (Savin et al. 2023) and to develop other transferable skills.

The use of active learning in higher education has been widely explored in several disciplines, with an increase in student achievement observed as a result of implementing active learning strategies despite the field of study (Sumanasekera et al. 2020; Kozanitis and Nenciovici 2022; Ting et al. 2023).

Practical labs, problem-based learning (PBL), and project-based learning (PBL) are some of the most commonly used active learning activities in engineering education. These activities are well suited to exploring scenarios found in real-life engineering projects (Das Neves et al. 2021). For example, López-Fernández et al.

demonstrated a positive impact on student motivation in an Aerospace postgraduate module through the use of PBL (López-Fernández et al. 2019).

The use of these active learning strategies has also been linked to the development of professional competencies (Hernández-de-Menéndez et al. 2019). Gómez-del-Rio et al. used a combination of lab sessions and PBL in a Mechanical Design undergraduate module, enabling students to improve their skills and competencies as part of the learning outcomes (Gomez-del Rio and Rodriguez 2022).Other active learning strategies, however, such as game-based learning, are less popular when teaching advanced engineering subjects.

1.2 Game-based Learning

Games are a powerful platform for change, increasing productivity, optimism, social connections, and the desire for an epic win (McGonigal 2011). Using games in the classroom can spark friendly competition and cooperation among peers, creating an engaging environment that supports students' learning (Plump and LaRosa 2017). This active learning approach of embedding games as part of the learning process is known as game-based learning (GBL). Games in educational settings can range from traditional board games such as puzzles, crosswords, quizzes, etc. (digital or non-digital) to computer-based or video games designed to meet specific course learning outcomes.

For the implementation of digital-based games, readily available platforms exist, a popular one being Kahoot (Mohammad Zadeh et al. 2024; Knight et al. 2022), which allows for game-based quizzes to be created by the teacher and deployed and answered by students through their mobile phones, with scores and leaderboards presented. Plump and LaRosa reported on the use of this platform in undergraduate business courses, noting an increase in student engagement and willingness to ask follow-up questions (Plump and LaRosa 2017).

It is important to note that these games must be accompanied by appropriate training and reflection. Bado emphasises that pre-game and post-game stages are needed for these tools to be practical. Students should be briefed on how to use the technologies and their purpose before using them, and debriefings should follow to discuss, clarify, and reflect on them (Bado 2022).

1.3 Aims and Objectives

Engineering Degree Apprenticeships (DAs) are transformative courses that combine working in industry (on-the-job learning) while studying for an academic degree at university. The development of knowledge, skills, and behaviours (KSBs) required for occupational competence in a job role is at the core of the course. Therefore, active learning approaches can be more beneficial in these courses to ensure effective learning. This work aims to introduce point-based gaming (PBG) through the implementation of a gamification approach in engineering degree apprenticeship modules for enhancing student engagement and deep learning, and comparison with conventional teaching methods. To evaluate the effectiveness of this method, we considered the mark of the final assessment for both PBG and traditional methods in delivering an advanced mechanical engineering module as a success criterion for students achieving the ILOs.

2 METHODOLOGY

Gamification is the application of game principles in a non-gaming context to enhance engagement (Deterding et al. 2011; Huotari and Hamari 2017). Game characteristics can help us achieve an effective learning environment (Sandford et al. 2006).We developed a point-based gaming (PBG) model that utilises the specifics of gamification that contribute to learning, such as low-stakes opportunities to practice, rapid disconfirmatory feedback, and support for cooperative social learning.

The PBG means students play as part of the team and anonymous characters, achieving points for different levels. Ultimately, the ones at the top of the leaderboard gain the trophy. As the levels progress, the points increase exponentially so that the students who could not achieve the points in the first activities do not lose hope, keep their engagement, and try for the epic win. Figure 1 illustrates the student-centred learning innovation flowchart and the four main stages of the PBG. This strategy is helpful for block delivery of modules (modules that are delivered in five full teaching days), a common delivery model in apprenticeship courses.

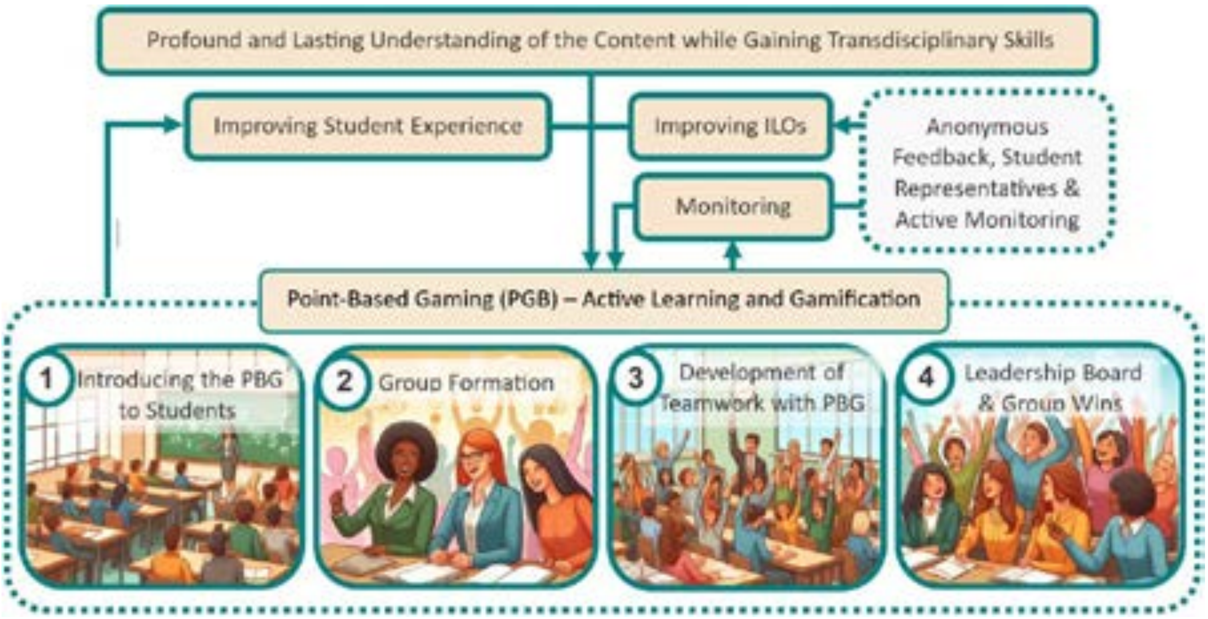


Figure 1. The flow chart of the student-centred learning innovation PBG pedagogy applied in this study, including setting a proper objective, improving the intended learning outcomes (ILOs) and student learning experience, implementing PBG, active learning and game-based learning, and monitoring and applying the changes—the arts in the flow chart are AI-generated using Microsoft Copilot.

This framework is an adaptation of the learning innovation operation, which consists of three main phases: designing, implementation and monitoring (Sancassani et al. 2018). This design aims to give the students a more profound and lasting understanding of the content by providing proper activities (point-based prizes), media, and resources. In this framework, the lecturer's focus is not just on selecting the content but also on designing the entire learning experience so that the students improve their transversal competencies: collaboration, creativity, communication, critical thinking, and a transdisciplinary mindset (Akimov et al. 2023), the ability to find connections among disciplines to solve current challenges or to provide new solutions (McLay et al. 2023). One important goal is to ensure that attending class can be more fun, engaging, and motivating for students and lecturers.

As presented in Figure 1, the PBG consists of four steps. First, the lecturer must introduce the PBG and the importance of having fun while learning to achieve a lasting understanding of the content to the students (Mayer et al. 2013). Students need to be reminded that these points are not marks and will not affect their marking and assignments. In the second step, students are asked to form groups and participate in the PBG activities. They may resist forming a functional group for the first activity, but step three usually resolves this issue.

In step 3, it is essential to motivate teamwork by introducing game rules that dedicate triple points for a team with all active members (interactions within each group) and times 100 points for them if they present their solution to the class (group interactions). As a result, students start forming a functional group. In step 4, it is time to introduce the leadership board, which records the student points throughout the day. The group with the highest number of points wins. The monitoring phase and confirmation are done with the help of student representatives, an anonymous feedback platform and active monitoring of students' reactions and engagement during the class. It is fundamental for the learning process.

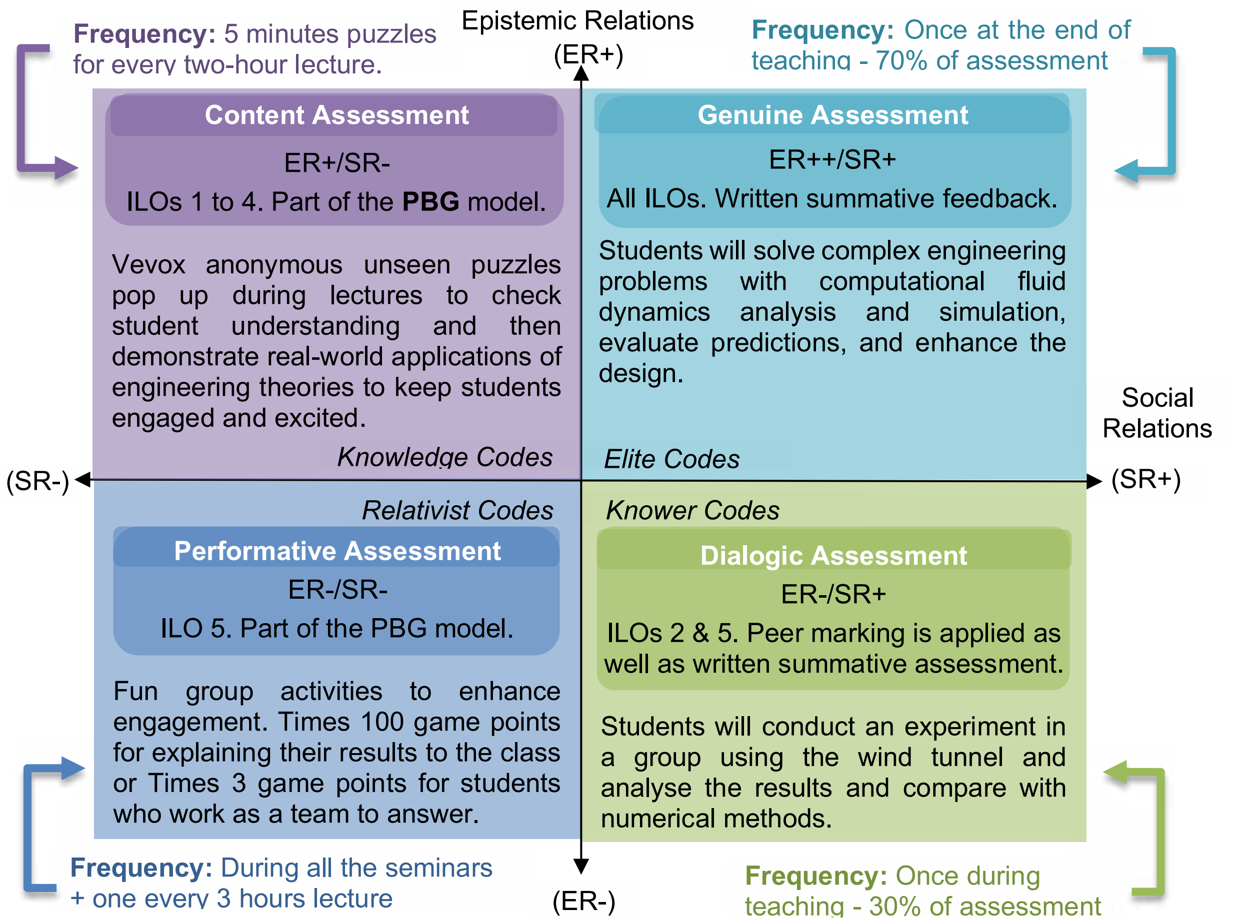
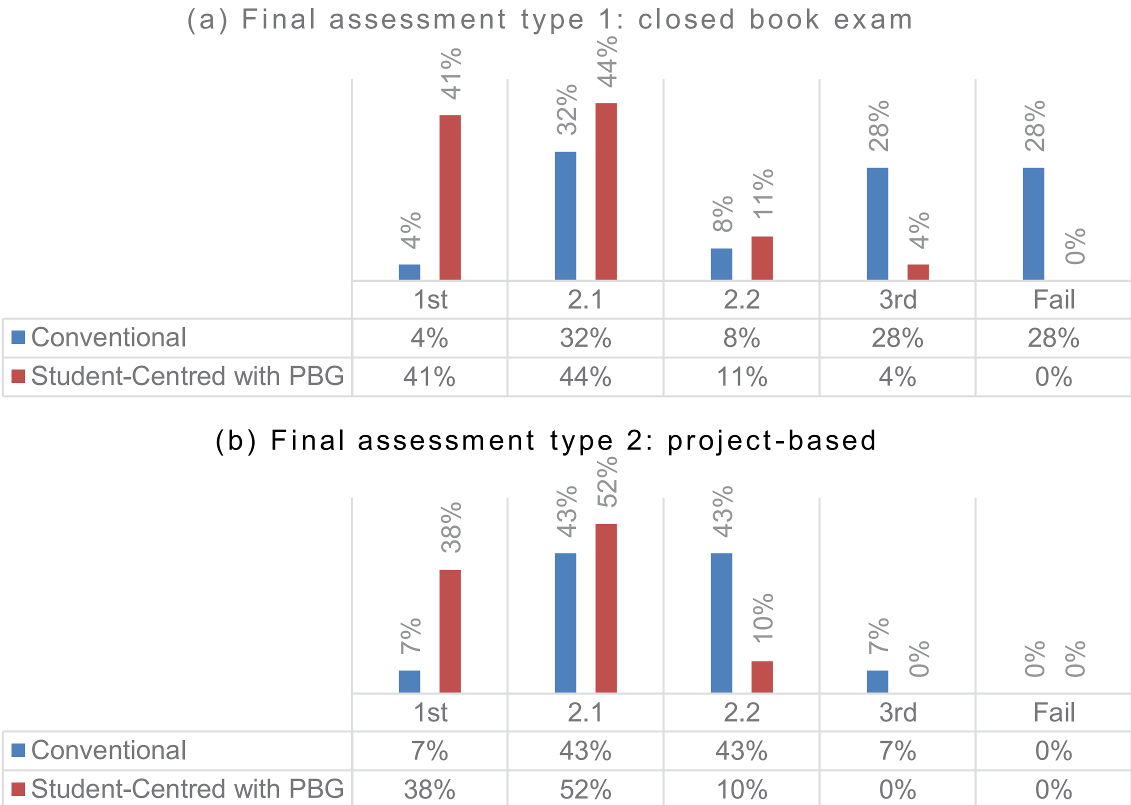


Figure 2. A framework of assessment inquiry specialisation plane was adapted from Maton (Maton 2013; Forde-Leaves et al. 2023) *and they are applied to the case study of this paper for the advanced engineering module. The ILOs for this module are to solve complex engineering problems and optimise design parameters (ILO1), critically examine different experimental and numerical data (ILO2), examine different assumptions for simplifying complex engineering problems (ILO3), apply innovative ideas into designs and examine their efficiency (ILO4), and demonstrate the ability to function effectively as an individual or as a member or leader of a team (ILO5).*

The content of PBG depends on the module and can be applied to different fields. The activities must include active learning, short anonymous quizzes, industry-related and real-life applications, theories, and calculations. Hence, they solve the activities using different tools, from the traditional paper and whiteboard to the Vevox platform and Engineering software packages. During the PGB activities, it is important that the focus is on deep learning, and they can link theories to real-life problems. Figure 2 presents the assessment inquiry specialisation plane adapted from Maton (Forde-Leaves et al. 2023; Maton 2013; Kukuczka 2024) for the case study of this practice paper. This plan includes the summative assessments, the PGB activities, their link to the ILOs, and their focus and frequency.

3 Results and Discussion

To evaluate the effect of PBG on student learning, the mark of the final assessment is considered for two types of assessment: type 1 is a closed book exam, and type 2 is a project-based assessment. For each type, the results are shown for two cohorts, one after conventional teaching and another after teaching based on the learning innovation method, including PGB. The content, level, and student entrance criteria to the degree are similar. Figure 3 presents the final assessment grade distribution results for the case studies.



	1st	2.1	2.2	3rd	Fail
Conventional	4%	32%	8%	28%	28%
Student-Centred with PBG	41%	44%	11%	4%	0%

	1st	2.1	2.2	3rd	Fail
Conventional	7%	43%	43%	7%	0%
Student-Centred with PBG	38%	52%	10%	0%	0%

Figure 3. Grade distribution differences of the final exam of an apprentice cohort with a conventional teaching method versus a cohort with a learning innovation method, which includes the PBG, for two assessment types: (a) closed book exam as the final assessment (70%), (b) project-based assignment as the final assessment (70%). These cohorts are skilled and well-experienced, which led them to achieve such an impressive performance.

It is important to point out that various factors of the learning innovation method influenced this change in learning performance, with PGB playing an effective part in it as well. The innovative learning method helped improve students' performance significantly for both closed-book and project-based final assessments. The number of students attending the class is 25 for both cases in the type 1 assessment. The results show a 37% increase in the 1st grade and a 12% increase in 2.1. The second assessment type also follows a similar trend: a 31% increase in the number of students in the 1st grade and a 9% increase in 2.2.

As expected, gamification incorporates essential components that are effective for learning and addresses the teacher's concerns regarding motivating students, their participation, and voluntary commitments.(Paciarotti et al. 2021). This framework also helps to achieve a high-quality education based on Ofsted criteria in-class observation (Ofsted 2019) especially in three key areas, by providing consistent opportunities to practice previously learned skills and knowledge, using appropriate technology and resources to clarify the meanings, and effectively checking for understanding through anonymous quizzes.

To ensure the success of this strategy, two factors must be considered while designing the core activities. First, the topics should be linked to engineering design practice and natural occurrences of relevant phenomena. Second, they apply to real-world challenges, active learning, and engagement. In the PBG activities, students were encouraged to answer the class activities in groups of three. These points were not related to any of the module's formal marks and were only defined to motivate students to participate in the game, which led to high engagement of the attendees for each day. It had previously been observed that following a conventional approach, only a few students would volunteer to participate in the activities or present their answers. Usually, only a few specific students participated in the conventional method.

PBG was incorporated into another module and had a similar response. Based on the module feedback, 91% to 95% of students found the subject exciting and intellectually stimulating and gained interdisciplinary skills to bring information and ideas together from different topics. Student achievement of the learning outcomes was evaluated using two assessments, including a group project assignment and an exam.

4 CONCLUSION

Creating an environment that promotes engaging and innovative learning experiences enhances students' interactions with the teacher and course materials, leading to better academic outcomes. This work presented a learning innovation framework for the point-based gaming (PBG) method in an advanced mechanical engineering course. The effects of PGB activities on academic performance were investigated by comparing the final assessment marks for two types of teaching: conventional and learning innovation-based with PBG. Apart from the enhanced student engagement and motivation, a significant increase in academic performance was achieved, with over 30% in the number of students achieving the 1st grade and a 10% increase in 2.1. This framework also helps to achieve a high-quality education based on the Ofsted criteria in-class observation. Another advantage of PBG is cost and time efficiency; it does not require high game design quality or support. This practice demonstrates the impact of incorporating PBG in delivering advanced engineering subjects.

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REFERENCES

Akimov, Nurken, Nurlan Kurmanov, Assel Uskelenova, Nazgul Aidargaliyeva, Dinara Mukhiyayeva, Saule Rakhimova, Bagdat Raimbekov, and Zhuldyz Utegenova. 2023. “Components of Education 4.0 in Open Innovation Competence Frameworks: Systematic Review.” *Journal of Open Innovation: Technology, Market, and Complexity* 9 (2): 100037. https://doi.org/10.1016/J.JOITMC.2023.100037.

Alten, David C.D. van, Chris Phielix, Jeroen Janssen, and Liesbeth Kester. 2019. “Effects of Flipping the Classroom on Learning Outcomes and Satisfaction: A Meta-Analysis.” *Educational Research Review* 28 (March): 1–18. https://doi.org/10.1016/j.edurev.2019.05.003.

Bado, Niamboue. 2022. “Game-Based Learning Pedagogy: A Review of the Literature.” *Interactive Learning Environments* 30 (5): 936–48. https://doi.org/10.1080/10494820.2019.1683587.

Cho, Hyun Jin, Kejie Zhao, Cho Rong Lee, Debra Runshe, and Chuck Krousgrill. 2021. “Active Learning through Flipped Classroom in Mechanical Engineering: Improving Students’ Perception of Learning and Performance.” *International Journal of STEM Education* 8 (1). https://doi.org/10.1186/s40594-021-00302-2.

Deterding, Sebastian, Dan Dixon, Rilla Khaled, and Lennart Nacke. 2011. “From Game Design Elements to Gamefulness: Defining ‘Gamification.’” *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, MindTrek 2011*, 9–15. https://doi.org/10.1145/2181037.2181040.

Forde-Leaves, Natalie, Jack Walton, and Ken Tann. 2023. “A Framework for Understanding Assessment Practice in Higher Education.” *Assessment & Evaluation in Higher Education* 48 (8): 1076–91. https://doi.org/10.1080/02602938.2023.2169659.

Freeman, Scott, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. 2014. “Active Learning Increases Student Performance in Science, Engineering, and Mathematics.” *Proceedings of the National Academy of Sciences of the United States of America* 111 (23): 8410–15. https://doi.org/10.1073/pnas.1319030111.

Garcia, Ivan, Carla Pacheco, Francisco Méndez, and Jose A. Calvo-Manzano. 2020. “The Effects of Game-Based Learning in the Acquisition of ‘Soft Skills’ on Undergraduate Software Engineering Courses: A Systematic Literature Review.” *Computer Applications in Engineering Education* 28 (5): 1327–54. https://doi.org/10.1002/cae.22304.

Gomez-del Rio, T., and J. Rodriguez. 2022. “Design and Assessment of a Project-Based Learning in a Laboratory for Integrating Knowledge and Improving Engineering Design Skills.” *Education for Chemical Engineers* 40 (February): 17–28. https://doi.org/10.1016/j.ece.2022.04.002.

Hernández-de-Menéndez, Marcela, Antonio Vallejo Guevara, Juan Carlos Tudón Martínez, Diana Hernández Alcántara, and Ruben Morales-Menendez. 2019. “Active Learning in Engineering Education. A Review of Fundamentals, Best Practices and Experiences.” *International Journal on Interactive Design and Manufacturing* 13 (3): 909–22. https://doi.org/10.1007/s12008-019-00557-8.

Howell, Rachel A. 2021. “Engaging Students in Education for Sustainable Development: The Benefits of Active Learning, Reflective Practices and Flipped Classroom Pedagogies.” *Journal of Cleaner Production* 325 (June): 129318. https://doi.org/10.1016/j.jclepro.2021.129318.

Huotari, Kai, and Juho Hamari. 2017. “A Definition for Gamification: Anchoring Gamification in the Service Marketing Literature.” *Electronic Markets* 27 (1): 21–31. https://doi.org/10.1007/S12525-015-0212-Z/TABLES/4.

Kukuczka, J. 2024. Designing assessment with LCT adapted from Forde-Leaves et al, 2023 and Maton, 2014. Unpublished learning material.

Knight, G., N. Powell, and G. Woods. 2022. “Combining Diagnostic Testing and Student Mentorship to Increase Engagement and Progression of First-Year Computer Science Students.” *European Journal of Engineering Education*, September. https://doi.org/10.1080/03043797.2022.2063109.

Kozanitis, Anastassis, and Lucian Nenciovici. 2022. “Effect of Active Learning versus Traditional Lecturing on the Learning Achievement of College Students in Humanities and Social Sciences: A Meta-Analysis.” *Higher Education*. https://doi.org/10.1007/s10734-022-00977-8.

Lax, Neil, James Morris, and Benedict J. Kolber. 2017. “A Partial Flip Classroom Exercise in a Large Introductory General Biology Course Increases Performance at Multiple Levels.” *Journal of Biological Education* 51 (4): 412–26. https://doi.org/10.1080/00219266.2016.1257503.

López-Fernández, Daniel, José Miguel Ezquerro, Jacobo Rodríguez, Jeff Porter, and Victoria Lapuerta. 2019. “Motivational Impact of Active Learning Methods in Aerospace Engineering Students.” *Acta Astronautica* 165 (May): 344–54. https://doi.org/10.1016/j.actaastro.2019.09.026.

Maton, Karl. 2013. “Knowledge and Knowers: Towards a Realist Sociology of Education.” *Knowledge and Knowers: Towards a Realist Sociology of Education*, January, 1–244. https://doi.org/10.4324/9780203885734.

Mayer, Igor, Harald Warmelink, and Geertje Bekebrede. 2013. “Learning in a Game-Based Virtual Environment: A Comparative Evaluation in Higher Education.” *European Journal of Engineering Education* 38 (1): 85–106. https://doi.org/10.1080/03043797.2012.742872.

McLay, Katherine Frances, Lauren Thomasse, and Vicente Chua Reyes. 2023. “Embracing Discomfort in Active Learning and Technology-Rich Higher Education Settings: Sensemaking through Reflexive Inquiry.” *Educational*

Technology Research and Development 71 (3): 1161–77. https://doi.org/10.1007/S11423-023-10192-6/METRICS.

Metzger, Kelsey J., and David Langley. 2020. “The Room Itself Is Not Enough: Student Engagement in Active Learning Classrooms.” *College Teaching* 68 (3): 150–60. https://doi.org/10.1080/87567555.2020.1768357.

Mohammad Zadeh, Maryam, Luke J. Prendergast, Jonathan D. Tew, and Daniel Beneroso-Vallejo. 2024. “Conceptualising Engineering Student Perceptions of Synchronous and Asynchronous Online Learning.” *European Journal of Engineering Education* 49 (1): 94–112. https://doi.org/10.1080/03043797.2023.2201178.

Neves, Renato Martins Das, Rui M. Lima, and Diana Mesquita. 2021. “Teacher Competences for Active Learning in Engineering Education.” *Sustainability (Switzerland)* 13 (16): 1–21. https://doi.org/10.3390/su13169231.

Ofsted. 2019. “How Valid and Reliable Is the Use of Lesson Observation in Supporting Judgements on the Quality of Education.” www.gov.uk/government/publications/education-inspection-framework-overview-of-research.

Paciarotti, Claudia, Gabriele Bertozzi, and Martin Sillaots. 2021. “A New Approach to Gamification in Engineering Education: The Learner-Designer Approach to Serious Games.” *European Journal of Engineering Education* 46 (6): 1092–1116. https://doi.org/10.1080/03043797.2021.1997922.

Plump, Carolyn M., and Julia LaRosa. 2017. “Using Kahoot! In the Classroom to Create Engagement and Active Learning: A Game-Based Technology Solution for ELearning Novices.” *Management Teaching Review* 2 (2): 151–58. https://doi.org/10.1177/2379298116689783.

Rogers, Everett M, Arvind Singhal, and Margaret M. Quinlan. 2014. “Diffusion of Innovations.” *Taylor & Francis Group*, April, 432–48. https://doi.org/10.4324/9780203887011-36.

Rounsevell, M D A, P J Loveland, T R Mayr, A C Armstrong, Diego de la Rosa, J.-P. Legros, Catalin Simota, and H Sobczuk. 2013. “Supporting Teachers in the Process of Adoption of Game Based Learning Pedagogy,” October, 156–62. https://doi.org/10.13039/501100000780.

Sancassani, Susanna, Paolo Marenghi, and Daniela Casiraghi. 2018. “A Multi-Scale Approach to Learning Innovation Design.” *EDEN Conference Proceedings* 0 (1): 475–82. https://doi.org/10.38069/edenconf-2018-ac-0061.

Sandford, Richard, Ben Williamson, and Ben Williamson Futurelab. 2006. “Futurelab: Games and Learning.” *Futurelab*. www.futurelab.org.uk.

Savin, Michele, Curry Bordelon, Colleen Moss, and Lela Baker. 2023. “Using Active Learning to Evaluate Student Competency Beyond Clinical Skills.” *Journal for Nurse Practitioners* 19 (5): 104596. https://doi.org/10.1016/j.nurpra.2023.104596.

Sharp, John G., Jane C. Sharp, and Emma Young. 2020. “Academic Boredom, Engagement and the Achievement of Undergraduate Students at University: A

Review and Synthesis of Relevant Literature.” *Research Papers in Education* 35 (2): 144–84. https://doi.org/10.1080/02671522.2018.1536891.

Sumanasekera, Wasana, Chase Turner, Kaven Ly, Philip Hoang, Travis Jent, and Thimira Sumanasekera. 2020. “Evaluation of Multiple Active Learning Strategies in a Pharmacology Course.” *Currents in Pharmacy Teaching and Learning* 12 (1): 88–94. https://doi.org/10.1016/j.cptl.2019.10.016.

Ting, Fridolin S.T., Ronnie H. Shroff, Wai Hung Lam, Raycelle C.C. Garcia, Chi Lok Chan, Wing Ki Tsang, and Ndudi O. Ezeamuzie. 2023. “A Meta-Analysis of Studies on the Effects of Active Learning on Asian Students’ Performance in Science, Technology, Engineering and Mathematics (STEM) Subjects.” *Asia-Pacific Education Researcher* 32 (3): 379–400. https://doi.org/10.1007/s40299-022-00661-6.

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MixedLAB: Mixed Reality to Teach Students Experimental Knowledge in Microfabrication

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Conference Key Areas: *Digital tools and AI in engineering education, educating the whole engineer: teaching through and for knowing, thinking, feeling and doing*
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ABSTRACT

We are developing a new approach to leverage Mixed Reality (MR) affordances for teaching microfabrication processes, such as performed in a cleanroom. Our goal is to design interactive MR content to improve microfabrication and cleanroom training practices. MR presents a promising avenue as it allows hands-free interaction with the system and diminishes cognitive load when learning complex content. We

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incorporate diverse learning techniques such as real-time feedback, scaffolding, simulations, inquiries, and multimodal interactions to enhance the efficacy and feasibility of educational practices in the design of applications. In a course about microfabrication in bachelor curriculum, we carried out hands-on training sessions in a real cleanroom environment. By the end of the course, five students completed their experiments. We observed that MR was effective in customizing learning experiences and increasing student engagement. Additionally, MR proved helpful for teaching assistants in clarifying complex concepts and phenomena related to the fabrication tools during practical sessions. Although the small sample size limits our ability to draw definitive conclusions, initial qualitative assessments and post-training evaluations suggest that integrating MR into practical engineering education holds great promise.

1 INTRODUCTION

1.1 Background

Learning microtechnology/nanotechnology (Micro/Nano-tech) can be difficult because of its multi- and interdisciplinary nature (i.e., a mixture of biology, physics, math, chemistry, and engineering). Microfabrication faces complicated teaching and learning problems. There is a significant demand in well-trained workforce, yet educational institutions often lack the necessary infrastructure. Students find it difficult to integrate knowledge from these diverse fields and to apply it to the 'invisible' micro-scale. Many are hesitant to operate in laboratory settings due to the intricacies involved. Microfabrication not only demands a grasp of these foundational concepts but also the development of practical skills through hands-on laboratory experiences. However, equipping a lab with the required facilities, including a cleanroom, alongside ensuring safety training and the availability of skilled personnel, poses its own set of challenges.

1.2 Literature Review

Extended reality (XR) is growing rapidly in a range of industries and education (Fortman and Quintana 2023). XR is the overarching term that encapsulates current and future development in virtual reality (VR), augmented reality (AR), and mixed reality (MR) (Logeswaran et al. 2021). The application of XR in engineering and STEM education is increasingly diverse and impactful. For instance, AR has been effectively utilized in chemistry lab experiments to enhance learning and training (Chen and Liu 2020), (Dinc et al. 2021), (Domínguez Alfaro et al. 2022). Besides, AR also has the potential to make abstract concepts more tangible, as demonstrated in physics (Radu et al. 2023), (Radu and Schneider 2019), or bioscience education (Reeves et al. 2021). In the context of VR education, VR supports mathematics education through embodied learning mechanisms, enhancing students' engagement and understanding (Chatain et al. 2023), problem-solving skills (Halabi 2020), etc. MR has been shown to improve learning outcomes across various STEM subjects, offering interactive and immersive experiences. In the field of microfabrication specifically, research is currently more limited but still noteworthy. For example, an accessible VR ecosystem provides immersive education in nanotechnology (Kamali-Sarvestani et al. 2020), and a recent MR application has been developed for microfluidics courses (De Micheli et al. 2022). The complex and interdisciplinary nature of microfabrication, which integrates elements of physics, chemistry, and mathematics, presents unique challenges in translating theoretical concepts into practical applications for students. XR technologies, therefore, offer promising solutions to these educational challenges by making intricate and often invisible aspects of microfabrication more accessible and understandable.

As for the pedagogical methods, mixed-method combines the qualitative and quantitative approaches to provide a comprehensive understanding (Borrego, Douglas, and Amelink 2009), which has been applied associated with XR studies (Johnson-Glenberg and Megowan-Romanowicz 2017). Additionally, core theories in learning sciences, such as Kolb's Experiential Learning Theory, emphasize the importance of hands-on training, enabling students to benefit from concrete experiences (Kolb 2014). The concept of scaffolding, introduced by Bruner, involves providing essential instructional support that gradually decreases as learners become more proficient (Bruner 2009). The use of interactive media in XR is particularly intriguing because it can dynamically and personally adjust this scaffolding. The idea of productive failure is activating the prior knowledge and attention to a hidden efficacy through the designed failures (Kapur 2008). These educational foundations have been widely applied across various topics((Fleischer et al. 2023), (Hou and Keng 2020), (Quintana et al. 2004), demonstrating their effectiveness in enhancing learning outcomes through XR technologies.

2 METHOD – APPLICATION DESIGN AND MODULES

In this practice paper, we introduce *MixedLAB*, an MR application designed to blend virtual and real environments for microfabrication learning. Unlike fully virtual simulations, *MixedLAB* complements physical experiments by bridging the gap between theory and hands-on practice. This tool allows students to visualize and understand complex processes before performing actual experiments, thereby boosting their confidence and competence.

By integrating MR tools like MixedLAB into our teaching, we preserve the irreplaceable value of tactile, hands-on learning while enhancing it with digital technology. This innovative approach promises to equip future engineers and scientists with the knowledge and skills needed to excel in an increasingly complex and interdisciplinary field.

Many MR and AR applications focus on replicating real-world interactions with high-fidelity and immersive environments. However, they often fall into the trap of emphasizing technological affordances over the student’s learning experience. To avoid this, we began our project design by conducting interviews and semi-structured investigations among students learning microfabrication. This helped us ensure that our design meets the real needs of students.

MixedLAB, designed for MR headsets like the HoloLens (Microsoft), utilizes the Microsoft Mixed Reality Toolkit (MRTK) to support specific learning scenarios in microfabrication. It offers a set of experiences that supplement the practical modules assigned by educators, with each module focusing on a specific skill or knowledge area in microfabrication. Additionally, the system's content can be customized for other subjects, making it versatile for broader educational applications. To address the high development costs of AR within Unity, we created an administrative platform that allows teachers to modify content, significantly reducing future development time and costs.

2.1 Description of *MixedLAB*

The present study applies a co-design methodology (Sanders and Stappers 2008), which invites the stakeholders into the design process, including teachers, researchers, and students.

The iterative process began with the definition of the educational need, which is to better teach students experimental knowledge with a deeper understanding. Besides, after the co-design process, we selected several topics that are fundamental and challenging since they require both theoretical knowledge and experimental experience. Subsequently, a low-fidelity prototype was created and evaluated. For this process, 8 students and researchers in engineering participated in a think-out-loud study and completed usability questionnaires. The think-out-loud process helped define problems in the first version such as no direct feedback and response after interacting with buttons, voice inputs are not intuitive, etc.

It is worth noting that after the first pilot study, we found that several topics such as photolithography in microfabrication are suitable for MR learning. This topic was chosen in the case study as it is one of the typical and fundamental experiments done repeatedly in introductory courses of both undergraduate and graduate curricula. Furthermore, students struggle to understand the phenomena and reactions during the fabrication process while operating advanced equipment because of the lack of visibility.

2.2 Application Design Principles

Figure 1 displays different screenshots from *MixedLAB's* learning modules. These codes, integral to physical, real-world scenarios, allow for an overlay of digital information, like visualizations and auditory feedback, directly onto actual experiences. When participants scan a placed QR code, *MixedLAB* guides them through relevant learning modules, such as substrate pre-treatment steps. The subsequent paragraphs will delve into how the application, adhering to essential learning science principles, was developed:

Scaffolding: The term “scaffolding” is used in learning science to refer to support designed to help participants learn productively in problem-solving contexts (Fischer 2018). We designed virtual representations that gradually display and support participants from different perspectives. For example, to help students understand why Hexamethyldisilane (HMDS) treatment does not work on chromium surfaces, we start by zooming in to show 3D structures of molecules at the nanoscopic level. Finally, we conclude and guide them through the experimental processes (Figure 1. a, b).

Real-time feedback: In practices, it is common that one teaching assistant (TA) needs to coach students in a group, which results in neglecting individual students’ needs and questions. However, the idea of *MixedLAB* is as participants engage in tasks, they receive immediate, contextual information about their actions. For instance, if a student makes a mistake, the system guides him/her to understand and correct it. This instantaneous feedback ensures that all the participants are engaged and learn through the interactive representations (Figure 1. c).

Personalized learning trajectory: In *MixedLAB*, personalized learning trajectory tailors the educational experience to each participant’s unique needs and learning speed in the MR affordances. It accommodates different learning styles and speeds, making the study of experimental practices more efficient and effective, as students can better focus on what they need for their improvement. At the same time, the system tracks students’ performance data such as their attempts on questions, time spent on the single questions, etc. Researchers can analyze students’ log data to adapt to the level of difficulties and problems students mostly struggle with (Figure 1. d).

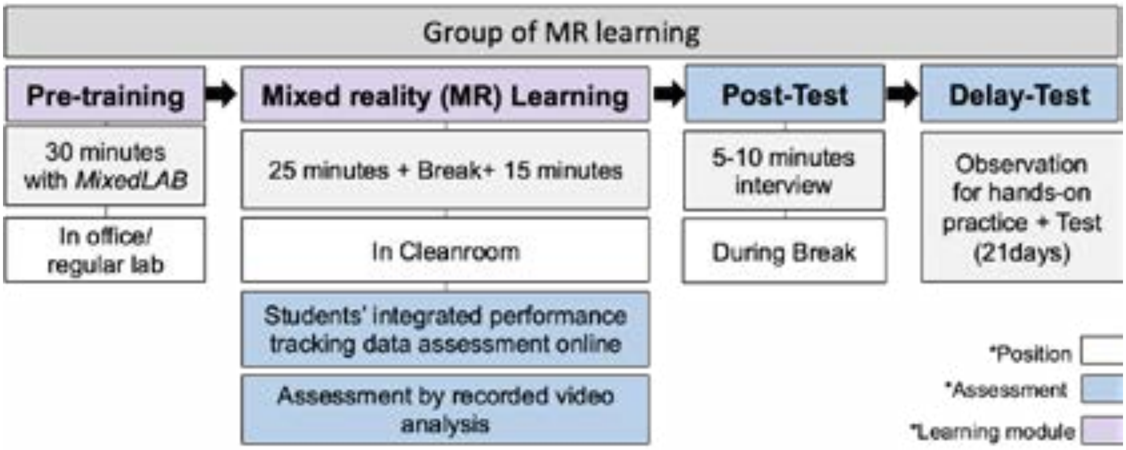
Reward system of gamification: Incorporating a rewarding system of gamification into the application enhances engagement and motivation in learning and has been used a lot in XR educational applications (Díaz et al. 2019). We applied a reward system to the questions to encourage students to answer the questions quickly and correctly. The participants' initial attempts at the task will be recorded. If they answer correctly within the allotted time, they will earn a golden coin. However, if they answer after the time limit, they will receive a silver coin instead. In this case, students are still allowed to explore different options but still get rewards for performances. This gamified approach makes the learning process more enjoyable and stimulating, encouraging continuous participation and effort (Figure 1. c).

Figure 1. First-person engagement with different design functionalities inside the MixedLAB application: (a) While learning pre-treatment in photolithography, it provides 3D model representations to display the reactions behind the theory. (b) A screenshot of the spin coating module process flows to finish the steps, which reminds participants to check their process and “check” virtually on the button. (c) A screenshot of real-time feedback and reward coins from the integrated quizzes. (d) A screenshot after selecting wrongly in the previous quiz step, a further explanation with simultaneous graphics and text are displayed.

3 METHOD – APPLICATION DESIGN AND MODULES

3.1 Participants and Curriculum

Once the Human Research Ethics Committee approved our proposed experiment (No: HREC000439), we invited undergraduate students to enrol in the practical course for microfabrication. Eight of the twelve undergraduate students participated



in the experiment voluntarily ($N_{class}=12$, $N_{MR}=8$). The students were invited to take part in the pre-training for HoloLens one week before the experiment. Each participant spent around 30 minutes on the 'playground' designed for them in the same *MixedLAB* application to get familiar with the basic functions. No participant reported their discomfort during the pre-training. Ultimately, five students were able to conduct the experiments due to scheduling conflicts. We obtained their consent before participation and assigned each a code to anonymously track their performance via the application. It is important to note that this performance tracking did not affect their official course grades, and no personal information was required to ensure anonymity. The entire process is illustrated in Figure 2.

Figure 2. Process flow of participation

3.2 Results and Discussion

Because of the low number targeted participants, we did not take the between-subjects comparison to split the volunteers into two conditions. Instead, we

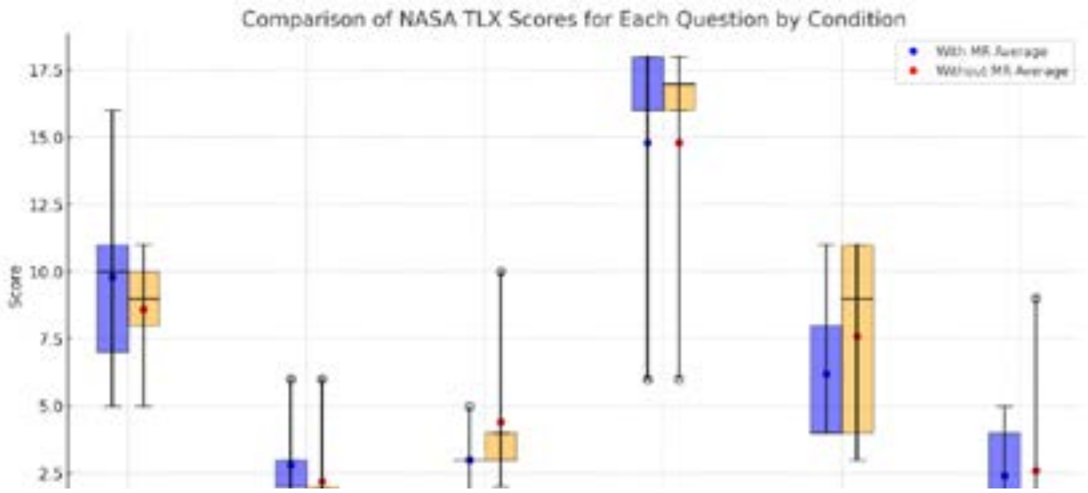


Figure 3. NASA TLS comparison between two conditions: students performed experiment with MR and then tested their knowledge without MR in the same environment after 21 days

calculated the NASA Task Load Index (TLX) (Hart and Staveland 1988) cognitive load of MR condition and Non-MR condition by within-group comparison in Figure 3. Although the result is not significant, we can still extract that it is slightly more physically demanding, and mentally demanding in MR condition. On the other hand, it is less temporal demanding, less frustrating, less stressful, and requires less effort but with higher successful performance.

In Table 1, We conducted semi-structured interviews with the students (see Table 1) to help researchers better understand which features of MR in engineering education students enjoyed. And those quotes are selected removing "no comments" and redundant feedback. From the table, we could interpret that students benefit from practical learning, personalized learning, interactions, etc. Also, we could see that experimenting with MR is unexpectedly natural and presenting differently compared with the classroom. As Figure 4 and Figure 5 depict that students are working individually with virtual guidance, this also coincides with their qualitative feedback (as P4 says).

Table 1. Feedback from students with semi-structure interview

Questions	Code	Voice answers transcripts
How do you feel after a mixed reality experience?	P3	"It is fun, it is really good, and it **changes from the classroom**."
	P1	"It is **natural**, actually I **can't really feel it**, I know where is dangerous and this makes me **feel safe**."
	P2	"In general, I am feeling good and it's **really fun**…"
What is the good part of the *MixedLAB* application for you?	P2	"I like it when you have the video **presenting something wrong** with sound effects that is bad (subsequence)."
	P3	"You can **see the stuff you have to do at the same time** as what you (are) do, if you are confused at something the instructions just by your side, you don't have to do in new place, a lot of paper of stuff."
	P4	"The best thing for me is I can **learn on my own pace**, I feel comfortable when I am learning. Sometimes when I feel it is fast, I am a little bit scary to say this is too fast so I missed a bit of something. But with HoloLens (*MixedLAB*), I wouldn't be because it was so interesting and I would like to know all the details provided…… I was swimming in it."
	P5	"At first, **I didn't expect this work well on me**… But, I can really learn practices that is not included in the classroom through this … I want to learn something practical, this could be good."
What do you think of the system embedded in practical teaching?	T1	"For me, it **saves a lot of energy and time**, I also joined the design so I know for those procedures I just need to observe the students' performances and focusing more on answering their creative questions, and check if they are making any serious mistakes…"
*T is the general code for teaching assistant, and *P is the general code for participants		

Fig. 4. A group of students learn and interact with MixedLAB individually

Fig. 5. Hands-free engagement with the digital panel in the cleanroom

4 SUMMARY AND OUTLOOK

In this paper, we introduced MR in engineering education, specifically microfabrication, and conducted a practice course with a small group of students. Due to the limited number of participants, we cannot state any certain conclusion. However, this practice paper allows us to explore more on the affordances provided by MR and conclude the efficient design principles and learning science principles that are aligned with them. Specifically, students enjoyed the personalized learning trajectory, the multi-media scaffolding compared to how they learn in class. The MR seems to work well if designed properly to guide them with scaffolds and experimental knowledge such as potential risks and failure, correct process, and various TA's experience. We can also conclude that students feel engaged with the MR tool while doing their experiment and it is a unique opportunity for students to bridge practical and theory simultaneously. We encourage to apply MR-assisted learning in practical experiments when students know they are safe in the environment and the instructions can be designed to distinguish virtualism and reality. Through qualitative analysis, it is worth knowing that for some subjects personalized MR-assisted learning could trigger higher confidence and achievement.

Besides, by reducing the time and effort required for TAs to provide individualized support, MR allows for more efficient and effective instructional practices. It would be promising to see whether MR enables TAs to focus more on direct interaction with students, offering timely feedback and guidance. Additionally, it is worth examining if students receive better support and personalized attention, enhancing their understanding and engagement.

Inspired by this study, we will follow up with a subsequent phase study focusing on how embodiment affects students' learning outcomes with MR, especially for conceptual understanding. Also, we will focus more on TAs' responses and tiredness while collaborating with MR tools. Ultimately, we aim to apply our concept to different experimental knowledge learning scenarios, which may lead to more efficient engineering education and science education.

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REFERENCES

Borrego, Maura, Elliot P. Douglas, and Catherine T. Amelink. 2009. “Quantitative, Qualitative, and Mixed Research Methods in Engineering Education.” *Journal of Engineering Education* 98 (1): 53–66. https://doi.org/10.1002/j.2168-9830.2009.tb01005.x.

Bruner, Jerome S. 2009. *The Process of Education, Revised Edition*. Harvard University Press.

Chatain, Julia, Rudolf Varga, Violaine Fayolle, Manu Kapur, and Robert W. Sumner. 2023. “Grounding Graph Theory in Embodied Concreteness with Virtual Reality.” In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction*, 1–13. Warsaw Poland: ACM. https://doi.org/10.1145/3569009.3572733.

Chen, Shih-Yeh, and Shiang-Yao Liu. 2020. “Using Augmented Reality to Experiment with Elements in a Chemistry Course.” *Computers in Human Behavior* 111 (October):106418. https://doi.org/10.1016/j.chb.2020.106418.

De Micheli, Andrea J., Thomas Valentin, Fabio Grillo, Manu Kapur, and Simone Schuerle. 2022. “Mixed Reality for an Enhanced Laboratory Course on Microfluidics.” *Journal of Chemical Education* 99 (3): 1272–79. https://doi.org/10.1021/acs.jchemed.1c00979.

Díaz, Paloma, Andri Ioannou, Kaushal Kumar Bhagat, and J. Michael Spector, eds. 2019. *Learning in a Digital World: Perspective on Interactive Technologies for Formal and Informal Education*. Smart Computing and Intelligence. Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-8265-9.

Dinc, Furkan, Aryadeepta De, Ayanna Goins, Tansel Halic, Marsha Massey, and Faith Yarberry. 2021. “ARChem: Augmented Reality Based Chemistry LAB Simulation for Teaching and Assessment.” In *2021 19th International Conference on Information Technology Based Higher Education and Training (ITHET)*, 1–7. https://doi.org/10.1109/ITHET50392.2021.9759587.

Domínguez Alfaro, Jessica Lizeth, Stefanie Gantois, Jonas Blattgerste, Robin De Croon, Katrien Verbert, Thies Pfeiffer, and Peter Van Puyvelde. 2022. “Mobile Augmented Reality Laboratory for Learning Acid–Base Titration.” *Journal of Chemical Education* 99 (2): 531–37. https://doi.org/10.1021/acs.jchemed.1c00894.

Fischer, Frank, ed. 2018. *International Handbook of the Learning Sciences*. New York, NY: Routledge.

Fleischer, Timo, Stephanie Moser, Ines Deibl, Alexander Strahl, Simone Maier, and Joerg Zumbach. 2023. “Digital Sequential Scaffolding during Experimentation in Chemistry Education—Scrutinizing Influences and Effects on Learning.” *Education Sciences* 13 (8): 811. https://doi.org/10.3390/educsci13080811.

Fortman, Jacob, and Rebecca Quintana. 2023. “Fostering Collaborative and Embodied Learning with Extended Reality: Special Issue Introduction.” *International Journal of Computer-Supported Collaborative Learning*, July. https://doi.org/10.1007/s11412-023-09404-1.

Halabi, Osama. 2020. “Immersive Virtual Reality to Enforce Teaching in Engineering Education.” *Multimedia Tools and Applications* 79 (3): 2987–3004. https://doi.org/10.1007/s11042-019-08214-8.

Hart, Sandra G., and Lowell E. Staveland. 1988. “Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research.” In *Advances in Psychology*, edited by Peter A. Hancock and Najmedin Meshkati, 52:139–83. Human Mental Workload. North-Holland. https://doi.org/10.1016/S0166-4115(08)62386-9.

Hou, H., and Su-Han Keng. 2020. “A Dual-Scaffolding Framework Integrating Peer-Scaffolding and Cognitive-Scaffolding for an Augmented Reality-Based Educational Board Game: An Analysis of Learners’ Collective Flow State and Collaborative Learning Behavioral Patterns.” *Journal of Educational Computing Research* 59:547–73. https://doi.org/10.1177/0735633120969409.

Johnson-Glenberg, Mina C., and Colleen Megowan-Romanowicz. 2017. “Embodied Science and Mixed Reality: How Gesture and Motion Capture Affect Physics Education.” *Cognitive Research: Principles and Implications* 2 (1): 24. https://doi.org/10.1186/s41235-017-0060-9.

Kamali-Sarvestani, Reza, Paul Weber, Marty Clayton, Mathew Meyers, and Skye Slade. 2020. “Virtual Reality to Improve Nanotechnology Education: Development Methods and Example Applications.” *IEEE Nanotechnology Magazine* 14 (4): 29–38. https://doi.org/10.1109/MNANO.2020.2994802.

Kapur, Manu. 2008. “Productive Failure.” *Cognition and Instruction* 26 (3): 379–424. https://doi.org/10.1080/07370000802212669.

Kolb, David A. 2014. *Experiential Learning: Experience as the Source of Learning and Development*. FT Press.

Logeswaran, Abison, Chris Munsch, Yu Jeat Chong, Neil Ralph, and Jo McCrossnan. 2021. “The Role of Extended Reality Technology in Healthcare Education: Towards a Learner-Centred Approach.” *Future Healthcare Journal* 8 (1): e79–84. https://doi.org/10.7861/fhj.2020-0112.

Quintana, Chris, Brian J. Reiser, Elizabeth A. Davis, Joseph Krajcik, Eric Fretz, Ravit Golan Duncan, Eleni Kyza, Daniel Edelson, and Elliot Soloway. 2004. “A Scaffolding Design Framework for Software to Support Science Inquiry.” *Journal of the Learning Sciences* 13 (3): 337–86. https://doi.org/10.1207/s15327809jls1303_4.

Radu, Iulian, Xiaomeng Huang, Greg Kestin, and Bertrand Schneider. 2023. “How Augmented Reality Influences Student Learning and Inquiry Styles: A Study of 1-1 Physics Remote AR Tutoring.” *Computers & Education: X Reality* 2:100011. https://doi.org/10.1016/j.cexr.2023.100011.

Radu, Iulian, and Bertrand Schneider. 2019. “What Can We Learn from Augmented Reality (AR)?: Benefits and Drawbacks of AR for Inquiry-Based Learning of

Physics." In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–12. Glasgow Scotland Uk: ACM. https://doi.org/10.1145/3290605.3300774.

Reeves, Laura E., Edward Bolton, Matthew Bulpitt, Alex Scott, Ian Tomey, Micah Gates, and Robert A. Baldock. 2021. "Use of Augmented Reality (AR) to Aid Bioscience Education and Enrich Student Experience." *Research in Learning Technology* 29 (January). https://doi.org/10.25304/rlt.v29.2572.

Sanders, Elizabeth B.-N., and Pieter Jan Stappers. 2008. "Co-Creation and the New Landscapes of Design." *CoDesign* 4 (1): 5–18. https://doi.org/10.1080/15710880701875068.

Can you Teach Cell Biology using Computer Simulations?

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Keywords: *Cell Biology, Modelling, Simulations.*

ABSTRACT

Computational modelling is important in the life sciences, but students may not be greatly exposed to it in typical curricula. This paper describes an innovative, one-semester Master's level course in cell biology that uses computer simulations as the primary learning tool. The course originated in the idea that performing simulations can increase students' biological insight by animating static textbook/blackboard images into dynamical life. The students identify a cellular behaviour and carry out simulation-based exercises, culminating in a semester project. In addition to mastering the course material, the students develop proficiency in transversal skills: they learn to disassemble the complexity of a living cell, and recreate it in a model; they use computers to probe biological questions, thereby developing their computational thinking; and they become aware of the computational resources and data management issues necessary to manage large data sets. Working in teams on a project helps improve their scientific collaboration and communication skills. These skills are highly transferable to other domains of research and industry. This course provides evidence that simulation-based teaching can enhance students' learning, and prepare them for careers in subjects such as cell biology that might not be obvious candidates for simulation-based learning.

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1 INTRODUCTION

In creative writing, a good novel delivers more than you might expect. A good course in science or engineering can do the same. Cell biology is an experiment-heavy discipline that generates large amounts of data, and it requires experience to manage both theory and data efficiently. However, within life science lecture courses, students are often exposed only to the static pictures that appear in textbooks or light and electron microscopy images. Because the world outside the classroom is more dynamic and complex than textbook images, how can students learn the core subject matter of cellular biology, and acquire proficiency in transversal skills such as model abstraction, data management, and hypothesis generation and testing?

This paper describes an innovative course in cellular biophysics — Computational Cell Biology that uses computer simulations as the main learning tool. A recent highly-cited meta-analysis of simulation-based learning has shown it to be beneficial in engineering curricula (Chernikova et al. 2020). Simulation-based learning in general may include role-playing scenarios, such as medical interventions, expertise development (Jossberger et al. 2022) as well as computer-based simulations. In the present paper, I restrict the discussion here to computer simulations carried out on digital computers, for which the students are required to set up, run, and analyse the results of the simulations.

Computer simulations have been used for many years to study complex dynamical systems, and this has led to the idea of Systems Dynamics Modelling (https://systemdynamics.org). This discipline focuses on quantitatively capturing the interactions, feedback, and evolution of complex systems in computer models. Although this perspective provides a more complete understanding of dynamical systems, it is not necessarily simple to persuade people of this (Senge 2020). In specific fields, simulations have been used to present introductory biology to non-biology students in STEM subjects (Kohn et al. 2018); to simulate processing of stone in mining (Akkoyun 2017); and econometric modelling (Fu et al. 2022). Training engineers in modelling and simulations is increasingly recognised as important (Magana 2017). These studies demonstrated the benefits for students of manipulating and analysing large datasets. Fu et al. (2022) showed that both high-achieving and lower-achieving students benefit from the transversal skills acquired in using simulations. Student motivation also increases when they are able to select and carry out their own simulation projects (Datta et al. 2010). In the course described in the present work, the core biological subject matter is encountered by the students through modelling and simulations. They acquire a range of transferable skills that are applicable to many data-heavy subjects. Funding agencies including the EU and Swiss National Science Foundation require applicants to prepare Data Management Plans before giving funding, and acquiring skills in data handling has become essential in laboratory work, industry, and large collaborative projects.

2 METHODOLOGY

2.1 Aims in setting up the course

I created the course Computational Cell Biology (CCB) in 2018 because I believe that computer simulations can be an effective tool for students in life sciences to gain insight into cellular dynamics by constructing a model and exploring its behaviour.

This active use of modelling provides opportunities for greater skill development and understanding than lectures alone. An innovative aspect of the CCB course is that it utilises three disparate components: 1) blackboard presentation of the core cell biology; 2) a quantitative study of mathematical models of typical cell biological dynamics, e.g., diffusion as a random walk; 3) a semester-long use of computer simulations, including the need to manage the large amounts of data produced. The students use the provided simulation tool to generate data on a cell biological model they construct. They analyse their data, and write up the work as a scientific paper which they present to the class at the end of the semester.

One challenge of this approach is revealed by the background quiz given in the first lecture. This samples what they already know about the biology, chemistry, mathematics, and numerical analysis that form the theoretical content of the course. The class is usually small (10 - 25 students, Fig. 1), and although the majority of the students are in the Faculty of Life Sciences, there are usually 1-2 from other faculties, such as mathematics, physics or materials science. At least half the students are female. One of the background questions is: *I prefer to think of biological questions in terms of a) equations, or b) experiments that reveal their behaviour*. Routinely, fewer than half the responses select a), showing that mathematical modelling of cell biology is not a common way of thinking for Master's students in the subject. I have observed that for many students it is the first time they have set up and run a simulation. For a sizeable minority, it is the first time they execute a programme from the command line of their laptop.

The teaching elements of the course are selected to help students develop transversal skills in abstraction, simulations, and managing large amounts of data, all while learning the core material. Active learning techniques are used in the lectures to help the students surmount their unfamiliarity with simulations. The need to work in groups to complete the project promotes a sense of engagement during the course. Students' progress is assessed in several ways: in class tests reveal how well students assimilate the core biology; but a greater weight is given to the homework exercises and project, which measure their learning in areas which I believe are more useful for their subsequent careers.

3 RESULTS

3.1 How has the course evolved?

Learning to use a complex software tool is difficult, and the learning curve is lowered when student share their knowledge with each other as they progress. The lectures and exercise periods have a dual use — presentation of the core cell biology, and preparing students for their project. Active learning opportunities have been increased over the years, and ideas on research data management incorporated. These have increased the students' transversal skills. Think-Pair-Share (TPS) opportunities allow the students to connect an abstract theoretical idea to concrete examples. This often reveals that although students may be able to describe a concept (e.g., diffusion), they have difficulty in generalising it beyond the cartoon picture in a textbook. TPS appears to enhance students' ability to *translate* a theoretical picture of cell biology into a working model.

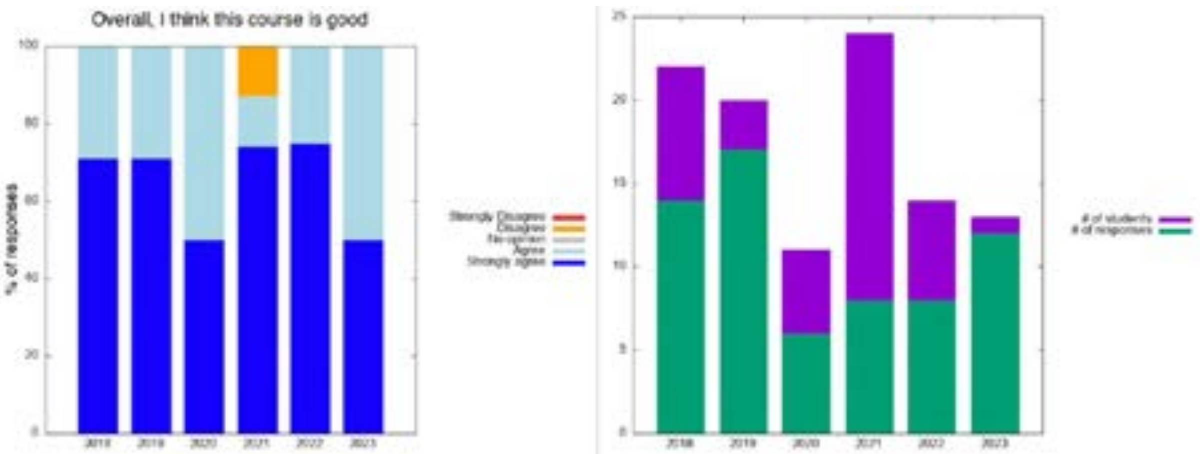

Figure 1. a) Overall student satisfaction with the course is high, and b) student feedback response rate is typically above 50%, indicating a high motivation level for the teaching style.

Feedback from the students consistently shows that they value this style of learning (Fig. 1a), and more than 50% of the students usually participate in the course evaluation, which also indicates their commitment (Fig. 1b). During the covid period (2020/21), another active feedback element was added to the course. After each (online) lecture, I asked the students to send me an email containing what they thought were the “Important Points” of the lecture. I would start the following lecture by presenting what I believe to be the Core Concepts, and we would discuss the similarity/differences between their views and mine. Now that the course is in person, I have retained the core concepts because students indicated that it helped them better assimilate the theoretical material.

During the exercise period, scaffolding exercises in the first 2-3 weeks lead students into the first homework exercise in which they perform simulations in their own time. The simulation tool is provided to the students, and is available on github (https://github.com/Osprey-DPD/osprey-dpd). Each year, one or two students download it and explore it further themselves. Because the codebase is around 500,000 lines of C++, they typically do not modify it, but they gain an appreciation for the complexity of simulation codes. Homework exercises, which usually require tens of simulations, prepare the students to manage their projects, which are 50% of the final grade. An additional benefit of the homework simulations is that students learn to anticipate the volume of data their project will generate. Even creating a naming scheme for the hundreds of files produced by their simulations can be overwhelming as well as tedious, and data management is a key transversal skill in research. Data Management Plans (DMP) are becoming a requirement of the Swiss National Science Foundation and the European Commission’s funding programmes. I introduce the concept of a DMP and the FAIR principles for managing research data: data should be annotated so that it is Findable, Accessible, Interoperable, and Reusable (see, for example, https://dmptool.org/general_guidance).

The students report in the annual course evaluation that the mixed nature of the teaching elements stimulates their interest in the material (Fig. 2a), although the workload is found to be challenging (Fig. 2b). The transversal skills are assessed as important for their future careers in academic and industrial research. This is supported by student comments (some text has been removed for brevity):

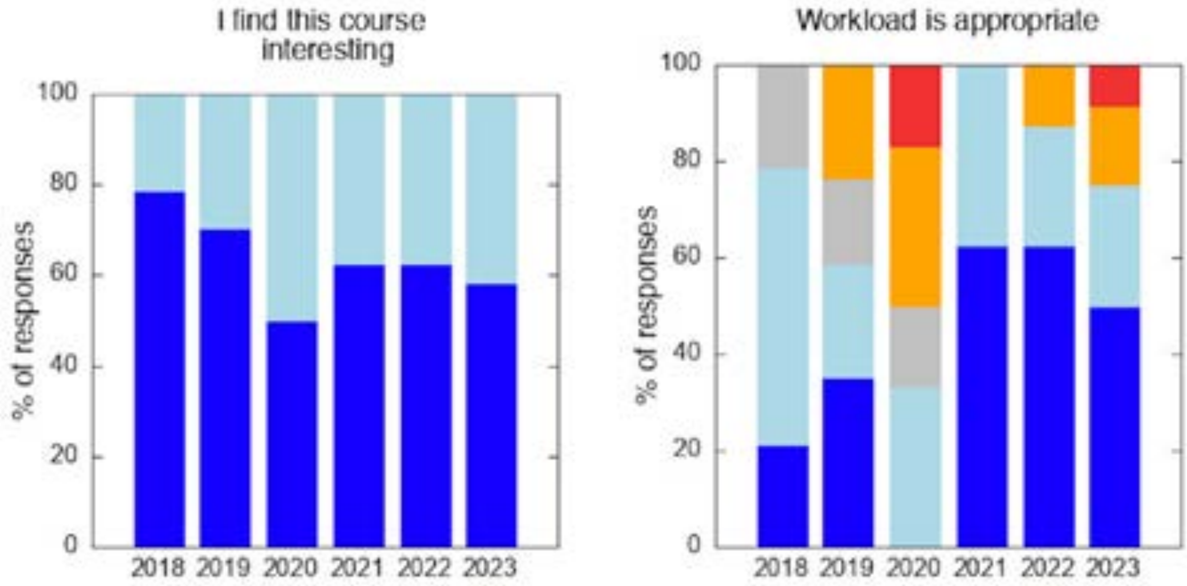

Figure 2. a) The course is consistently found to be interesting. This is attributed by the students to the mix of exercises, theory, and class discussions. b) The workload is found to be challenging, but overall manageable. (Color coded responses as in Figure 1.)

2023 I found this course interesting since we had exams to assess what we saw in the lectures, and projects to work on the computational side. I learned a lot about computational cell biology and biophysics and I am interested in learning more.

2020 Great course to give intuition about the concepts governing behaviour at the cellular scale. One of the only courses trying to bring together different disciplines in such a useful, applied, understandable manner. Course makes me feel more ready for handling this kind of problem and data in a professional setting later on.

2018 The course is very interesting. The practical component of the course is very useful to learn more about each topic in the theoretic part of the lesson.

Finally, the distinctive structure of the course has not affected the students' grades, as almost all students pass each year (Fig. 3). Interestingly, the variance in the marks increased during the covid period (2020). NB. The number of students indicated in Figure 3 is less than that in Figure 1b because not all students who initially register for the course go on to take it for credit.

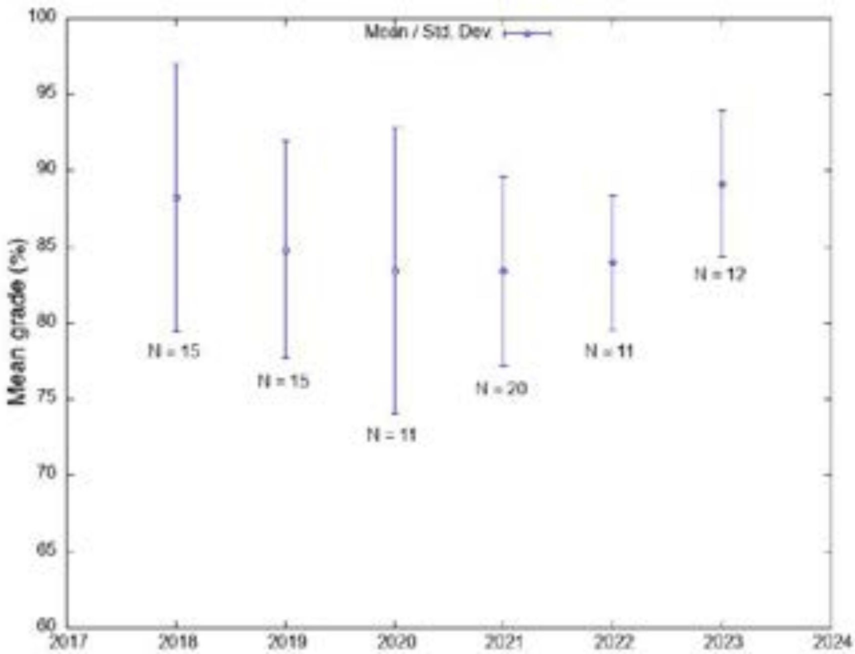

Figure 3. Mean percentage grade of the students taking the course for credit for the years in which the course has been taught. The grade is accumulated from the course assessment elements as described in Section 2 Methodology. Error bars are the standard deviation of the distribution.

4 SUMMARY

Cell biology involves dynamic phenomena in living cells, a perspective that lectures alone cannot convey. This Master's level course uses computational modelling to help the students acquire a better appreciation of the dynamics inside cells. They also gain important transversal skills relating to open-source software and the FAIR principles of research data management. Active learning techniques promote student engagement in the class, and group problem solving allows them to explore larger cell biology problems than they could manage individually. Course evaluation feedback (Figures 1, 2) reveals that the students find this mix of theoretical and practical exploration encourages them to learn. The concept of exploring a subject using computational modelling could be applied to many engineering disciplines provided certain criteria are met. Primary among these is that a suitable simulation tool must be available (preferably open source to allow students to examine its structure); students must be able to master the simulations in the time available; and relevant and interesting problems in the field should be amenable to simulation. Practically, it is crucial that sufficient exercise time be allocated to bring the students up to speed with running simulations, which might limit this approach to smaller class sizes (< 25), unless the students are already familiar with the technique or trained assistants are available. Finally, the combination of traditional lectures with simulations creates a demanding workload (Figure 2b), which is here alleviated by encouraging the students to send questions by email, and discussing them at the beginning of each class.

My goal with the course is to have the students leave with the attitude of "always be asking questions." Translating complex dynamical phenomena into a set of simulations reveals what is important in a problem, and what is ignorable. These are important conceptual skills that can be applied in their subsequent careers.

REFERENCES

O. Akkoyun. New simulation tool for teaching-learning processes in engineering education. *Comput. App. Eng. Educ.* 25 (2017): 404 – 410. https://doi.org/10.1002/cae.21807.

O. Chernikova, N. Heitzmann, M. Stadler, D. Holzberger, T. Seidel, F. Fischer. «Simulation-Based Learning in Higher Education: A Meta-Analysis.” *Rev. Education Research* 90 (2020): 499-541. https://doi.org/10.3102/0034654320933544.

A. K. Datta, V. Rakesh, D. G. Way. “Simulation as an Integrator in an Undergraduate Biological Engineering Curriculum.” *Comput. App. Eng. Educ.* 21 (2013): 717 - 727. https://doi.org/10.1002/cae.20519.

J. Fu, M. Sun, M. Wang. “Simulation-Assisted Learning about a Complex Economic System: Impact on Low- and High-Achieving Students.” *Sustainability*, 14 (2022): 6036-6053. https://doi.org/10.3390/su14106036.

H. Jossberger, J. Breckwoldt, H. Gruber. “Promoting Expertise Through Simulation (PETS): A conceptual framework.” *Learning and Instruction* 82 (2022): 101686. https://doi.org/10.1016/j.learninstruc.2022.101686.

C. Kohn, M. J. Wiser, R. T. Pennock, J. J. Smith, L. S. Mead. “A digital technology-based introductory biology course designed for engineering and other non-life sciences STEM majors.” *Comput. App. Eng. Educ*. 26 (2018): 1227-1238. https://doi.org/10.1002/cae.21986.

A. J. Magana. “Modeling and Simulation in Engineering Education: A Learning Progression.” J*. Prof. Issues Eng. Educ. Pract*. 143 (2017): 04017008. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000338.

P. M. Senge. Why practicing a system’s perspective is easier said than done. *Applied Developmental Science*, *24*(1) (2020) 57–61. https://doi.org/10.1080/10888691.2017.1421429.

OPEN LIFE CYCLE ASSESSMENTS (LCA) TOOL FOR SUPPORTING THE DEVELOPMENT OF SUSTAINABLE ENGINEERING PRACTICES

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Conference Key Areas: *Teaching the knowledge, skills and attitudes of sustainable engineering, Curriculum development and emerging curriculum models in engineering.*
Keywords: *Life Cycle Assessment (LCA), Sustainability, Project-Based Learning, Excel-based Tool, Multidisciplinary*

ABSTRACT

Amidst the escalating urgency to address environmental degradation and sustainability challenges, there exists a critical gap in engineering education: the inadequate integration of Education for Sustainable Development (ESD). In response to this challenge, this paper presents an innovative Excel-based tool tailored for multidisciplinary engineering programs. This tool aims to seamlessly integrate Life Cycle Assessments (LCA) into engineering curricula, fostering project-based learning. Developed for undergraduate students, the tool uses a T-shaped teaching approach providing engineering training across breadth of disciplines, while emphasizing an in-depth training of fundamental engineering skills as well. The tool is developed in a user-friendly format, with step-by-step guidance, and focused on adaptability for interdisciplinary collaboration. Through iterative development and feedback, the paper discusses challenges, strategies, and the potential impact of this tool on engineering education, ultimately contributing to the cultivation of socially and environmentally responsible engineers.

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1 INTRODUCTION

With the increasing need for solutions for climate crisis, there is an increasing demand for including Education for Sustainable Development (ESD) across different engineering disciplines and institutes (UNESCO 2020). ESD when integrated with engineering, encompasses teaching principles and practices that equip students with the knowledge and skills to develop solutions that balance environmental, social, and economic considerations, aiming to address global challenges (Huntzinger et al. 2007). It covers various methods, including life cycle assessment (LCA), green design and technology, renewable energy systems, waste management strategies, eco-efficient manufacturing processes, sustainable infrastructure development, and environmental impact assessment techniques(Byrne et al. 2010; Kamp 2006).

LCA, especially, is important for holistic teaching of sustainability in engineering as it provides comprehensive insights into environmental impacts across the entire lifecycle of sustainable solutions, thus aiding informed decision-making (Mälkki and Alanne 2017). LCA is a method used to evaluate the environmental impacts of a product or process throughout its entire life cycle, i.e. from raw material extraction, manufacturing, transportation to the usage and disposal (Hauschild et al. 2018).

Multiple efforts have been made to use LCA in different curricula all around the world (Piekarski et al. 2019; Cosme et al. 2019; Hauschild, Rosenbaum, and Olsen 2018; Bevilacqua et al. 2015). All these studies show that the tools which are deployed to teach LCA are proprietary tool and need licensing rights on either the software or the databases, e.g. Simapro[i], GaBi[ii], Umberto[iii], OpenLCA[iv], etc. Thus, it limits many universities and institutes to teach LCA in an effective manner without being dependent on a hefty cost or licensing limitations (Viere et al. 2021). At the same time, LCA is a very applicative skill and thus for teaching LCA and other sustainable engineering education methods, project-based setup is ideal. Project-based approach involves students to learn through hands-on, real-world projects that foster inquiry, collaboration, and critical thinking (Uziak 2016; Frank et al. 2003). With given complexity of the project-based approaches, the tools need to be easy to use and open for students to be used.

Noticing the lack of any LCA open tools which can be easily used in project-based environment, a tool was developed, and this paper introduces this innovative Excel-based tool designed to integrate LCA into the engineering curriculum. The tool aims at addressing the scarcity of open tools and data for teaching LCA at the undergraduate level. Developed for the "Ecological Design" course at The Engineering and Design Institute-London (TEDI-London), the tool guides second-year undergraduate students through a project-based learning approach cantered on the sustainable renovation of a large building renovation project in London. The purpose of the tool is to be further adapted and developed iteratively and used for other courses and institutes as well.

The paper progresses as follows: Section 2 discusses the method employed for tool development, followed by Section 3 which provides reflection and outlook on challenges & successes of the tool, and Section 4 concludes the paper.

2 METHOD

The LCA excel-based tool was specifically crafted for a 2nd year undergraduate course “Ecological Design” at The Engineering and Design Institute-London (TEDI-London). It is important to reflect on the institute (TEDI-London) and the module (Ecological Design) itself before looking into the tool itself, as the author developed this module and tool to fit in perfectly within the module learning outcomes/objectives (“Apply ecological considerations and assess the environmental impact of the design of an a complex eco-product, process or construction”) and the ethos of institute (“world-conscious global engineering"). Figure 1 shows how the tool was developed as a subobjective of the module, which is further a key objective module of the institute itself. It is important to note here that though this tool was developed for the institute and the module with a project case study in mind, this paper attempts to support adaptation of the tool for different project case studies (in different institutes and modules) as well.

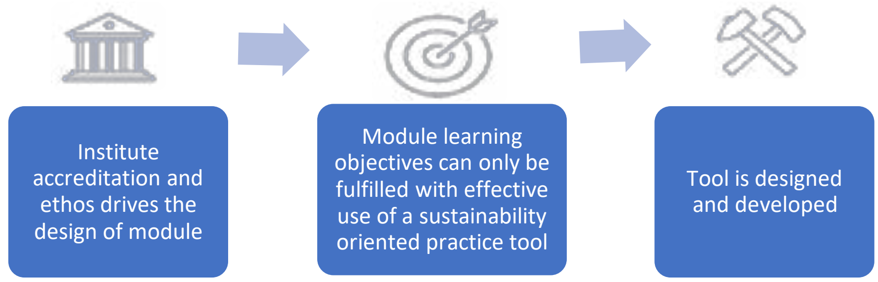

Figure 1: Steps towards development of tool: alignment with institute and module objectives

2.1 Introduction to the institute

TEDI-London, a specialist institute, uses two main approaches for setting up any curriculum. First, nearly all modules follow a project-based learning approach for teaching design and engineering. Secondly, there is always an emphasis on global design approach, focused on responsible engineering i.e. integrating ethical considerations, sustainability principles, and cultural perspectives into the design process to address global challenges. In simple words, each module is developed with consideration of two main steps: (i) a well-organized blend of theoretical instruction, applied tasks, and active engagement with topic-related case studies, and (ii) the execution of authentic case studies in partnership with businesses or other entities.

2.2 Module development

The module on ecological design adopted a consistent approach in teaching LCA, applied within the context of a sustainable renovation project focusing on a building in London.

Project and module objectives: This project focused on the transition of a building from an event venue to a large commercial office space. Students in the ecological design module developed a concept design considering environmental and societal impacts, including energy consumption and end-of-life aspects. They also communicated their engineering processes, assumptions, calculations, and models to the client and stakeholders. All these module objectives were derived from the “Accreditation of Higher Education Programmes” or AHEP in engineering, matched to this module, in line with the UK Standard for Professional Engineering Competence (UK-SPEC)[v].

<u>*Step-by-step synced learning process*</u>**:** The module follows a step-by-step process that mirrors the sequential stages of LCA, which is shown in Figure 2 below (distributed over 10-week module).

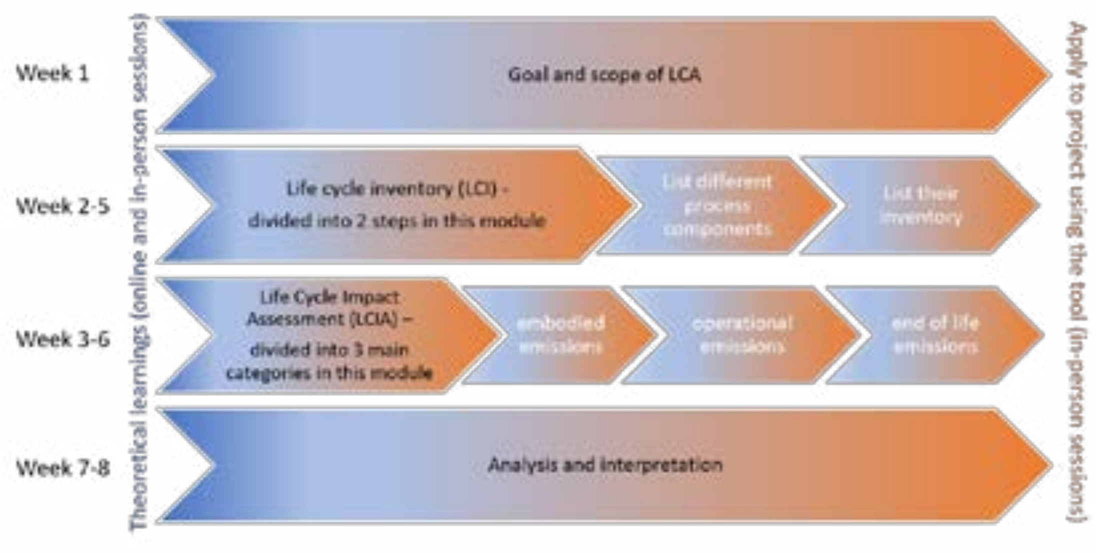

Figure 2: Steps of LCA and syncing with the learning process over the module

Simultaneously, students apply the theories they've learned in the module to a project using an Excel-based tool, ensuring a smooth project-based learning approach.

<u>*Emphasis on fundamental skills*</u>**:** In the module, the main goal was to ensure that students understood the basic principles of LCA and could apply their engineering knowledge to carry out assessments and calculations. Instead of relying solely on software, which often simplifies the process, students were encouraged to think critically and perform calculations themselves.

<u>*T-shaped teaching/learning approach*</u>: The module focused on developing "T-shaped" professionalism, where students gain deep expertise in one area (the vertical stroke of the "T") and broad interdisciplinary skills (the horizontal stroke) (Heinemann, 2009; Elmquist & Johansson, 2011). Mechanical engineering provided vertical expertise on operational emissions (case of a heat pump mechanical design to reduce the operational emissions), while environmental engineering offered horizontal knowledge on building related LCA for sustainable renovations (covering the different emission types across the entire life cycle of a building, e.g. construction/ embodied emissions, operational emissions, etc.). This T-shaped teaching approach, as shown in Figure 3, ensured students acquired specialized skills and a holistic understanding of LCA, aligning with global engineering challenges.

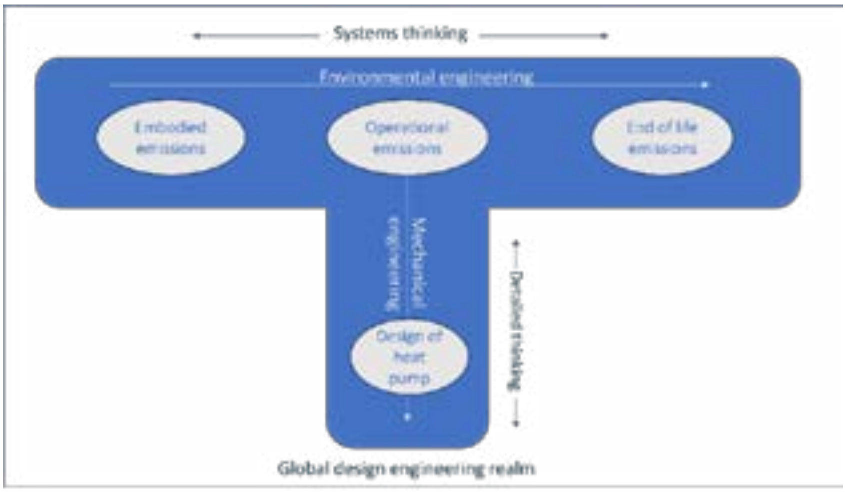

Figure 3: T-shaped teaching/learning approach used for teaching the module

2.3 Tool development

The methodology draws insights from an existing paper and PhD thesis of the author, which was focused on development of a tool for conducting LCA of buildings (Shinde et al. 2024). Similar structure of database and in-built calculations was set up with different data parameters to compute the final total emissions contributed by a building. This tool, consisting of 9 distinct sheets and 3 example sheets, serves as a structured framework guiding students through the multifaceted process of conducting a thorough LCA analysis (in this context, especially for a building construction and renovation process). Figure 4, aligned with steps listed in Figure 3 shows the synchronisation of the tool development with the different stages of LCA. The following subsections discuss each stage, and the including sheets in the tool briefly.

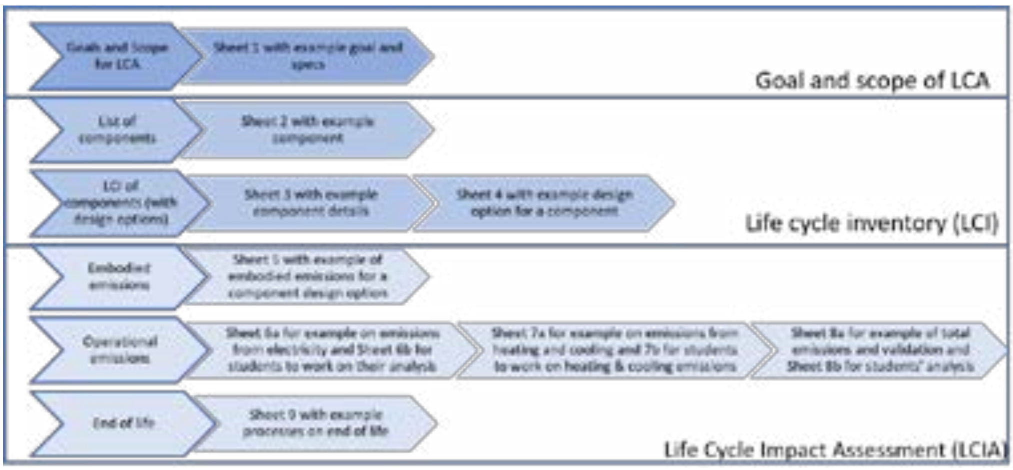

Figure 4: Steps for setting up the excel-based LCA tool

<u>*Goals and Scope for LCA*</u>

The cornerstone of any LCA endeavour lies in setting clear goals and defining the scope of the assessment. Sheet 1 (screenshot in Figure 5) provides a platform for students to articulate these critical elements, establishing the parameters within which the analysis will operate. An example goal, such as reducing greenhouse gas emissions by 20% over the product's lifecycle, along with accompanying specifications, sets the stage for subsequent analysis.

Figure 5: Screenshot of Sheet 1 (goal and scope) in the excel based LCA tool

List of Components

Sheet 2 fosters the systematic compilation of all pertinent components relevant to the product or process under assessment. Students utilize this sheet to identify and categorize components, ensuring a comprehensive evaluation of the entire system. Example of components include roofs, walls, windows, etc.

Life Cycle Inventory (LCI) of Components

Detailing the life cycle inventory of each component, Sheet 3 offers a nuanced understanding of its journey from extraction to disposal. Students delve into the intricacies of raw material extraction, manufacturing processes, transportation logistics, and disposal methods. An example component, such as the steps and processes in designing a roof is accompanied by multiple design options, allowing students to compare various environmental impacts associated with each choice.

Embodied Emissions

Sheet 4 and 5 (screenshot in Figure 6) zooms in on the calculation of embodied emissions incurred during the production and assembly of components. Students grapple with the upstream impacts inherent in manufacturing processes, recognizing the significance of early-stage decisions in minimizing environmental footprints. An example scenario elucidates the embodied emissions linked to a specific design option, underscoring the necessity of holistic consideration in LCA analyses.

Figure 6: Screenshot of Sheet 5 (embodied emissions) in the excel based LCA tool

Operational Emissions and validation

Dedicated to operational emissions, Sheets 6a, 6b, 7a, and 7b shed light on energy consumption throughout the life cycle, stemming from electricity consumption, heating, and cooling processes. Sheet 8a (screenshot in Figure 7) and 8b provides students with a structured template to validate total emissions within the context of their individual projects, reinforcing the importance of meticulous scrutiny in LCA practices.

Building info		building area (approx. gross internal area for operational use, sq.m)	40000
		building lifetime (years)	60
1. Appliances and lighting	Source and emissions	electricity source	UK electricity grid + smart b
		emissions per kWh of electricity source (kgCO_2-eq/kWh)	0.15
	Electricity demands	building electricity demand per square meter (kWh/sq.m./year)	100
		total electricity related operational emissions (kgCO_2-eq/sq.m./yea	15
2. Heating and hot water (+ cooling, as the same system is used)	Source and emissions	heating (and cooling) system energy source	UK electricity grid
		emissions per kWh of heating system energy source (kgCO_2-eq/kW	0.09
	Systems and demands	Heating (and cooling) system	3 Air source heat pump
		Heating system heating capacity (kW)	1028
		Coefficient of performance for heat pumps	3
		Electricity needed per square meter (kWh/sq.m./year)	75.044
		total heating related operational emissions (kgCO_2-eq/sq.m./year)	6.75
3. (Additional) Cooling system	Source and emissions	Additional cooling system cooling energy source	UK electricity grid
		emissions per kWh of cooling system energy source (kgCO_2-eq/kWh	0.15
	Systems and demands	Additional cooling system	radiant chilled panels
		Cooling system energy requirements (kWh/sq.m./year)	38.24
		total chilled panels related operational emissions (kgCO_2-eq/sq.m./	5.74
		Total operational emissions (kgCO_2-eq/sq.m./year)	**27.49**
		Validation data from BI	**26.57**

Figure 7: Screenshot of Sheet 8a in the excel based LCA tool

End of life

Concluding the LCA journey, Sheet 9 contemplates the end-of-life stage, exploring disposal, recycling, and reuse options for components. Through an example scenario, students evaluate the environmental impacts of various end-of-life strategies.

3 REFLECTION AND OUTLOOK

In the following section, personal reflections from the author and informal student feedback are discussed which reflects on the methodology, offering insights into challenges faced, successful strategies employed, and the overall evolution of the curriculum over successive iterations.

Successes

- One notable success in integrating the tool into teaching LCA was students' thorough understanding of the method and its effective stepwise application in large projects.
- Additionally, students showed keen interest in further developing the tool for group assessments, recognizing its value for ease of sharing and collaboration among group members.
- The tool allowed students to grab the fundamental principles of engineering better than introducing a pre-existing tool. For instance, if they used a tool like Simapro to assess the LCA of a product, they wouldn't manually calculate emissions associated with manufacturing because the software provides pre-existing data. However, in the module, students were prompted to conduct these assessments using provided data, matching it appropriately and then making their own estimations. This approach aimed to deepen their

understanding and analytical skills rather than relying on automated processes.

Challenges and Iterations

- Informal feedback collected from students regarding the tool's efficacy and areas for improvement has been integrated into the methodology. This qualitative data helped in understanding user experience, addressing challenges, and refining the tool to better meet student needs and expectations. For instance, the addition of example sheets for operational emissions was implemented based on student feedback, leading to increased comfort and proficiency in using the tool.
- Challenges arose regarding accessing the right information and sources due to the vast array of available data, such as emissions factors associated with concrete. Students found it time-consuming to navigate multiple sources. To address this for the next year's adaptation of the module, the tool will be coupled with either free/ licensed database(s) or project-specific databases through stakeholder engagement would be obtained.

Broader Insights

Beyond its immediate functionalities, the tool's broader outlook reveals significant insights. The scarcity of open software and data for teaching LCA underscores the need for accessible resources in the education sector. Additionally, the consideration of regional aspects in LCA projects emphasizes the importance of tailoring curricula to local contexts, ensuring relevance and applicability. Aligning with environmental engineering principles, the tool fosters a holistic understanding of LCA, bridging mechanical and environmental perspectives. Furthermore, its potential impact on professional accreditation suggests that integrating LCA into engineering education could better prepare future engineers for industry standards.

4 CONCLUSION

The development and implementation of the updated Excel-based tool for integrating LCA into the engineering curriculum have provided valuable insights into its effectiveness and broader implications. The tool's efficacy stems from several key features: it is based on existing researched tools, offers easy-to-understand guidance with stepwise instructions, is well-suited to project-based learning, aligns with the institute's multidisciplinary Design Engineering Program, emphasizes fundamental engineering skills, and aligns with Engineering for Sustainable Development (ESD) education goals.

The initial acceptance of the tool has been positive for the module, but further surveys, student feedback, and implementation of additional project case studies will provide insight into its long-term effectiveness. The tool has potential applicability across various engineering disciplines, fostering sustainability education in diverse fields e.g. it can be integrated in a civil or mechanical engineering project looking at a specific (construction or manufacturing) process or product in any institute keen on integrating sustainability education. Moreover, its relevance aligns with initiatives such as the Engineering Professors Council (EPC) Sustainability Toolkit[vi] and Engineers Without Borders (EWB)'s Competency Compass[vii], providing avenues for collaboration and resource-sharing within the wider engineering education community. Potential integration with would highlight its potential role in advancing sustainability education beyond institutional boundaries, supporting global engineering initiatives.

In essence, this paper not only presents a practical tool for LCA integration but also encourages reflection on the broader implications for engineering education, emphasizing collaboration, adaptability, and the shared responsibility of preparing future engineers for sustainable practice.

REFERENCES

Bevilacqua, Maurizio, Filippo Emanuele Ciarapica, Giovanni Mazzuto, and Claudia Paciarotti. 2015. "'Cook & Teach': Learning by Playing." In *Journal of Cleaner Production*, 106:259–71. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2014.11.085.

Byrne, Edmond, Cheryl Desha, John Fitzpatrick, and Karlson Hargroves. 2010. "ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT: A REVIEW OF INTERNATIONAL PROGRESS." In . International Symposium for Engineering Education. .

Cosme, Nuno, Michael Z. Hauschild, Christine Molin, Ralph K. Rosenbaum, and Alexis Laurent. 2019. "Learning-by-Doing: Experience from 20 Years of Teaching LCA to Future Engineers." *International Journal of Life Cycle Assessment* 24 (3): 553–65. https://doi.org/10.1007/s11367-018-1457-5.

Frank, Moti, Ilana Lavy, and David Elata. 2003. "Implementing the Project-Based Learning Approach in an Academic Engineering Course." *International Journal of Technology and Design Education* 13:273-288.

Hauschild, Michael Z, Ralph K Rosenbaum, and Stig Irving Olsen. 2018. *Life Cycle Assessment*. 2018th ed. Springer International Publishing. https://doi.org/https://doi. org/10.1007/978-3-319-56475-3.

Huntzinger, Deborah N, Margot J Hutchins, John S Gierke, and John W Sutherland. 2007. "Enabling Sustainable Thinking in Undergraduate Engineering Education*." *Enabling Sustainable Thinking in Undergraduate Engineering Education." International Journal of Engineering Education* 23 (2): 218.

Kamp, Linda. 2006. "Engineering Education in Sustainable Development at Delft University of Technology." *Journal of Cleaner Production* 14 (9–11): 928–31. https://doi.org/10.1016/j.jclepro.2005.11.036.

Mälkki, Helena, and Kari Alanne. 2017. "An Overview of Life Cycle Assessment (LCA) and Research-Based Teaching in Renewable and Sustainable Energy Education." *Renewable and Sustainable Energy Reviews*. Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.11.176.

Piekarski, Cassiano Moro, Fábio Neves Puglieri, Cristiane Karyn de Carvalho Araújo, Murillo Vetroni Barros, and Rodrigo Salvador. 2019. "LCA and Ecodesign Teaching via University-Industry Cooperation." *International Journal of Sustainability in Higher Education* 20 (6): 1061–79. https://doi.org/10.1108/IJSHE-11-2018-0206.

Shinde, Rhythima, Aleksandra Kim, and Stefanie Hellweg. 2024. “Bottom-up LCA Building Stock Model: Tool for Future Building-Management Scenarios.” *Journal of Cleaner Production* 434 (January). https://doi.org/10.1016/j.jclepro.2023.140272.

UNESCO. 2020. “Education for Sustainable Development: A Roadmap.” ..Transforming Our World: The 2030 Agenda for Sustainable Development. . 2020.

Uziak, Jacek. 2016. “A Project-Based Learning Approach in an Engineering Curriculum.” *Global Journal of Engineering Education* 18 (2): 119–23.

Viere, Tobias, Ben Amor, Nicolas Berger, Ruba Dolfing Fanous, Rachel Horta Arduin, Regula Keller, Alexis Laurent, et al. 2021. “Teaching Life Cycle Assessment in Higher Education.” *International Journal of Life Cycle Assessment* 26 (3): 511–27. https://doi.org/10.1007/s11367-020-01844-3.

[i] https://simapro.com/
[ii] https://sphera.com/product-sustainability-software/
[iii] https://www.ifu.com/umberto/
[iv] https://www.openlca.org/
[v] https://www.engc.org.uk/ahep
[vi] https://epc.ac.uk/resources/toolkit/sustainability-toolkit/
[vii] https://www.ewb-uk.org/global-responsibility-competency-compass/

ENGINEERING PRACTICES AND CORE CONCEPTS IN SCHOOLS: TEACHING THE FUTURE ENGINEERS

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Keywords: *primary education, secondary education, engineering practices, engineering core ideas*

ABSTRACT

The framework of primary and secondary STEM education has given engineering education an unprecedented role until now. However, this centrality is not supported by a solid framework from a didactic point of view, resulting in superfluous and lacking proposals. This communication addresses three questions that point to the future of engineering teaching in school: What literacy in engineering should be promoted? What engineering practices should school develop among students? What are the central ideas that should be taught in schools? Taking as a reference the more consolidated and well-founded field of research on science education, we propose a list of engineering practices and a first approximation of engineering core ideas in order to bring an engineering epistemological perspective in school STEM education.

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1 INTRODUCTION

Giving relevance to Science, Technology, Engineering and Mathematics, whether integrated or not, has marked the direction of many educational policies and has been pervasive in current educational debates, resulting a topic of interest in the field of education research (Bybee 2013; Johnson et al. 2020). Within this STEM education approach, and influenced among others, by the perspective of design as a new twenty-first century literacy (Pacione 2010; Blikstein 2013), the role of engineering education has been modified, gaining more prominence and centrality in pre-college education (Li et al. 2019; Pleasants and Olson 2019). This new engineering education perspective seeks to promote both an engineering literacy for all and to meet the forecasted demand for skilled engineers in the years to come. However, critical voices have denounced the existence of a gap between these intentions and the real presence of engineering education in compulsory education, especially in primary and lower secondary education (Bagiati et al. 2015). In this paper, we consider an epistemological perspective for engineering education as a basis for defining what engineering practices and which engineering core ideas should be developed among primary and secondary school students in order to promote a sound engineering education in compulsory education.

1.1 Engineering in school STEM education: what are we talking about?

In our opinion, some of the motivations and potential benefits of enhancing the presence of engineering in pre-college education somewhat undermine the true *raison d'être* of what engineering education should be, which would, in turn, explain the shortcomings pointed out when it comes to engineering school education. For instance, the perspective of engineering as a context that can improve students' learning in science and mathematics is fundamentally based on an idea of education focused on the products of engineering -technology- (e.g.: energy and power technologies) instead of on the idea of developing among students the understanding of engineering as a standalone discipline. In fact, engineering contents are commonly taught not as a specific subject but within other more general subjects commonly related to science or technology (Bonsall, Bianchi, and Hanson 2022).

At this regard, we agree with McComas and Burgin (2020) who point to the lack of entity of technology compared to engineering and propose the acronym of SEM education instead of STEM, to avoid redundancies. While discussions regarding differences between engineering and technology from areas such as philosophy are still unresolved (Krupczak et al. 2012; Norström 2014; Smit 2016) our vision is that technology is the product of the activity carried out by engineers, that is, the product of engineering practice and we propose this perspective for enhancing engineering education at school. In contrast with educational references that use engineering and technology as synonyms, arguing that both engineering and technology have as their philosophical core the resolution of practical problems(Varnado and Pendleton 2004), or that engineering education is a content already included in technology education (Williams 2010) we claim that shift -giving engineering its own entity in education- would be aligned with claims of authors like Lewis (2005) or Rogers (2006) that point to the need to propose changes in technological education so that the field reaches an agreement with engineering as content.

Hence, from a STEM education perspective that seeks to educate students so that they are able to “identify, apply and reflect upon the way we think, do and talk in Science, Engineering and Mathematics (in a more or less integrated fashion) to understand, decide and act on complex problems and to build creative solutions, using the appropriate technologies and collaborating with others in a critical, reflective and value-driven way, through the enactment of the own agency and the authoring of the contribution of diverse people to minimize the inequalities in the STEM field” (Couso, Grimalt-Álvaro, and Simarro 2022) we see engineering literacy as the one that entails both knowledge of the technologies themselves, to be able to use them and to make decisions about them in an informed manner, as well as of the nature of the process that leads to their design and development (ITEEA & CTETE 2020). A quality engineering education must focus not only on the results of engineering as a discipline (technology) but also in the participation in what we call practices, those cognitive, social and discursive activities that characterize the discipline (Peters-Burton 2014; Gattie and Wicklein 2007).

1.2 Engineering practices: an epistemic view of engineering in school

There is a growing consensus that engineering education should place disciplinary practices as a central focus (Cunningham and Carlsen 2014a; National Research Council 2012) in the same way that scientific practices are for science education (Duschl and Grandy 2013; Osborne 2014). Recognizing engineering as a cognitive, social and cultural activity (Bucciarelli 2003) implies recognizing that it encompasses specific ways of doing, talking, thinking, valuing and being (Couso and Simarro 2020a). From this sociocultural perspective of education, the participation of students in school-based engineering practices analogous to those of the professional engineering world becomes a central element of 21st engineering education. However, while in science teaching the relevance of practices and an epistemic view of school science have already transformed most educational proposals, in the case of engineering education the focus on technology is still ubiquitous and the idea of engineering practices is still scarcely developed.

An example can be found in the eight engineering practices proposed by the National Research Council (National Research Council 2012) which presents engineering as the participation in a set of practices that require the simultaneous coordination of both knowledge and skills. Despite the crucial paradigm shift that entails viewing the teaching and learning of engineering not as the mastery of a generic problem-solving approach but as the promotion of active student participation in engineering practices, we consider the NRC engineering framework insufficient. The main reason is that the list of practices is too dependent on and interlinked with the list for scientific practices: only two practices are specific to engineering (defining problems and designing solutions) while the rest are exactly the same for both science and engineering. In this regard, and from an epistemic viewpoint, we strongly disagree with authors, such as Bybee (2011), who claim that with the exception of their goals, science and engineering practices are parallel and complementary. As Cunningham and Carlsen (2014b) argue, we believe that a subtle differentiation between science and engineering does not capture the epistemic differences between the two disciplines, and thus does not reflect certain salient engineering values that are essential to the engineering discipline and, at the same time, differentiate it from other (Couso and Simarro 2020a). The NRC curriculum framework do not sufficiently emphasize the important differences between both disciplines, science and engineering (Cunningham and Carlsen 2014a), and their statements, built in the image and likeness of scientific practices, do not encapsulate key elements of the nature of the engineering activity. Given the relevance that the list of eight engineering practices has on educational standards and curriculum designs, we consider the need for a new conceptualization of engineering practices in which the idiosyncratic differences between science and engineering are reflected. This is not to avoid an interdisciplinary STEM teaching approach where both science and engineering are considered, but to help teachers to improve students' understanding and knowledge both *of* and *about* engineering either in disciplinary or interdisciplinary oriented curricula.

1.3 Engineering core concepts

Following with the NRC framework, the imbalance between science and engineering is also evident for the so-called core concepts that, together with the idea of scientific and engineering practices and the crosscutting concepts, represent one of the three dimensions of this curricular framework. The perspective of focusing science teaching towards the construction of core ideas or "big ideas" (Harlen 2010) has been fundamental in science teaching for decades. From this perspective, these core ideas are understood as those structuring ideas that have the potential to explain a large number of different phenomena, offering coherence between them and allowing their development throughout schooling.

In front of the eleven core ideas for science, only two central ideas are listed for engineering, being their nature very different from the idea of core concepts. As Cunningham and Carlsen (2014b) point out with respect to the first engineering core concept (ETS1: Engineering Design), its definition is more linked to the idea of activity (defining and delimiting an engineering problem, developing possible solutions and optimizing the design solution) but not to concepts, ideas or theories that must be the conceptual basis of engineering practice. Similarly, the second core idea (ETS2: Links among engineering, technology, science, and society) is far from being a central idea of engineering and is more a reflection on the relationship between science and engineering that: 1) is not included in the central ideas of science, and 2) gives an idea, as specified, of engineering and technology as a mere application of science (Ortiz-Revilla, Adúriz-Bravo, and Greca 2020). Once again, the effort to equate engineering content with scientific content is limited by the lack of an epistemic vision that exalts the idiosyncrasy of each discipline without denying the interrelationships between them.

Evidently, the core concepts included in the NRC framework are not the only ones proposed in the literature as engineering core ideas. In the review by Silk and Schunn (2008), the following are identified as specific engineering concepts: structure-behavior-function, trade-offs, constraints, optimization and systems, subsystems and control. Although relevant, these ideas are somewhere between crosscutting concepts, understood as those that are useful for both science and engineering and that are associated with a scientific-technological way of thinking (National Research Council 2012) and the practices discussed above but they do not represent a way of structuring knowledge in engineering. More recently, the new standards for technological and engineering literacy (ITEEA & CTETE 2020) also include the idea of central engineering concepts but, again, it does so in an inconsistent way when defining operational categories, mixing elements of diverse nature (some related to practices (resources, requirements, trade-offs, optimization), others related to transversal concepts (system and process) and others more related to specific technologies (control)).

Be that as it may, the great diversity that exists and the lack of agreement between all the proposals show that there is still no broad agreement on the complete set of central ideas in engineering on which to base its practices. From a competence point of view, however, it is necessary to establish what this knowledge is, which are these key ideas that must serve as a basis for participating in engineering practices (assessing, for example, whether a solution is optimal or not, may require knowing the resources available and their long-term availability). There is no doubt, therefore, that engineering education requires these specific ways of looking at the world created by and for humans, thus establishing some central ideas of engineering that, as in the case of science, help to propose the curricula and educational approaches of the discipline.

2 METHODOLOGY

In order to give answer to the purposes of our work, we conducted a literature review addressing the following questions: 1) *Which should be the epistemic characteristics of engineering practices in comparison to the scientific and engineering practices proposed by the NRC framework?* and 2) *Which are the engineering concepts that are more commonly presented in engineering and technology primary and secondary curricula or standards?*

Regarding the first question, our search strategy was carried out following the PRISMA Protocol (Page et al. 2021) as data selection strategy. This review involved the identification of key words and the selection of peer review journals in the fields of engineering education, STEM education and philosophy. The key words that guided the review were: nature of technology, nature of engineering, engineering practices, technology practices, STEM practices, engineering education and technology education. Identified publications were screened in order to exclude those that could fall out of the scope of our work. Specifically, we exclude those publications that restricted the meaning of technology to that of computer science and those that treated STEM as a metadiscipline, without distinguishing engineering specific practices. As reported in the results sections, the salient characteristics of engineering were identified within this literature review by contrasting them with the scientific ones using the Family Resemblance Approach (FRA) to NOS (Erduran and Dagher 2014).

A second rapid literature review (Cirkony et al. 2022) was carried out also with grey literature. In particular, official technology and engineering curricula and standards - for primary and secondary education levels- were selected and compared, using the NRC engineering practices as a guiding dimension for the comparative grid. The combination of both comparatives resulted in a first set of eight practices based on the NRC engineering practices but nuanced by both the engineering epistemic characteristics as well as the practices highlighted in other curricula proposals. In parallel, and following a Grounded Theory approach (Glaser and Strauss 1967) the first draft of these practices where applied as categories for analysing primary school student's activity in a particular educational engineering context (in this case, a Tinkering activity in an informal education setting, (Simarro 2019). The aim was to analyse the validity of these categories to analyse students' participation in engineering practices and to identify emerging categories that could enrich the theoretical proposal. As a result, changes to the initial proposal were made, with the addition of new practices and with the inclusion of nuances to the existing ones. On the other hand, the answer to the second question was addressed also by the rapid literature review of the same official technology and engineering curricula and standards. A second grid was generated, grouping the contents presented in each curricula and standards by topic, resulting in a proposal of dimensions that encapsulate the essence of the contents: technologies' development, nature and application. Inspired by the 10 big ideas of Harlen (2010), a set of 10 core engineering concepts covering these three dimensions was proposed.

3 RESULTS

3.1 School engineering practices from an epistemic view

A review from an epistemic point of view of the differences between the aim, spheres of activity, forms of knowledge, values and quality criteria and methodological rules of science and engineering (Couso and Simarro 2020b) can serve as a starting point to qualify the engineering practices proposed by the NRC. Thus, recognizing that the main objective of science and engineering is different (building reliable explanations of natural phenomena and optimal solutions created by humans, respectively) can help to understand when a classroom proposal is promoting certain scientific practices or, on the other hand, it focuses on the development of other practices linked to engineering. Aspects such as the nature of the products of each discipline (theories, laws, models vs. technologies, processes, etc.), the quality criteria and methodological rules (more or less linked to idealization) and, especially, the dimensions that characterize the respective practices (inquiry, modelling and arguing vs. creating, testing and arguing) have served us to propose a first list of engineering practices that, inspired by the list proposed by the NRC, seeks to capture the essence of engineering as single discipline (Table 1) (Simarro and Couso 2021)

Table 1. Alternative proposal to the NRC Engineering Practices

NRC 2012 practices definition	**Alternative proposal[1]**
Defining problems	Defining **and delimiting** engineering problems
Developing and using models	Developing and using **prototypes and simulations**
Planning and carrying out investigations	Planning and carrying out **tests**
Analyzing and interpreting data	Analyzing and interpreting data **to identify points for improvement**
Using mathematics and computational thinking	Using mathematics and computational thinking, **scientific models and available technologies**
Designing solutions	**Identifying and/or developing multiple solutions and selecting the optimal one**

---	**Materializing the solution**
Engaging in argument from evidence	Engaging in argument from evidence
Obtaining, evaluating, and communicating information	Obtaining, evaluating, and communicating information

[1] Changes highlighted in bold.

3.2 Towards the construction of engineering core concepts

Inspired by key scientific ideas and based on a review of various current technology curricula or standards (e.g.: ITEA (2007)) we present a first proposal for the central ideas of engineering by classifying them according to: how technologies are developed (including the exploitation of natural resources), what their nature is (what they are and how they are used) and what their applications are (in what contexts they are used and what particularities characterize each context). Although preliminary, these ways of structuring knowledge in engineering could be the pillars to structure a solid framework that allows defining these central ideas so necessary for engineering education.

Table 2. Proposal for key engineering Ideas

Key Idea	Example
1. The Earth has resources that are useful to respond to the needs of human beings.	On Earth we find minerals that are used as a base to make objects such as kitchen utensils.
2. The natural resources that we take advantage of to obtain energy and materials are limited.	Fossil fuels serve society as a source of energy for many processes. However, these resources are limited and shortages are expected in the future.
3. Depending on the characteristics and properties of the materials, they will have some applications or others.	Given its lightness and easy processing, cardboard is a good alternative for packaging design.
4. There are many ways, some more efficient than others, to transfer, store and distribute energy and transform materials so that it is more usable for human beings.	In a hydroelectric plant, the potential energy of water is used to produce part of the electrical energy necessary for humanity.
5. Technologies make it possible to take advantage of materials and energy to: facilitate processes, obtain and exploit resources and produce new technologies.	Simple machines are a basic example of how to facilitate a process by transforming energy into work...
6. Technologies are designed to provide an optimal response to certain needs, taking into account available resources and considering existing limitations.	In the case of home construction, you can seek to minimize the cost by disregarding aspects such as space (smaller rooms) without the home ceasing to fulfill its basic function.

7. The functions of each technology depend on the parts of which they are composed.	When analyzing a technology such as a manufacturing robot, we must identify the parts that make it up and that allow it to carry out its task: mechanical elements such as gears, electronic components such as position sensors and microprocessors, etc.
8. Technologies combine to result in new, more complex technologies.	Current vehicles include both simple machines such as the wheel and more cutting-edge technologies such as artificial intelligence in the case of autonomous cars.
9. Changes in human needs, as well as the availability of new technologies and new scientific knowledge, result in an evolution of technologies.	The evolution of communication systems has been clearly influenced by scientific and technological advances. The knowledge and exploitation of electromagnetic signals, as well as the appearance of electronics, explains the information and communication society in which we currently live.
10. The basic needs of human beings to which technology responds are: food, housing, health, transportation, communication and production.	Recent technological developments such as production automation or the Internet are explained by humanity's need to respond to its basic needs.

4 SUMMARY AND ACKNOWLEDGEMENTS

The role that engineering plays, and should play, in primary and secondary education is still limited and often misinterpreted (ITEEA & CTETE 2020). In this sense, engineering education is still a growing field if we compare it with a consolidated field such as science education (Bonsall, Bianchi, and Hanson 2022). In this communication, we advocate for including an explicit epistemological perspective for improving STEM education, whether it is integrative or not. Our aim has been to discuss the main areas of potential development of engineering education and to make a first proposal for what we consider the corpus of this discipline should entail: an epistemic view on engineering education resulting in a proposal of engineering practices based on it and a first approach for addressing the core ideas of engineering.

There is no doubt that in our proposal there are still certain aspects that require a higher level of specificity. On the one hand, the engineering practices we have proposed have been based primarily on the current NRC list of practices. There are, however, other perspectives that seem equally or more suggestive to us, such as the idea of engineering habits of mind (Lucas, Hanson, and Claxton 2014) or the perspective that is framed in the contexts of use proposed by the ITEEA (ITEEA & CTETE 2020). These frameworks can enrich our proposal and serve as inspiration to define other more useful approaches to be brought to the classroom. Moreover, our proposal does not gather the NRC idea that engineers not only design new technologies, but are also responsible for manufacturing, operating, inspecting and maintaining them. From this perspective, one might ask whether, beyond engineering practices linked to design, other practices linked to the use and maintenance of technology should be considered. Although some authors have tried to define “technology practices” (Vasquez, Comer, and Sneider 2013) these are far from what we understand as practice, resulting in a list of generic competences and not ways of doing, speaking and thinking.

In parallel, we have also highlighted the urgency of having central engineering ideas that allow for greater structuring of learning, focusing the curricular design on a brief set of ideas in which to deepen this learning. Having a more systematized way of understanding the world created by humans, in the same way that the central ideas in science allow us to understand the natural world, is an essential requirement to help teachers to improve their educational proposals, guiding engineering learning progressions (Bonsall, Bianchi, and Hanson 2022). Our proposal of ten key ideas for engineering is transversal to all branches of engineering to be appropriate for what we could call “school engineering”: the engineering knowledge and competence necessary within a view of engineering for all or engineeringliteracy. This first proposal, however, requires a collective effort to better define these central ideas of engineering, also contemplating engineering ideas that take into consideration the concepts or theories of different areas of knowledge of engineering (e.g.: how in simple machines the increase in distance leads to a decrease in the force to be exerted (idea 7 applied to the field of mechanics) or how the development of semiconductors represented a revolution for the field of electronics (idea 8 applied to the field of electronics)). In turn, the proposal of key ideas for engineering must be enriched with ideas about engineering based on existing knowledge about the nature of engineering. This work, which should be the result of a debate between the educational community and the professional field in engineering and technology, can result in a very useful tool for the advancement of engineering education.

Finally, beyond these three pillars (epistemic view, engineering practices and core ideas), we believe it is necessary to highlight another dimension that should become relevant, not only in the field of engineering teaching, but also in the rest of the STEM disciplines. A quality STEM education, and engineering education in particular, must encourage critical and reflective thinking among students, which allows them to act in accordance with certain values. As Hansson (2007) points out, engineering already operates with certain concepts loaded with values such as justice, well-being or environmental risk. Defining which engineering values should be developed among students and how is also an objective that should guide engineering teaching. Works such as that of McGowan and Bell (2020) and their proposal for critical sociotechnical literacy seem to point the way towards this update of engineering education.

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REFERENCES

Bagiati, Aikaterini, So Yoon Yoon, Demetra Evangelou, Alejandra Magana, Garene Kaloustian, and Jiabin Zhu. 2015. “The Landscape of PreK-12 Engineering Online Resources for Teachers : Global Trends.” *International Journal of STEM Education* 2 (1). https://doi.org/10.1186/s40594-014-0015-3.

Blikstein, Paulo. 2013. “Digital Fabrication and ‘Making’ in Education: The Democratization of Invention.” In *FabLabs: Of Machines, Makers and Inventors*, edited by J. Walter-Herrmann and C. Büching, 1–21. Bielefeld: Transcript Publishers.

Bonsall, Amy, Lynne Bianchi, and Janet Hanson. 2022. “A Scoping Literature Review of Learning Progressions of Engineering Education at Primary and Secondary School Level.” *Research in Science and Technological Education*. Routledge. https://doi.org/10.1080/02635143.2020.1799780.

Bucciarelli, Louis L. 2003. *Engineering Philosophy*. *International Journal of Machine Consciousness*. Vol. 2. Delft University Press. https://doi.org/10.1142/S1793843010000369.

Bybee, Rodger W. 2011. “Scientific and Engineering Practices in K–12 Classrooms.” *Science Teacher* 78 (9): 34–40. https://doi.org/10.3917/rac.023.0226.

Bybee, Rodger W. 2013. *The Case for STEM Education: Challenges and Opportunities*. Arlington, Virginia: National Science Teachers Association.

Cirkony, Connie, Mark Rickinson, Lucas Walsh, Jo Gleeson, Mandy Salisbury, and Blake Cutler. 2022. “Reflections on Conducting Rapid Reviews of Educational Research.” *Educational Research* 64 (4): 371–90. https://doi.org/10.1080/00131881.2022.2120514.

Couso, Digna, Carme Grimalt-Álvaro, and Cristina Simarro. 2022. “Problematizing STEM Integration from an Epistemological and Identity Perspective.” In *Controversial Issues and Social Problems for an Integrated Disciplinary Teaching*, 183–96.

Couso, Digna, and Cristina Simarro. 2020a. “STEM Education through the Epistemological Lens: Unveiling the Challenge of STEM Transdisciplinarity.” In *Handbook of Research on STEM Education*, edited by Carla C. Johnson, Margaret J. Mohr-Schroeder, Tamara J. Moore, and Lyn D. English, 17–28. Taylor and Francis Inc.

Couso, Digna, and Cristina Simarro. 2020b. “STEM Education through the Epistemological Lens: Unveiling the Challenge of STEM Transdisciplinarity.” In *Handbook of Research on STEM Education*, edited by Carla C. Johnson, Margaret J. Mohr-Schroeder, Tamara J. Moore, and Lyn D. English, 17–28. Taylor and Francis Inc.

Cunningham, Christine M, and William S Carlsen. 2014a. “Precollege Engineering Education.” In *Handbook of Research on Science Education*, edited by Norman G Lederman and Sandra K Abell, 747–58. Mahwah, NJ.

Cunningham, Christine M, and William S Carlsen. 2014b. “Teaching Engineering Practices.” *Journal of Science Teacher Education* 25 (2): 197–210. https://doi.org/10.1007/s10972-014-9380-5.

Duschl, Richard A., and Richard Grandy. 2013. "Two Views About Explicitly Teaching Nature of Science." *Science and Education* 22 (9): 2109–39. https://doi.org/10.1007/s11191-012-9539-4.

Erduran, Sibel, and Zubeida R. Dagher. 2014. *Reconceptualizing the Nature of Science Education for Science Education. Scientific Knowledge, Practices and Other Family Categories*. http://legacy.lclark.edu/org/journal/.

Gattie, David K, and Robert C Wicklein. 2007. "Curricular Value and Instructional Needs for Infusing Engineering Curricular Value and Instructional Needs for Infusing Engineering Design into K-12 Technology Education." *Journal of Technology Education* 19 (1): 6–18. https://digitalcommons.usu.edu/ncete_publications.

Glaser, Barney G, and Anselm L Strauss. 1967. *Discovery of Grounded Theory: Strategies for Qualitative Research*. Chicahgo, IL: Aldine.

Hansson, Sven Ove. 2007. "What Is Technological Science?" *Studies in History and Philosophy of Science Part A* 38 (3): 523–27. https://doi.org/10.1016/j.shpsa.2007.06.003.

Harlen, Wynne. 2010. "Principles and Big Ideas of Science Education." https://doi.org/978 0 86357 4 313.

ITEA. 2007. *Standards for Technological Literacy: Content for the Study of Technology*. *Standards for Technological Literacy: Content for the Study of Technology*. https://doi.org/1887101020.

ITEEA & CTETE. 2020. "Standards for Technological and Engineering Literacy."

Johnson, Carla C., Margaret J. Mohr-Schroeder, Tamara J. Moore, and Lyn D. English. 2020. *Handbook of Research on STEM Education*. Edited by Carla Johnson, Margaret Mohr-Schroeder, Tamara Moore, and Lyn D. English. 1st ed. New York, NY: Routledge. https://doi.org/https://doi.org/10.4324/9780429021381.

Krupczak, John, John W. Blake, Kate A. Disney, Carl O. Hilgarth, Randy Libros, Mani Mina, and Steven R. Walk. 2012. "Defining Engineering and Technological Literacy." *Proceedings of the 2012 Annual Conference of the American Society for Engineering Education*. https://lib.dr.iastate.edu/ece_books/3/.

Lewis, Theodore. 2005. "Coming to Terms with Engineering Design as Content." *Journal of Technology Education* 16 (2): 37–54.

Li, Yeping, Alan H Schoenfeld, A Andrea, Arthur C Graesser, Lisa C. Benson, Lyn D. English, and Richard A. Duschl. 2019. "Design and Design Thinking in STEM Education." *Journal for STEM Education Research* 2:93–104. https://doi.org/https://doi-org.are.uab.cat/10.1007/s41979-019-00020-z.

Lucas, Bill, Janet Hanson, and Guy Claxton. 2014. "Thinking like an Engineer: Implications for the Education System." *A Report for the Royal Academy of Engineering Standing Committee for Education and Training*. http://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-summary.

McComas, William F., and Stephen R. Burgin. 2020. “A Critique of ‘STEM’ Education: Revolution-in-the-Making, Passing Fad, or Instructional Imperative?” *Science and Education* 29 (4): 805–29. https://doi.org/10.1007/s11191-020-00138-2.

McGowan, Veronica Cassone, and Philip Bell. 2020. “Engineering Education as the Development of Critical Sociotechnical Literacy.” *Science and Education* 29 (4): 981–1005. https://doi.org/10.1007/s11191-020-00151-5.

National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press. https://doi.org/https://doi.org/10.17226/13165.

Norström, Per. 2014. “Technological Knowledge and Technology Education.” http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-144875; urn:isbn:978-91-7595-078-5.

Ortiz-Revilla, Jairo, Agustín Adúriz-Bravo, and Ileana M. Greca. 2020. “A Framework for Epistemological Discussion on Integrated STEM Education.” *Science and Education* 29 (4): 857–80. https://doi.org/10.1007/s11191-020-00131-9.

Osborne, Jonathan. 2014. “Teaching Scientific Practices: Meeting the Challenge of Change.” *Journal of Science Teacher Education* 25 (2): 177–96. https://doi.org/10.1007/s10972-014-9384-1.

Pacione, Chris. 2010. “Evolution of the Mind: A Case for Design Literacy.” *Interactions*, 6–11. https://doi.org/10.1145/1699775.1699777.

Page, Matthew J., Joanne E. McKenzie, Patrick M. Bossuyt, Isabelle Boutron, Tammy C. Hoffmann, Cynthia D. Mulrow, Larissa Shamseer, et al. 2021. “The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews.” *The BMJ* 372 (March). https://doi.org/10.1136/bmj.n71.

Peters-Burton, E.E. 2014. “Is There a ‘Nature of STEM’?” *School Science and Mathematics* 114 (3): 99–101. https://sharepoint.ecn.purdue.edu/epics/teams/Public%20.

Pleasants, Jacob, and Joanne K. Olson. 2019. “What Is Engineering? Elaborating the Nature of Engineering for K-12 Education.” *Science Education* 103 (1): 145–66. https://doi.org/10.1002/sce.21483.

Rogers, George E. 2006. “The Effectiveness of Project Lead the Way Curricula in Developing Pre-Engineering Competencies as Perceived by Indiana Teachers.” *Journal of Technology Education* 18 (1): 66–78.

Silk, Eli M., and Christian D. Schunn. 2008. “Core Concepts in Engineering as a Basis for Understanding and Improving K-12 Engineering Education in the United States. Final Draft of a Report to the National Academy of Engineering Committee on Understanding and Improving K-12 Engineering Education in the United States.” http://www.ams.org/samplings/math-awareness-month/08-reputation.pdf.

Simarro, Cristina. 2019. “El Paper Del Tinkering En l’educació STEM No Formal.”

Simarro, Cristina, and Digna Couso. 2021. “Engineering Practices as a Framework for STEM Education: A Proposal Based on Epistemic Nuances.” *International Journal of STEM Education* 8 (1). https://doi.org/10.1186/s40594-021-00310-2.

Smit, Renée. 2016. “The Nature of Engineering and Science in Curriculum: A Case Study in Thermodynamics.”

Varnado, Terri E., and Leslie K Pendleton. 2004. “Technology Education/Engineering Education: A Call for Collaboration.” In *Proceedings of the International Conference of Engineering Education*. Gainesville.

Vasquez, Jo Anne, Michael Comer, and Cary Sneider. 2013. “What Are the STEM Practices?” In *STEM Lesson Essentials, Grades 3-8. Integrating Science, Technology, Engineering, and Mathematics*, 192. Heinemann.

Williams, P. John. 2010. “Technology Education to Engineering: A Good Move?” *The Journal of Technology Studiees* 36 (2): 10–19. https://doi.org/10.21061/jots.v36i2.a.2.

A FRAMEWORK TO PREPARE ACADEMIC AND INDUSTRY EDUCATORS TO DELIVER CONTINUING ENGINEERING EDUCATION

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Conference Key Areas*: Building the capacity and strengthening the educational competences of engineering educators; Building the capacity and strengthening the educational competences of engineering educators*

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ABSTRACT

The World Economic Forum emphasises the importance of developing individual skills, as part of a "Skills Economy," and that not developing skills within a workforce is an operational and business risk. Within a multi-generational workforce, this places great emphasis on workforce development, including up- and re-skilling for older generations, and also providing targeted development of younger generations (as part of retaining capable graduates within organisations). This will require capable and effective Continuing Engineering Education (CEE) Educators to design and provide these learning activities (courses) in engineering disciplines. Whilst greater emphasis is now placed on educator training and development in Universities, this training is typically focused on students who have recently left school. It does not necessarily prepare staff to design and deliver training activities for professional engineers. Currently, there is a lack of an outline of key considerations to include in a development course for CEE Educators, and it is this gap that this paper addresses.

This paper will explore the different educational paradigms/frameworks suitable for CEE educators to facilitate the effective learning of practising engineers. Firstly, a review of literature relating to principles and considerations for the education of professional learners, particularly in the area of engineering, was carried out to create a proposed model that would be required in a CEE Educator training programme. A set of recommendations for developing CEE Educator training is proposed.

1 INTRODUCTION

1.1 Skills economy and importance of Continuing Engineering Education courses

Recent changes in society and technology - Industry 4.0, Industry 5.0, and Society 5.0 (Huang et al. 2022) - have highlighted the need for practising engineers to continue developing themselves and the importance of lifelong learning and ongoing professional development. As such, there is an up-and-re-skilling need to meet society's and communities' emergent and future needs. Additionally, in many countries registered, professional engineers have a requirement to engage in Continuing Professional Development (CPD) every year to maintain their currency (ENGINEERS EUROPE 2024; International Engineering Alliance 2013). So, there is a clear demand for impactful CPD courses.

Whilst many universities have long-standing engagement with industry in the provision of CPD and Continuing Engineering Education (CEE) courses, these courses were not always a core strategic focus of universities and departments. In many cases they were individual initiatives of faculty members with close ties to the industry, and personal interest in CEE. Consequently, educators are often not given specific support to prepare them to deal with professional, practising engineers with potentially different motivations and differing personal and professional circumstances.

1.2 Current approaches to educator development

Most current approaches for supporting lifelong educator development, both general and more engineering-specific, exhibit a lack of a systematic approach. Many previous works focus their efforts on identifying the necessary competencies and skills of such educators (Van den Broeck et al. 2022; Bernhardsson and Lattke 2011). These can be very broad, ranging from teachers shifting to facilitators while being leading experts in their field, all the way to being able to act as psychologists when necessary (Chakrabarti et al. 2021). Other works focus on how the institutions hosting CEE educators must develop to support them regarding equipment and policies, create learning communities, and offer incentives for their development (Miranda et al. 2021). The common denominator here is that in both levels, the focus is on "what" needs to be done, yet the "how" is still not well discussed. Besides the case of the AGADE and the EMAE projects that created a training course and a Master’s programme, respectively, for educators, most approaches seen in the literature on education professionalization do not offer a clear professionalization path (Bernhardsson and Lattke 2011). They suggest, among other things, that teachers should develop through experiencing being a CEE educator, try to be the leading expert in their field, perform relevant research, individually invest time for their own development (Collins 2009), and seek the help of AI and technology (Diaz Lantada 2020). Therefore, the lack of organized knowledge and models ("how") that can bridge the competencies required from CEE educators ("what") is already identified as a core issue, and this paper will aim to address it (Ioannou 2023).

1.3 Aim/Focus

Consequently, this research aimed to create a development framework for CEE Educators that drew together factors relevant to support efficacy of practice and excellent learning by CEE Educators. Moreover, recommendations are made to those responsible for supporting faculty in delivering effective CEE learning activities.

2 METHODOLOGY

A sequential, multi-qualitative method was used to create the CEE Educator Development Framework. Firstly, a review of the literature was undertaken to understand a) existing practices in preparing engineering educators to work with professional and practising learners (as outlined above) and b) educational models and factors that are similar and different when considering professional learners, and what this means for preparing educators to support these learners.

Secondly, these factors were synthesised into a CEE Educator Development Framework highlighting the specific areas required to improve CEE course development and delivery. Illeris' learning model provides a helpful framework to scaffold these factors, as this model focuses on the presence and interaction of two different processes – learner and their environment; and cognitive process of acquisition (Illeris 2018).

In terms of limitations, this exploratory study uses a non-systematic literature review to determine the model factors, so future work will look to enhance this model with an evidence synthesis method. After this, the validation and utility of the model will need to be evaluated against a broader range of institutional practices and contexts.

3 DEVELOPING A CONTINUING ENGINEERING EDUCATOR DEVELOPMENT MODEL

Professionals need continuous engineering education to meet current and future societal challenges, but professional learning occurs differently than in universities. These professional learners, often with several years of working experience already, have different mindsets and needs regarding content and skills acquisition. Additionally, appropriate forms of delivery of information are essential to meet engineers' needs. Professionals frequently seek just-in-time information to meet acute gaps in knowledge due to the rapid development of technology and interdisciplinary challenges. Moreover, the context and motivation for learning are notably different, so any development of a CEE Educator framework needs to incorporate these critical aspects.

For professional learners, theories such as Andragogy and Heutagogy are highly relevant (Chacko 2018). Knowles' andragogical principles highlight personal factors, such as being intrinsically motivated to learn, knowing why they are studying and taking responsibility for their decisions, and contextual, in that they want to draw on experiences and that the learning is applicable (Youde 2018). Heutagogy is linked with a self-directed learning (and a learner-centric) model, where the learner wants agency in how they study, and the CEE educators act as "activators, deliberate change agents and as directors of learning" (Hattie 2010, 25). Moreover, CEE educators actively use a combination of "reciprocal teaching, feedback, teaching students self-verbalization, meta-cognition strategies, direct instruction, mastery learning" (ibid 2010, 243). These approaches may not always be evident in standard educator preparation but are essential for understanding motivation, learning, and teaching approaches suitable for a CEE context.

Context is essential in the context of professional learning, as professional learning can take place both in formal and informal settings. Hence, educational theories such as *Situated Learning (SL)* theory and *Cognitive Apprenticeship* (Collins et al. 1989; 2009) that focus on the interaction between learning and the social situation in which the learning of a skill occurs are relevant (Julien 2021). In situated learning, social co-participation activities in which social engagements occur are favourable elements to provide a context and facilitate learning (e.g. creating learning experiences in which real-life activities resembling and taking place in practical work environments are suitable contexts that promote deep learning and develop skills). SL theory links with experiential and workplace learning (Helyer et al. 2020), which are relevant in engineering contexts (Rouvrais, Remaud, and Saveuse 2020), and to a*ctive learning* methods (Kolb and Kolb 2020). Problem-based and similar inquiry and critical thinking methods encourage problem-solving and meta-cognitive learning that stimulates skills development. Moreover, constructivist approaches (Woozley 2020) are relevant in stimulating collaborative and reflection settings.

Exploring the different learning contexts further, Fink refers to company-oriented methods, such as just-in-time or on-demand targeting defined topics/goals, and university-oriented methods, which are already made *and target a group of companies or individuals* (Fink 2001). Additionally, competency-based education and its application in engineering continuing education programs (Chappell, Gonczi, and Hager 2020) are critical as they align with industry requirements and to impactful (lifelong) learning amongst professionals (Pichette and Watkins 2018). Workplace learning, such as on-the-job learning that takes place in the professional environment, can be an effective focus company learning approach and can take the form of courses (formal teaching or training), research-oriented in which professionals work in a project within the working context), or on-the-job training where employees learn in the workplace (Nørgaard et al. 2024). Furthermore, collaboration models between academia and industry in delivering continuing engineering education and discussed strategies for fostering partnerships, identifying industry needs, and co-designing educational programs (Bikard, Vakili, and Teodoridis 2019) are pertinent to consider, particularly how this impacts the competences that a CEE Educator will need to possess to deliver collaborative courses effectively.

Consideration is also needed in how best to deliver the education, considering learners want agency and flexibility. Flexible learning provides opportunities for gaining the necessary knowledge and skills regardless of time, location, and level (Mathou, Sarazin, and Dumay 2023). Flexibilization, enabled by digital tools and systems, brings training for professionals close to their reality. In this regard, modularization (Nielsen et al. 2021) is frequently used to provide individual, functional units of knowledge that can be tailored to the professional learners' level. Modules, commonly offered digitally in Learning Management Systems, provide independent pieces of information accompanied, in most cases, by feedback and self-assessment exercises. Modules also include simulations of production systems (Svetlik 2020) to enable engineers to manage their own learning process and monitor progress. Furthermore, the self-contained modules represent tasks that, in the form of building blocks, can also be aligned to other modules or can be offered as just-in-time components; these modules are a functional resource to provide information when needed, to refresh knowledge, to engage in tasks by following pre-knowledge modules on the knowledge they miss, and alike, for specific tasks.

Interestingly, flexibilization and modularization can bring efficiency as individual learning takes place, and educators and companies can reduce manual efforts as if the simulation can resemble scenarios that serve as effective use cases.

The above review of educational theories is summarised in Table 1 below, where the considerations above have been mapped to one of the two dimensions of Illeris' model (Illeris 2018). The synthesised model for CEE Educator Development is presented in Figure 2. The factors identified resonate with the co-researchers (experienced CEE practitioners and educators), so they are credible (within the limitation of these educators' current experiences and practices).

Table 1: Summary of educational concepts relevant to developing the CEE Educator framework (mapped to whether they relate mainly to the incentive or interaction dimensions of Illeris's (2018) learning model).

Educational theory/approach	**Characteristics**
Andragogy (Knowles, Holton & Swanson, 2014; Youde 2018; Chacko 2018)	**Incentive**: 1) Intrinsic motivation; 2) Know why they are learning; 3) Take responsibility for their decisions.
	Interaction: 4) Apply experiences.
Situated Learning Theory (Julien 2021)	Content;
	Incentive & Interaction: 1) Context; 2) Community Participation.
Cognitive Apprenticeship (Collins, Brown & Newman 2009)	**Incentive:** Social interaction.
	Interaction: 1) Modelling; 2) Coaching; 3) Scaffolding; 4) Skill development.
Constructivism (Piaget 1971; Rannikmäe, Holbrook, and Soobard 2020)	**Incentive:** 1) Knowledge is socially constructed; 2) Knowledge is personal; 3) Motivation drives learning
	Interaction: 4) Knowledge is constructed actively (rather than passively absorbed); 5) Learning is an active process;
Experiential and active learning methods (Kolb and Kolb 2020)	**Interaction:** 1) Learning by doing; 2) Learning through reflection on doing; 3) Concrete experience, reflective observation, abstract conceptualization, active experimentation
Company-oriented methods (Nørgaard et al. 2024)	**Incentive:** 1) On-demand targeting defined topic/goals; 2) real-life and authentic learning.
	Interaction: 3) Project-oriented activities; 4) Workplace learning; 5) Collaborative/co-creation; 6) Interdisciplinary learning.
Flexibilization/blended learning (Mathou, Sarazin, and Dumay 2023)	**Incentive:** 1) Self-directed learning.
	Interaction: 2) Modularization; 3) Tailor-made; 4) Use of simulation.

Competency-based education (Chappell, Gonczi, and Hager 2020)	**Incentive:** 1) Competency orientation.
	Interaction: 2) Focus On Mastery; 3) Integrated Development; 4) Relevance To Real-World; 5) Learner-Centric; 6) Outcome-Based; 7) Differentiated.

Figure 1: CEE Educator Framework, structured after Illeris (Illeris 2018) .

4 FIVE RECOMMENDATIONS FOR ADOPTING THIS CONTINUING ENGINEERING EDUCATION FRAMEWORK

The CEE Educator Framework above recognises that CEE training and education come from various providers and will involve both formal and informal development methods (whether separately or as part of an integrated approach). This model seeks to be sufficiently general, so it has consciously not examined content (that may be either leading-edge knowledge, for example, driven by AI and latest technology advances, or around inter- and trans-disciplinary approaches that seek to equip practising engineers with more advanced or new skills to tackle emerging challenges in society and within their workplaces). Recognising the importance of the learner's motivation (incentive), a learner-centric model was used to construct the CEE Educator Framework. A set of recommendations based on this framework are outlined below (in no particular order of importance):

1) A learner-centric model is essential within the framework, and any CEE Educator course needs to equip the educator with theories, concepts, and practical tools to understand the motivations of their learners. Moreover, making this explicit in marketing materials and highlighting these motivations within the course (for both learner and educator) is essential.

2) Related to this first point is the create CEE Educator courses that respond to motivations (whether shaping to match the intrinsic motivation or through formal recognition and reward – external motivation – within their organisational contexts);
3) Understanding the motivations and the nature of the content will influence how best to deliver any CEE Educator course, so a critical learning outcome for any CEE Educator course will be that the educator understands how incentive and interaction need to be aligned. Therefore, courses for CEE Educators need to introduce them to different modalities of CEE courses:
    a. Leading-edge technical courses where the CEE educator will likely be the expert. Within the CEE Educator courses, then education models need to consider how best to share this content whilst engaging the reasons why these professional learners (and their organisations) can benefit from this new knowledge; this could include clear examples;
    b. Transversal skills courses are where you try to develop professional competences. There is a need within the CEE Educator courses to introduce how best to link the intended skills back to the individual in their professional context, whether from modeling, role-playing, or through workplace learning and reflective practice;
    c. "Organisational change" courses are where learners seek to understand how to best support change, such as diversification or responding to technological disruption. Ensuring learners can critically recognise how best to adopt this into their practice is vital within CEE educator courses. Facilitating and encouraging critical reflection in learners will be more important in these instances.
4) The CEE Educator courses around assessment practices (if these are formal courses leading to credits) need to introduce authentic and aligned strategies to the motivational aspects. As such, emphasis on workplace, work-based, and reflective assessments and simulations will need further exploration; this may require collaboration between educators and employers;
5) In the development of any CEE Educator course, then recognition needs to be given that these courses must model best practice, such as flexibility, allowing self-directed and personalised navigation and pace of study, as well as encouraging educator competences (such as being comfortable to facilitate and encourage co-discovery).

5 SUMMARY AND FUTURE WORK

This paper has synthesised a CEE Educator framework from various educational theories relevant to professional learning within a learner-centric model. Illeris' model was adopted to structure this model, highlighting the interdependency between the learners' motivation and how any CEE course should be delivered.

Recognising the limitations of this current research, then future research needs to focus on: a) a more systemic review of educational factors, using evidence synthesis methods; b) conducting a survey of current CEE providers to understand how they currently support their educators, to test and refine the current framework; c) to evaluate the current model against current practices more rigorously; d) to develop accompanying guidance notes and case studies to support those who want to create CEE Educator courses; and e) to explore more fully around the acquisition (content –

incentive) dimension, as professional learners may be experts in the practice where the educator has less expertise, so the educator may feel challenged in how best to adapt their teaching practices to make the most of this rich learning environment that allows learners and educator to co-discover and learn from each other.

REFERENCES

Bernhardsson, Nils, and Susanne Lattke. 2011. “Core Competencies of Adult Learning Facilitators in Europe.”

Bikard, Michaël, Keyvan Vakili, and Florenta Teodoridis. 2019. “When Collaboration Bridges Institutions: The Impact of University–Industry Collaboration on Academic Productivity.” *Organization Science* 30 (2): 426–45. https://doi.org/10.1287/orsc.2018.1235.

Chacko, Thomas V. 2018. “Emerging Pedagogies for Effective Adult Learning: From Andragogy to Heutagogy.” *Archives of Medicine and Health Sciences* 6 (2): 278. https://doi.org/10.4103/amhs.amhs_141_18.

Chakrabarti, Soma, Patricia Caratozzolo, Bente Norgaard, and Ellen Sjoer. 2021. “Preparing Engineers for Lifelong Learning in the Era of Industry 4.0.” In , 518–23. https://doi.org/10.1109/WEEF/GEDC53299.2021.9657247.

Chappell, Clive, Andrew Gonczi, and Paul Hager. 2020. “Competency-Based Education.” In *Understanding Adult Education and Training*, 191–205. Routledge.

Collins, Allan. John Seely Brown, and Susan E. Newman. 1989. *Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics (Technical Report No. 403).* BBN Laboratories, Cambridge, MA.

Collins, Jannette. 2009. “Lifelong Learning in the 21st Century and Beyond.” *Radiographics: A Review Publication of the Radiological Society of North America, Inc* 29 (2): 613–22. https://doi.org/10.1148/rg.292085179.

Diaz Lantada, Andres. 2020. “Engineering Education 5.0: Continuously Evolving Engineering Education.” *International Journal of Engineering Education* 36 (November): 1814–32.

ENGINEERS EUROPE. 2024. “FEANI Policy on Continuing Professional Development.” 2024. https://www.engineerseurope.com/.

Fink, Flemming K. 2001. “Modelling Continuing Professional Development in an Innovative Context.”

Hattie, John. 2010. *Visible Learning: A Synthesis of over 800 Meta-Analyses Relating to Achievement*. Reprinted. London: Routledge.

Helyer, Ruth, Tony Wall, Ann Minton, and Amy Lund. 2020. *The Work-Based Learning Student Handbook*. Bloomsbury Publishing.

Huang, Sihan, Baicun Wang, Xingyu Li, Pai Zheng, Dimitris Mourtzis, and Lihui Wang. 2022. “Industry 5.0 and Society 5.0—Comparison, Complementation and Co-Evolution.” *Journal of Manufacturing Systems* 64 (July): 424–28. https://doi.org/10.1016/j.jmsy.2022.07.010.

Illeris, Knud. 2018. “A Comprehensive Understanding of Human Learning.” In *Contemporary Theories of Learning*, 2nd ed. Routledge.

International Engineering Alliance. 2013. “Graduate Attributes & Professional Competencies.” 2013. https://www.ieagreements.org/.

Ioannou, Nicoletta. 2023. “Professional Development of Adult Educators: A European Perspective.” *International Review of Education* 69 (July): 379–99. https://doi.org/10.1007/s11159-023-10014-0.

Julien, John. 2021. “Explaining Learning: The Research Trajectory of Situated Cognition and the Implications of Connectionism.” In *Situated Cognition*. Routledge.

Knowles, Malcolm S., Elwood F. Holton III, and Richard A. Swanson. 2015. *The adult learner: The definitive classic in adult education and human resource development*. Routledge.

Kolb, Alice, and David Kolb. 2020. “Eight Important Things to Know about the Experiential Learning Cycle.” *Australian Educational Leader* 40 (3): 8–14. https://doi.org/10.3316/informit.192540196827567.

Mathou, Cécile, Marc A. C. Sarazin, and Xavier Dumay. 2023. “Reshaping the Teaching Profession: Patterns of Flexibilization, Labor Market Dynamics, and Career Trajectories in England.” In *The Palgrave Handbook of Teacher Education Research*, edited by Ian Menter, 185–210. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-16193-3_59.

Miranda, Jhonattan, Christelle Navarrete, Julieta Noguez, José-Martin Molina-Espinosa, María-Soledad Ramírez-Montoya, Sergio A. Navarro-Tuch, Martín-Rogelio Bustamante-Bello, José-Bernardo Rosas-Fernández, and Arturo Molina. 2021. “The Core Components of Education 4.0 in Higher Education: Three Case Studies in Engineering Education.” *Computers & Electrical Engineering* 93 (July): 107278. https://doi.org/10.1016/j.compeleceng.2021.107278.

Nielsen, Morten Skogstad, Ann-Louise Andersen, Thomas Ditlev Brunoe, and Kjeld Nielsen. 2021. “Modularization Across Managerial Levels and Business Domains: Literature Review & Research Directions.” *Procedia CIRP*, 54th CIRP CMS 2021 - Towards Digitalized Manufacturing 4.0, 104 (January): 3–7. https://doi.org/10.1016/j.procir.2021.11.005.

Nørgaard, Bente, Juebei Chen, Carla Kornelia Smink, Aida Guerra, and Xiangyun Du. 2024. “Engineering Educators’ Professional Learning for Educational Change in a PBL-Base and Cross-Institutional Programme in Africa: A Q-Study.” *European Journal of Engineering Education* 49 (2): 236–56. https://doi.org/10.1080/03043797.2023.2250738.

Piaget, Jean. *The theory of stages in cognitive development* (1971).

Pichette, Jackie, and Elyse K Watkins. 2018. “Competency-Based Education: Driving the Skills-Measurement Agenda.”

Rannikmäe, Miia, Jack Holbrook, and Regina Soobard. 2020. “Social Constructivism—Jerome Bruner.” In *Science Education in Theory and Practice: An Introductory Guide to Learning Theory*, edited by Ben Akpan and Teresa J. Kennedy, 259–75. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-43620-9_18.

Rouvrais, Siegfried, Bernard Remaud, and Morgan Saveuse. 2020. “Work-Based Learning Models in Engineering Curricula: Insight from the French Experience.” *European Journal of Engineering Education* 45 (1): 89–102. https://doi.org/10.1080/03043797.2018.1450846.

Svetlik, Jozef. 2020. *Modularity of Production Systems*. https://doi.org/10.5772/intechopen.90844.

Van den Broeck, Lynn, Sofie Craps, Una Beagon, Johanna Naukkarinen, and Greet Langie. 2022. *Lifelong Learning as an Explicit Part of Engineering Programmes: What Can We Do as Educators? A Scoping Review*. https://doi.org/10.5821/conference-9788412322262.1327.

Woozley, A. D. 2020. *Theory of Knowledge: An Introduction*. London: Routledge. https://doi.org/10.4324/9781003074663.

Youde, Andrew. 2018. “Andragogy in Blended Learning Contexts: Effective Tutoring of Adult Learners Studying Part-Time, Vocationally Relevant Degrees at a Distance.” *International Journal of Lifelong Education* 37 (2): 255–72. https://doi.org/10.1080/02601370.2018.1450303.

DEVELOPING SOCIALLY RESPONSIBLE ENGINEERS THROUGH ENGINEERS WITHOUT BORDERS' ENGINEERING FOR PEOPLE DESIGN CHALLENGE

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Conference Key Areas: *Teaching the knowledge, skills and attitudes of sustainable engineering; educating the whole engineer: teaching through and for knowing, thinking, feeling and doing.*
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ABSTRACT

Engineers can play a significant role in addressing the current and future global challenges, but such an approach will require innovative educational approaches to nurture the required competences. The Engineering for People Design Challenge (EfPDC) from Engineers with Borders (EWB) is one such innovative approach for engineers to develop a better understanding of sustainable development and their place as an engineer to impact positively on people and planet. EWB provide an annual design brief that requires students to develop human-centred solutions to a complex, community-based challenge. Whilst some evaluation of the adoption of this programme within engineering programmes exists, currently there is limited evaluation in the UK of the EfPDC. This research aims to determine what competences are developed, using the competency frameworks of UNESCO and EWB to structure the findings. Key findings highlight that a range of skills relevant to nurturing responsible engineers are developed through the EfPDC, including greater empathy for communities (end-users), ethical decision making and collaboration.

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Also, the UNESCO and EWB competency frameworks help to determine what is being developed already and provide a frame for how to enhance future deliveries.

1 INTRODUCTION

1.1 Engineering for Sustainable Development

It is recognised that engineering can play a significant role achieving the UN Sustainable Development Goals (UNESCO 2021). So, unsurprisingly these requirements are being reflected in requirements for professional registration as an engineer (Taylor 2018; WFEO 2018), including in the accreditation of engineering education programmes (ENAEE 2022; Engineering Council UK 2020). Moreover, it is acknowledged that innovative approaches are required to facilitate the development of the required sustainable engineering competences (UNESCO 2021) and to make engineering a more inclusive profession (NEPC 2024). However, this requires a shift in how engineering programmes are delivered to create the changemakers of the future (Hitt et al. 2023; EWB 2024).

One such approach to nurture these future changemakers is the Engineering for People Design Challenge (EfPDC), organised by Engineers Without Borders (EWB, 2023a). This Design Challenge is an annual competition where EWB provide a rich, high-quality, community-based design brief. The location of the community is different each year, and in recent years has included Cambodia, Glasgow (Scotland), Johannesburg amongst others. Participation in EfPDC is voluntary, with universities signing up to this challenge, and national competitions are held in a range of countries, e.g., in UK, Australia, USA, South Africa. In the EfPDC student teams tackle this open, community-focused design brief to design human-centred, engineering solutions. These solutions respond to the needs and desires of that community, with creating relevant long-term solutions of benefit to the community being a key success criterion of the competition.

Some evaluation of the EfPDC has taken place already, with many studies in the USA and Australia (e.g., Brodie et al, 2013), but some of these studies being over 10 years ago. There is one study in the UK (Poursharif et al., 2021) that examined the implementation of the EfPDC at one UK university, using a one-week intensive delivery with students across different year groups and from different disciplines volunteering to participate; outcomes showed improvement in a range of importance skills (ethical decision making; problem solving; creative thinking and communication). Of note, how each university embeds the EfPDC challenge within their context varies – from voluntary to embedded within a module or course; from single programme to multi-disciplinary; from single year to across year groups. Therefore, with only one published UK evaluation then there is clearly a gap of evaluation of EfPDC in UK universities and to reflect the diverse ways in which EfPDC can be implemented. Moreover, there is a need for further contemporary evaluation of EfPDC, and one that reflects current thinking around Education for Sustainable Development and development of relevant skills as competences. This study has chosen the UNESCO (2018) Competences and Global Competency Compass from EWB (2023) frameworks to consider which competences are developed within the EfPDC.

1.2 Context of this research and research question

Glasgow Caledonian University (GCU) in Scotland offers the EfPDC within a credit-bearing module that is a mandatory part of the students' first semester of their programme of study. Students engage with the challenge over one semester (12 weeks) in multi-disciplinary teams; students from three different programmes take this module and were mixed as equitably as possible within timetabling constraints. A Design Thinking approach is used throughout to introduce students to human-centric and user-specific design (Figure 1), with encouragement to empathise (McDonagh and Thomas, 2010). Students engage in two-hour workshops each week with their team supplemented by self-study time where teams complete follow-up creative, research and design activities; workshop activities are supported by tutors and facilitators. Assessment is based on producing a team outcome report (week 12), team presentation (week 6) and an individual reflective essay about the experience (week 12).

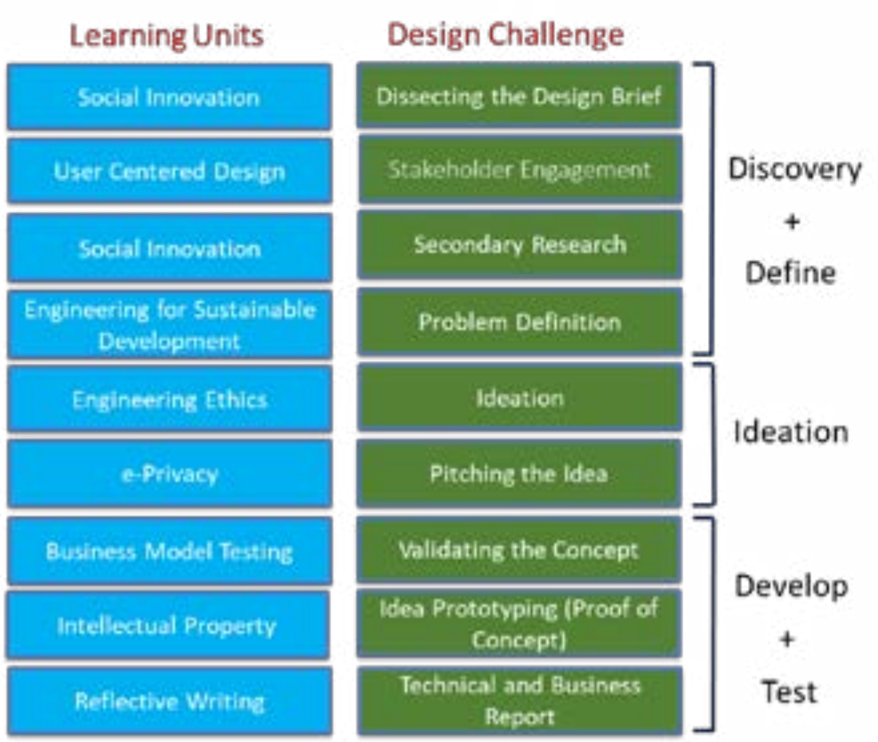

Figure 1: overview of topics covered (learning units), relationship to the Engineering for People Design Challenge and to Design Thinking

Therefore, the research question for this research is "Which sustainable development competences do students participating in the Engineering for People Design Challenge gain?"

1.3 Engineering for Sustainable Development and Global Responsibility competences

Particular competences are required for engineers to engage successfully within sustainable development projects, particularly those that seek to also develop global and socially responsible competences. For this research two relevant competency frameworks have been adopted: 1) the UNESCO (2018) model of competences for sustainable development, and 2) the EWB (2023) Global Competency Compass. The competences outlined in these frameworks are summarised in table 1. There are overlaps in these – such as in systems thinking, collaboration, anticipatory (purposeful).

Table 1: competences for sustainable development (UNESCO, 2018) and global responsibility (EWB, 2023).

Sustainable Development Competences	**Global Responsibility Competences**
- Systems thinking - Anticipatory - Normative - Strategic - Collaboration - Critical thinking - Self-awareness - Integrating problem-solving	- Responsible - Professional value; Sound reasoning; Technology stewards - Purposeful - Life-centred design; Building resilience; Advocate - Inclusive - Diversity, equity and social justice; Facilitates; Creative collaborator - Regenerative - Social and ecological well-being; Mitigating and adapting; Systems thinker

2 METHODOLOGY

A survey method was used to evaluate the competences developed during the Engineering for People Design Challenge. As this research is based on a continuation of previous research around this module before EfPDC challenge was implemented (Nesbitt and Smith 2022), as well as reflecting future comparative research with another UK university that has embedded the EfPDC in a different manner, then the existing questionnaire was refined based on discussions, as well as to align with the existing ethical approval (approval of 7th September 2023). The areas addressed by the questionnaires were around identity, sustainability and sustainable development, and skills and competences. The questionnaire had a set of Likert-style responses, as well as more open questions for students to complete.

Pre and post-surveys at GCU were administered via MS Forms. Students were given time in scheduled classes to complete the survey, but voluntarily participation was emphasised. A “pre” survey was conducted in week 2 of the semester and asked students to consider previous team working (before university) and the level of confidence and skills that they possessed. The “post” survey being conducted in the last two weeks of the semester, and asked students to self-evaluate on the skills that they possessed after the EfPDC. The list of skills was the same for both pre- and post-surveys and focused around a) the nature of the previous group work, such as how open-ended and society-focused the project was, as well as how much the project related to what the respondent cared about [7 aspects]; b) a range of skills across team-working, futures-thinking skills, responsible engineering skills [17 skills]; and c) confidence in some key skills – making ethical decisions, problem solving, creative thinking and in communicating [4 skills]. In the analysis then the 5-point Likert-style responses (strongly agree to strongly disagree for a) nature of project and c) confidence; and not at all to all the time for b) skills use) were translated to a 1 to 5 numeric scale (1 for strongly agree/all the time, and 5 for strongly disagree/not at all). Subsequently, means were calculated for the pre- and post-surveys and deltas analysed.

Qualitative responses (Table 2) were deductively coded against the competency frameworks above to seek greater insights; multiple codes were found in some of the richer qualitative responses. Through this coding by the researchers, then it was determined whether students had commented on a specific competency.

Table 2: Open-ended questions from post-survey that were coded

Question	Question
Q8	Has your perspective changed as to what an engineer does and can do based on this experience (participation in the Engineering for People Design Challenge)?
Q9	What does the term sustainable development mean to you?
Q10	How do you think the term sustainable development relates to the work of engineers and scientists?
Q13	What do you think that you have gained (personally, professionally, and socially) from this learning activity (Engineering for People Design Challenge)?

3 RESULTS

A response rate for the pre-survey was 81.3% (83 respondents from 102 students registered for the class) for the pre-survey, with 68 respondents indicating that they had previous team experiences (so 66.7% of respondents). The response rate was 61.8% (63 respondents) for the post-survey; 1 response from the post-survey was excluded as all answers were empty.

3.1 DOMINANT SHIFTS IN RELEVANT SKILLS AFTER EWB DESIGN CHALLENGE

For all bar one of the 28 questions, then there was a positive shift in the mean, with the one question ("the problem was given to us to solve") that showed a negative shift having a delta of 0.025 (so interpreted as no change). Positive shift means that students self-assessed that their agreement, utilisation of skills and confidence had increased. The positive deltas ranged from 0.045 to 0.914.

Figure 2 below shows most significant changes (delta >0.25) in skills (relating to 10 of the 17 skills). Students have viewed they have enhanced skills relating to responsibility, purpose, awareness of communities (inclusive), as well as developing regenerative solutions. These responses were supported in other questions (nature of project work with delta of 0.65 for "our solution would help a particular group of people in society" and 0.423 delta for "problem required us to generate a solution for end-user." Additionally, skills such as futures thinking (anticipatory), self-awareness, problem solving, and collaboration were identified by students as having changed through this experience. Again, these aspects were supported by the questions around confidence (Figure 3).

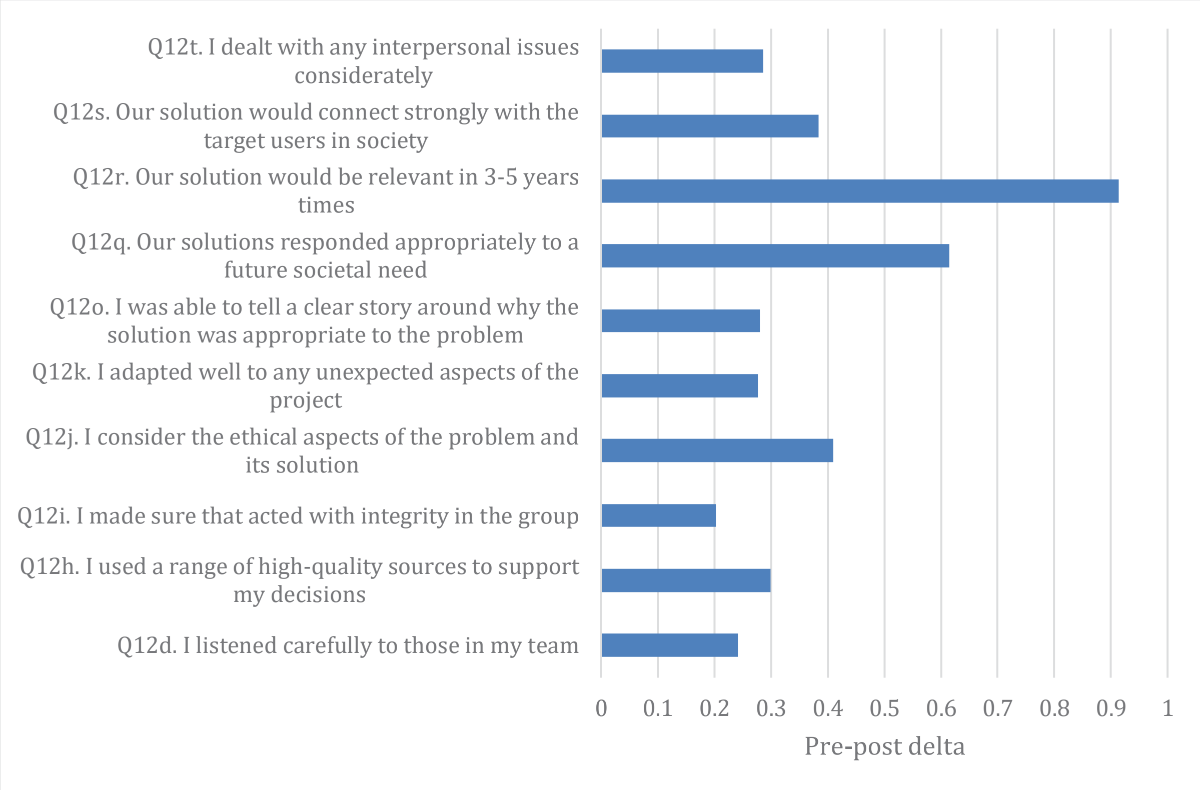

Figure 2: deltas in means between pre- and post-surveys

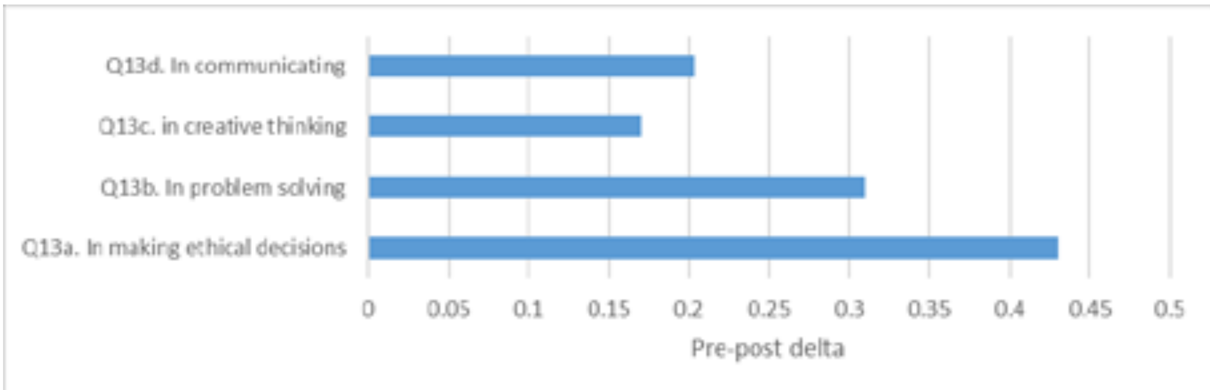

Figure 3: deltas in means between pre- and post-surveys around self-assessed confidence.

3.2 MAPPING AGAINST UNESCO ESD COMPETENCES

Table 3 highlights the count of competences from coding of four qualitative questions and demonstrates a broad coverage against the UNESCO ESD competences, particularly around collaboration:

> *"I gained a better understanding as to how to work in a team when personalities and ideas clash.*" (R13)

> *"I gained a better understanding as to how to work in a team when personalities and ideas clash.*" (R14)

Moreover, self-awareness around sustainable development was evident in responses, such as "*an engineer to me now is someone who has the ability to impact anyone or anything through their designs and initiative.*" (R15)

Also, integrated problem solving features in many responses of students:

"I have realised there is a much more thought-out process before you start tackling a problem." (R27)

"Learned how to assess design challenges from the ground up and ways in which I could improve my ideas." (R29)

It was also reassuring to see that some respondents appreciated the futures-focused competences that they were developing, although some responses appeared close to the Brundtland (1987) definition, so this requires further investigation.

Table 3: coding of qualitative responses from four questions against UNESCO ESD Competences

Competence	Q8	Q9	Q10	Q13
Systems Thinking	-	-	1	1
Anticipatory	-	11	5	1
Normative	2	-	7	3
Strategic	-	-	-	-
Collaboration	4	10	4	36
Critical Thinking	-	1	4	4
Self-awareness	17	31	27	6
Integrated Problem Solving	1	10	10	3
Not coded	49	16	13	14

The not-coded responses here related to one-word response (such as 'yes' or 'no'); short phrases (such as 'not too sure') as well as responses that could not be coded against the frameworks (such as referring to progress generally). There was also the isolated response that did not understand that developing competences around human-centred design was part of being an engineer:

"I feel like my perspective on University has changed rather than engineering due to the fact that I just feel like there is little to no aspect of engineering being introduced within this design part other than the socialising within the class but that can be said for any type of study/occupation." (R37)

This is an aspect that requires further investigation.

3.3 MAPPING AGAINST EWB GLOBAL COMPASS COMPETENCES

Table 4 below shows the count of mapping of the four open questions against the EWB Global Compass Competences (GCC). It is evident that responsibility, particularly professional value, is strongly reflected in responses:

They are here to make a better place for people who cannot do it themselves, they bear the responsibility of providing for the greater good of the world. (R35)

Engineers and scientists must take careful and thoughtful consideration to a number of factors when creating solution such as environmental factors, sustainability, human rights, future proofing, etc. (R36)

Also, it is clear that teamwork (mapped to Creative Collaborator) is a skill that students have developed during the EfPDC. Additionally, students have gained an understanding of socio-ecological systems, the UN SDGs and appreciate the long-term wellbeing of communities with many responses being similar to this response, "*Trying to develop economies and find solutions to problems without further harming environment*" (R53).

Table 4: coding of qualitative responses from four questions against EWB Global Compass Competences.

Dimension	Competence	Q8	Q9	Q10	Q13
Responsible	Professional Value	15	16	36	9
	Sound Reasoning	2	1	2	9
	Technology Steward	-	3	1	-
Purposeful	Life-Centred Design	1	2	2	2
	Building Resilience	-	-	-	-
	Advocate	-	-	1	-
Inclusive	Diversity, Equity & Social Justice	-	6	4	3
	Facilitation	-	-	-	-
	Creative Collaborator	2	-	-	28
Regenerative	Social & Ecological Wellbeing	2	27	23	1
	Mitigating & Adapting	-	1	1	-
	Systems Thinker	-	-	-	-
Not coded	Not coded	41	16	12	15

4 CONCLUSIONS AND NEXT STEPS

In conclusion, this research has identified that the Engineering for People Design Challenge embedded into a first-year, semester-long, credit-bearing module does indeed develop important competences and skills that are relevant to nurturing responsible engineers. With regards to the research question, which sought to understand which competences are developed, then the most frequently identified ones (Tables 3 and 4) relate to 1) anticipatory thinking, 2) collaboration, 3) self-awareness, 4) integrated problem solving, 5) professional value, 6) sound reasoning, 7) diversity, equity and social justice, 8) creative collaborator, and 9 social and ecological wellbeing.

Also, the competency frameworks used allow a clearer mapping of what skills the students perceive as having developed during the challenge. However, there is the odd voice that does not yet appreciate that engineering is a profession that addresses societal and human needs, and this requires further investigation.

Future work will be to move beyond cohort averages, to consider shifts in individual student's perceptions. Moreover, running focus groups to better explore these findings is planned. Furthermore, using the competency frameworks to explicitly discuss with students the skills that they have developed to support careers through workshops is planned. Finally, reviewing the teaching, learning and assessment approach through the lenses of the competency frameworks will seek to evaluate how the Design Challenge can be enhanced further, including how to assess these competences directly within the delivery by the tutors.

REFERENCES

Brodie, Lyn, Lesley Jolly, Caroline Crosthwaite, and Lydia Kavanaugh. "Improving First-year Engineering Education Using the Engineers Without Borders Australia Challenge: what worked for whom under what circumstances." In *2013 ASEE International Forum*, pp. 21-43. 2013.

Brundtland, Gro Harlem. 1987. “Our Common Future: Report of the World Commissoin on Environment and Development.” Accessed 1st April 2024. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

Buys, Laurie, Evonne Miller, Matthew Buckley, and Lesley Jolly. "The 'Engineers without Borders' Challenge: does it engage Australian and New Zealand students with sustainability?." In *Proceedings of the Ireland International Conference on Education (IICE-2013)*, pp. 123-128. Infonomics Society, 2013.

ENAEE. 2022. “Standards and Guidelines for Accreditation of Engineering Programmes.” Accessed 1st February 2024. https://www.enaee.eu/eur-ace-system/standards-and-guidelines/#standards-and-guidelines-for-accreditation-of-engineering-programmes.

Engineering Council UK. 2020. “The Accreditation of Higher Education Programmes. Fourth edition.” Accessed 1st February 2024. https://www.engc.org.uk/media/3464/ahep-fourth-edition.pdf.

Engineers Without Borders (EWB). 2023a. “Engineering for People Design Challenge.” Accessed 1st February 2024. https://www.ewb-uk.org/upskill/design-challenges/engineering-for-people-design-challenge/.

Engineers Without Borders (EWB). 2023b. “Development of Competency Compass.” Accessed 1st March 2024. https://www.ewb-uk.org/wp-content/uploads/2023/06/Simple-Version-of-Learning-Library.pdf.

Engineers Without Borders (EWB). 2024. “Reimagined Degree Map.” Accessed 27th March 2024. https://www.ewb-uk.org/reimagined-degree-map/.

Hitt, Sarah Jayne, Jonathan Truslove, and Cindy Cooper. "How To Use New Tools To Integrate Sustainability Into Engineering Teaching." *In SEFI Annual Conference Proceedings, Dublin, September 2023*.

McDonagh, Deana, and Joyce Thomas. "Rethinking design thinking: Empathy supporting innovation." *Australasian Medical Journal* 3, no. 8 (2010): 458-464.

NEPC. 2024. “Rethinking engineering and technology skills for a world in which both people and planet can thrive.” Accessed 27th March 2024.

https://nepc.raeng.org.uk/media/r3paa3og/nepc-engineers-2030-vision-and-principles-consultation-march-2024.pdf.

Nesbitt, Alan and Christopher J. M. Smith. “Nurturing future engineering skills through self-determined innovation and entrepreneurship project work: a case study of a Scottish University.” In *International Symposium of Engineering Education, Glasgow, Sept 2022.*

Poursharif, Goudarz, Tamer Panagiotis Doss, Rebecca Broadbent, and Gillian Knight. "Developing global engineers through interdisciplinary PBL and design thinking." In *2021 IEEE Global Engineering Education Conference (EDUCON)*, pp. 194-198. IEEE, 2021.

Taylor, Elizabeth. 2018. “Capacity Building for sustainable development through the International Engineering Alliance Accords.” Accessed 1st February 2024. https://www.wfeo.org/wp-content/uploads/stc-technology/IFEC-CAST/9-Elizabeth%20Taylor.pdf.

UNESCO. 2021. “Engineering for sustainable development: delivering on the Sustainable Development Goals.” Accessed 1st February 2024. https://unesdoc.unesco.org/ark:/48223/pf0000375644.

UNESCO. 21018. “Learning to transform the world: key competencies in education for sustainable development.” Accessed 1st February 2024. https://unesdoc.unesco.org/ark:/48223/pf0000261802.

WFEO. 2018. “WFEO Engineering 2030: a plan to advance the achievement of the UN Sustainable Development Goals through engineering.” Accessed 1st February 2024. http://www.wfeo.org/wp-content/uploads/un/WFEO-ENgg-Plan_final.pdf.

E4E – Engineers for Europe: a study about the future of Engineering profession

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Keywords: *E4E, Engineers Competences, Online Training, Skills Survey, Future Engineers*

ABSTRACT

The paper discusses a project focused on the future of the engineering profession and the emerging requirements for developing appropriate professional competencies. The aim of the project is to bridge the gap between society's needs for engineering performance and the provision of suitable education and training. It is structured into four chapters. The first chapter outlines the inception of the initiative,

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the formation of the consortium, and the operational methods during the funding period. The second chapter addresses the assessment phase, evaluating both current and future training needs for graduating and practicing engineers by offering relevant online courses. The third chapter details the design and preparation of the training courses for testing and validation. Finally, the fourth chapter explores potential scenarios and advancements for the engineering profession, considering adaptations to evolving societal needs for development and progress. Conclusions to define the strategy for the future of engineers and diagnostics of engineering training needed will be produced at the end of the project E4E.

1. INTRODUCTION

1.1. E4E Introduction and Description

The aim of the E4E project is to enhance understanding and insight into the engineering profession in Europe. The subsequent actions are geared towards enhancing the quality of engineering education and continuous training, fostering innovative capacity, and improving the effectiveness of the engineering workforce. Proposed methods include the establishment of an online training platform, the creation of strategic and benchmarking reports, conducting dedicated stakeholder surveys, and launching extensive dissemination campaigns to share produced outputs. The project also aims to develop digital bridging tools to facilitate seamless connections between training and practical application for active engineering professionals and between academia and engineering companies.

One of the key challenges to address within the E4E project is the information gap concerning the collection and accessibility of relevant data for stakeholders. Certain consortium partners, such as national professional engineering associations, can systematically contribute by conducting surveys among their members and maintaining ongoing dialogues with engineering companies and government agencies. These associations can offer comprehensive insights into member engineers' backgrounds, education, ongoing professional development, career paths, training needs, and labor conditions. Such data is crucial for informing effective policy-making and implementing reliable actions to support the education, training, and personal development of engineers and their respective businesses.

Another significant challenge tackled by the E4E project is the human resources aspect of the engineering landscape. There is a widespread shortage of engineers across most economies worldwide, and in Europe, this shortage underscores the need to promote and nurture the engineering profession to inspire current professionals and prospective students alike. Shifting demographics and changing perceptions of the engineering field have further exacerbated the scarcity of engineering talent. This situation raises pertinent questions about training programs, recruitment strategies, working conditions, salary structures, mobility opportunities, career advancement, and potential career setbacks.

1.2. Partners of E4E

The project brings together partners representing various sectors, including professional engineering organizations, academia, vocational education and training (VET) institutions, and companies. On the academic side, partners include universities of applied sciences, research universities, and European associations. In the business sector, partners consist of national engineering associations, supplemented by organizations such as engineering student associations, young engineers' groups, the council of engineering chambers and the association of the HVAC industry and professionals. Academic and vocational training partners play a crucial role in providing stakeholders involved in initial education and lifelong learning opportunities for engineers. Additionally, the consortium includes a quality accreditation agency for higher education programs like engineering.

Partnership comprises thirteen organizations from eight European Union countries, the project spans a duration of thirty-six months and receives a public grant of approximately EUR 1.5 million from the European Union Commission's Erasmus+ program. Coordination of the project is done by an European professional engineering organization with members that are national professional engineering organizations from 33 different countries (Engineers Europe, 1951). The project aims to establish a European Engineering Professional Skills Council, identify and define new trends in engineering education, and develop innovative training programs for the engineering profession. It's worth noting that the E4E project aligns with the objectives of current European policies in education and training, particularly in addressing future skills mismatches and promoting excellence in competence development for engineers. The project seeks to facilitate proactive dialogue between the engineering industry and the education and training sector, focusing on continuing professional development.

Among the project's outputs are the establishment of a permanent observatory of the engineering profession, the definition of entrepreneurial competencies for engineers, the creation of four online training courses tailored to emerging needs in the engineering field, and the proposal of an Engineering Skills Passport aligned with current European Union frameworks. Additionally, the project aims to develop an Engineers Europe Skills Compass to update the competencies required for the engineering profession. Task management within the consortium is divided among vertical and horizontal working groups dedicated to the six working packages. All Engineering stakeholders can participate in the project activities at any time since the significance of the work done will be more valuable with increased participation and diversified contribution.

2. METHOD FOR OVERVIEW OF COMPETENCES NEEDED

2.1. Description of Survey

The "Engineers for Europe" (E4E) project seeks to narrow the gaps between education, training, and industry while operationalizing EU competence frameworks. At the core of the E4E project lies the challenge of how educational innovations and curricula can align systematically and proactively with the evolving needs of industry and the increasingly dynamic and diverse roles that engineers play. As underlined in literature (Aljohani et al, 2022), there is a need to strike a balance between providing education that encourages the skills, values, and attitudes required by society at large and meeting the expectations of the market. The industries of the future require engineers who, as representatives of their technological domains, can leverage innovation and leadership to integrate specialized expertise with the ability to navigate creatively across boundaries in complex environments (Taylor, 2019). Project is coordinated by an European

Within the E4E project's second work package (WP2), there is a focus on skills monitoring and anticipation tools. WP2 aims to develop a sustainable and effective framework and systemic approach for identifying the skills and competences needed to address societal challenges. This framework entails assessing the current situation regarding the demand and supply of skills and competences for the engineering profession, with particular emphasis on non-technical aspects such as digital skills, green skills, and resilience through transversal, professional, and entrepreneurial skills. Additionally, it involves anticipating future needs, while the third work package considers strategic considerations regarding the evolution of skills demand and supply for the engineering profession.

The framework/methodology underscores an operational approach to analyzing the engineering profession, combining primary and secondary research methods to gather relevant data and identify opportunities and challenges. Primary research involves utilizing focus groups, interviews, and questionnaire-based surveys with representatives across the entire education, training, and industry spectrum. Secondary research relies on desktop analysis to capture specific trends in the engineering profession. The methodology aims to offer actionable insights to stakeholders in the profession on addressing skills shortages and mismatches and promoting the acquisition of digital, green, resilience, and entrepreneurial skills among engineers.

Over a period of two months, from May 15 to July 15, 2023, the project partners issued a survey to various stakeholders, comprising 33 closed questions. A total of 3045 fully completed responses were received. Responses from the seven countries' engineering professional organizations represented in the E4E consortium (Belgium, Germany, Greece, Spain, Ireland, Portugal and Slovakia) were isolated, resulting in 802 applicable responses. The survey covered topics such as sustainability, engineering education, stakeholder policies, and entrepreneurship. The majority (about 88%) of respondents were professionally active, with about 65% having more than 10 years of professional experience in either industry or the educational sector. The survey findings offer insights into the issues that the E4E project should prioritize to support European policy development through independent study and engagement as an impartial advisor. Concerning validation of the first survey, this phase is not addressed in the project during the first year of the project. The second survey is ongoing in the second year of the project and will be analysed in the next phase of the project.

2.2. Main Outcomes of Enquiry

The survey results provided fourteen insights relevant to the development of a Skills Strategy (E4E, 2023), which can be categorized into four overarching themes:

1. Role of Education Providers:

Engineers benefit most from competency-based learning, with critical thinking, collaboration, and communication skills identified as crucial professional requirements. Specific policy measures are needed to foster diversity and inclusion by encouraging experimental and problem-based learning opportunities that cultivate ethical decision-making skills. Additionally, attracting a more diverse talent pool to the engineering profession necessitates mentorship programs and diversity/inclusion training for professionals and organizations. Finally, universities/technical schools should collaborate with industry to develop formal or informal curricula aligned with job market needs.

2. Emphasizing Sustainability:

Increasing emphasis on sustainability and environmental concerns, alongside greater utilization of automation and AI in engineering processes, emerged as priorities for the engineering profession in the next five years (2023-2027). This requires innovation and technological advancement in renewable energy and green infrastructure, emphasizing sustainability principles in formal engineering education and training. Engineers play a crucial role in promoting green energy and efficiency by implementing new technologies and providing technical expertise and guidance to businesses, particularly SMEs, to encourage sustainable practices.

3. Employment Opportunities:

There is widespread agreement that the majority of new job opportunities will arise in completely new occupations or existing ones undergoing significant transformations in content and skill requirements. Concerns are raised about shortages of engineers in fields such as electrical/electronic, ICT, and agronomic/environmental engineering to support these growth areas. Additionally, respondents view skills gaps in the local labor market as a greater obstacle to business transformation (60%) than a shortage of investment capital (37%) across various industries.

4. Partnership:

Collaboration between industry and educational institutions, alongside investments and increased funding in research and development (R&D) for emerging technologies, are deemed the most effective tools for addressing skill shortages in digital, green, resilience, and entrepreneurship within the engineering profession. Entrepreneurship is recognized as a key competence for enhancing European competitiveness, with R&D efforts focusing on developing a social and green economy. Professional engineering organizations have a role in fostering an entrepreneurial mindset among engineers and promoting interdisciplinary collaboration among their members.

It is underlined that the project is ongoing until September 2025 and the results presented correspond to the first half of the project. These observations are preliminary in terms of the analysis of the engineering needs and will be complemented by the ensuing questionnaire that is more focused and concise.

3. Online Training Courses

3.1. Tailoring and Design

The E4E courses are carefully crafted to empower engineers, equipping them with advanced competencies (knowledge, attitudes, and skills) to augment their professional prowess. As such, the intended beneficiaries encompass engineers at qualification levels 5, 6 (technician and first-cycle degree – bachelor level), and 7 (second-cycle degree – master level). Drawing from the findings of research conducted to monitor trends in the engineering profession, project established clear objectives for developing courses aimed at fostering competencies deemed essential for all engineers, irrespective of their area of specialization. These competencies, defined according to the European Commission frameworks (EQF), are pivotal for the engineering profession.

Transversal skills pertinent to the engineering profession encompass green skills (sustainability), digital skills, entrepreneurship skills, and life skills, sometimes defined as soft skills. These four groups of skills (may also be designated as competencies) derive from the existing European Frameworks: GreenComp, DigComp, Entrecomp and Lifecomp (European Education Area, 2023) . The significance of green skills, including political agency, is increasingly pronounced (Atkisson et al., 2018), with engineers expected to address sustainability challenges set forth by the European Union, such as the transition to a circular economy and decarbonization.

Digital skills, such as information and data literacy, hold crucial importance in the contemporary engineering landscape (Van Den Bossche et al., 2019). Proficiency in digital tools and platforms enables engineers to streamline processes, boost productivity, and deliver innovative solutions with greater efficiency, thereby positioning them as catalysts for progress and agents of sustainable development across various sectors.

Entrepreneurship skills, such as opportunity recognition, empower engineers to innovate and commercialize solutions, thereby augmenting their technical prowess with invaluable competencies essential across diverse functions and roles within the profession (Fayolle et al., 2015). Engineers equipped with entrepreneurship skills not only spearhead technological advancements but also foster economic growth, job creation, and societal advancement by translating ideas into impactful solutions and ventures.

Soft skills, such as communication and teamwork, are indispensable for fostering effective collaboration and project management in engineering endeavors (Murthy et al, 2021). These skills are fundamentally linked to adaptability, change management, and societal engagement, encompassing principles of resilience. Professionals endowed with these transferable competencies enable companies and industries to address complex challenges, drive innovation, and make meaningful contributions to sustainable development.

These competencies, also called transversal and transferable skills, are essential for the engineering profession, as these are learned and proven abilities which are commonly seen as necessary or valuable for effective action in virtually any kind of work, learning or life activity. These competencies are 'transversal' because these are not exclusively related to any particular context (job, occupation, academic discipline, civic or community engagement, occupational sector, group of occupational sectors, etc.). (Cedefop, 2021).

3.2. Courses Composition

Each of these skill groups has been structured into individual courses. The intended learning outcomes/competencies for the E4E courses were selected from four frameworks: DigiComp (Vuorikari et al., 2022), GreenComp (Bianchi, 2022), EntreComp (Bacigalupo, 2016), and LifeComp (Sala, 2020). This resulted in a 'constructive alignment' (Biggs, 1996), (Biggs et al, 2011), (Loughlin et al, 2020) of the competencies/learning outcomes, with the learning objectives derived from these frameworks. The methodology employed for creating the E4E courses adopted a modular approach, ensuring that each of the four courses comprised at least three modules (EQF levels ranging from 4 to 7), each focusing on the development of competencies within the respective skill groups outlined in the mentioned frameworks.

All modules will be made available online without access restrictions, utilizing Open Educational Resources (OERs) such as micro-videos, papers, other documents, practical activities, tests, etc. The necessity for courses grounded in academia-industry collaboration was emphasized by the primary research survey results. A teaching manual will be provided for the local piloting of these courses.

Regarding assessment, the consortium will develop a Self-Assessment Tool (E4E SAT) for users to evaluate their level of readiness, understanding, and competence in transversal skills. As for certification, each course will be equivalent to 0.5 to 1.5 ECTS credit points in terms of workload, with a total duration of 12.5 to 45 hours, inclusive of synchronous hours, in-person training, and autonomous work conducted by the trainees. Certificates of participation will be issued by the partners delivering the courses. Additionally, participants will receive micro-credentials, operationalizing the "European Approach to Micro-Credentials" (European Commission, 2022).

4. CONCLUSIONS AND RECOMMENDATIONS

Surveys provide valuable insights into the literature concerning future engineering requirements, including professional demands and the competences graduates need for their future careers. These careers often lack clear identification at the outset of their educational journeys. However, as discussed by Fleming et al. (2024) in their analysis of the technical and professional skills essential in the engineering profession, it is also crucial to focus on the preferences of employers. This study, unlike prior studies that relied on disparate methods to aggregate multiple previous studies, analyzed a single sample of 26,103 job advertisements for engineering positions. This approach enabled them to identify a broader range of more specific professional and technical skills than previous studies conducted on a national scale, capturing the pulse of the engineering profession and offering a more refined understanding for the future.

Future surveys conducted by E4E might also consider evaluating engineering programs and the perceived alignment or misalignment between education and the competences required in the engineering sector. By adopting frameworks like the Systems Approach for Better Education Results in Workforce Development (World Bank, 2013) framework and utilized by Fleming et al. (2024), the project can gain insights into the gaps between educational offerings and the profession's requirements. Additionally, utilizing databases related to the engineering profession can provide further understanding of prevailing input/output synergies and factors facilitating them.

The contemporary engineering landscape necessitates a multifaceted skill set beyond technical expertise, encompassing green skills, digital proficiency, entrepreneurship, and soft skills. The E4E project aims to equip engineers with new competencies covering transversal knowledge, attitudes, and skills, with a focus on innovative entrepreneurship, digital, green, and life skills as part of Continuing Professional Development (CPD). CPD plays a pivotal role in enhancing transversal skills for engineers, preparing them to excel not only as technical specialists but also as versatile professionals capable of driving impactful change in a rapidly evolving world. By investing in CPD, engineers can cultivate skills vital for collaborating across disciplines, fostering innovation, and embracing emerging technologies confidently.

As for future actions, defining stakeholders with justification for their status and communication outreach is essential. These stakeholders may have national, regional, European, or global areas of influence, and relevant contacts should be collected and stored in the project Observatory. Engineers Europe should manage these active stakeholders during and after the project conclusion. Passive future activities should focus on providing information to all stakeholders, including data about the engineering profession, its academic, professional, social, or regulatory aspects. This information could be centralized in a platform like an observatory, addressing issues such as CPD provision for engineers, engineer salaries, qualification frameworks, current engineering trends, international agreements, relevant events, mobility schemes/tools, and potential future scenarios for the engineering profession.

Looking ahead, the observatory could assist in defining priorities for actions, such as the sustainability response of engineers as outlined in the UNESCO II Engineering report (Engineering for Sustainable Development). It could also compile examples of potential training opportunities for engineers, including additional competences that may become mandatory for active engineers. Moreover, the observatory could collect concrete data and training opportunities for engineers to promote sustainability in their actions and assess the influence of Artificial Intelligence (or Machine Learning) in the engineering profession.

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REFERENCES

Aljohani, N. R., Aslam, A., Khadidos, A. O., & Hassan, S.-U., Bridging the skill gap between the acquired university curriculum and the requirements of the job market: A data-driven analysis of scientific literature, Journal of Innovation & Knowledge, 7(3), 100190. 2022, https://doi.org/10.1016/j.jik.2022.100190.

Atkisson, A., & McDonnell, S. Green engineering: Environmentally conscious design of chemical processes. John Wiley & Sons, 2018.

Bacigalupo M. Kampylis P, Punie Y. and Van Den Brande L., “EntreComp: The Entrepreneurship Competence Framework”, EUR 27939 E, Luxembourg (Luxembourg): Publications Office of the European Union, 2016..

Bianchi, G., Pisiotis, U. and Cabrera Giraldez, M., GreenComp The European sustainability competence framework, Punie, Y. and Bacigalupo, M. editor(s), EUR 30955 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-46485-3, doi:10.2760/13286.

Biggs, J., “Enhancing teaching through constructive alignment”, Higher Education 32, 347–364, 1996, https://doi.org/10.1007/BF00138871.

Biggs, J., Tang, C., “Teaching for quality learning at university: what the student does”, Maidenhead: McGraw-Hill, 2011, ISBN 9780335242757.

Cedefop, The future of vocational education and training in Europe: volume 3: the influence of assessments on vocational learning, Luxembourg: Publications Office. Cedefop research paper, No 90, 2022 http://data.europa.eu/doi/10.2801/067378

E4E, D2.3, “Results of primary and secondary research: inputs to E4E Skill Strategy”, 2023, www.engineers4europe.eu.

Engineers Europe, https://www.engineerseurope.com/.

European Education Area, Strategic Framework, European Commission, 2023, https://education.ec.europa.eu/.

European Qualification Framework (EQF), “Description of the eight EQF levels”, 2017, https://europa.eu/europass/en/description-eight-eqf-levels.

European Commission, “Flexible, inclusive learning opportunities”, 2022, https://education.ec.europa.eu/education-levels/higher-education/micro-credentials.

Fayolle, A., Gailly, B., & Lassas-Clerc, N., “Assessing the impact of entrepreneurship education programmes: A new methodology”, Journal of European Industrial Training, 39(4), 309-331, 2015.

Fleming, G. C., Klopfer, M., Katz, A., & Knight, D., “What engineering employers want: An analysis of technical and professional skills in engineering job advertisements”, Journal of Engineering Education, 2024, https://doi.org/10.1002/jee.20581.

Loughlin, C., Lygo-Baker, S., & Lindberg-Sand, Å., “Reclaiming constructive alignment”, European Journal of Higher Education, 2020, *11*(2), 119–136, https://doi.org/10.1080/21568235.2020.1816197.

Murthy, K. Machet, T., “Systematic Literature Review of Students’ Perception of Employability Skills”, Proceedings of REES AAEE, The University of Western Australia, Perth, Australia, 2021.

Passow, H. J., & Passow, C. H., “What competencies should undergraduate engineering programs emphasize? A systematic review”, Journal of Engineering Education, 106(3), 475–526, 2017, https://doi.org/10.1002/jee.20171.

Sala, A., Punie, Y., Garkov, V. and Cabrera Giraldez, M., “LifeComp: The European Framework for Personal, Social and Learning to Learn Key Competence”, EUR 30246 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-19417-0, doi:10.2760/922681, JRC120911.

World Bank, “What matters for workforce development: a framework and tool for analysis”, Systems Approach for Better Education Results (SABER) working paper series, no. 6, Washington, D.C.: World Bank Group, 2013, http://documents.worldbank.org/curated/en/608191468326178977/What-matters-for-workforce-development-a-framework-and-tool-for-analysis.

Taylor, A., “Engineering education systems that are fit for the future”, 2019, https://raeng.org.uk/media/3c0l1oyl/engineering-education-systems-that-are-fit-for-the-future-conference-report.pdf.

Bossche, V., Gijselaers, P., Segers, W., Kirschner, P., “Transfer of learning: Participants' perspectives on the transfer of learning in collaborative learning environments”, D. H. Jonassen (Ed.), Handbook of research on educational communications and technology (pp. 91-101). Springer, 2019.

Vuorikari, R., Kluzer, S. and Punie, Y., “DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes”, EUR 31006 EN, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/490274.

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Developing the Inclusive Mindset of the Future for Engineering Education

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Conference Key Areas: *Diversity, Equity, and Inclusion in our Universities and in our Teaching; Curriculum Development and Emerging Curriculum Models in Engineering.*
Keywords: *Engineering Education Pathways; Flexible Curricula; Diversity, Equity, and Inclusion*

ABSTRACT

We are living in extraordinary times as citizens of the world. Digital transformation is affecting everyone and everything we do, globalization is a disruptive force to our business, industry and our societal structures, and climate change is an existential threat to humanity. In the U.S., racial inequities are finally being recognized by many and we are beginning to seek solutions that will finally lead to a nation that practices the idea that all are created equal. These issues are not unique to the U.S.; mass disruptions are occurring across the globe.

Engineering education is not immune to these changes. How many creative problem-solvers, who would have become excellent engineers, have we driven from our programs or never given an opportunity over the years? How many inventors and entrepreneurs have we failed to inspire to join our ranks? How many out-of-the-box thinkers have we lost from engineering due to the rigidity of our curriculum? For at least 50 years, we have endeavored to diversify the engineering profession with marginal success. Deficit-based efforts have attempted to “fix” underrepresented groups so that they could fit into the white male culture of engineering, but the systemic challenges facing diverse, aspiring engineers runs much deeper.

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In June of 2020, a Task Force of the American Society for Engineering Education was challenged to review the current state of engineering and engineering technology education in preparing engineers in the U.S. The Task Force was charged with taking a fresh look at the preparation of engineers and ways to fundamentally improve the access, diversity, success, and preparation of undergraduate engineering students. Their efforts built upon the foundational work of the 1955 Grinter Report, which still has a significant influence on today's engineering curricula and culture. This paper describes the work of the Task Force to date and outlines future plans for affecting real change in engineering education in the U.S. and briefly outlines similar efforts occurring across the globe.

1. BACKGROUND

1.1 Grinter Report

In May of 1952, in response to the Cold War and growing scientific and technological achievements of the Soviet Union, the president of the American Society for Engineering Education (ASEE) appointed a committee to look at the current state of engineering education in the U.S. The 1955 report, now commonly referred to as the Grinter Report (Grinter et al, 1955), brought about a sea change in the preparation of engineers and became a foundational document for engineering education that still has a significant influence on the engineering curricula today. The Grinter Report also likely impacted engineering on a global scale. In large part, theory replaced practical hands-on work. We have done some tinkering around the edges, added in a capstone design project, but the basic structure of our curricula remains unchanged since ~1955. We have added a few topics as they became relevant and replaced Fortran with various other languages along the way, but we were mostly adding and hardly ever subtracting. We live in a digital world where students can instantaneously look things up on their phones that might have taken us hours to track down in the library. Yet, our curriculum has not fully embraced these changes. We are stuck in 1955. Although changes have been made to reflect today's digital, inclusive, global, and rapidly changing society, these changes have not gone far enough.

One driving motivation for the current ASEE Task Force is that we believe our curriculum is unattractive to under-represented groups when selecting careers and is not optimally preparing *all* students for their future careers. As Richard Riley stated: **"**We are currently preparing students for jobs that don't yet exist, using technologies that haven't been invented, in order to solve problems we don't even know are problems yet".

We have designed a system that is inflexible, uninspiring, and unattractive to the vast majority of our population. We do not take full advantage of all we have learned about the science of learning since 1955 to improve teaching and learning and increase student success (Nyamapfene, 2021). In reality, the engineering curriculum has long-lasting impacts on the engineering culture. This is our "all hands-on deck" moment and we cannot afford to continue along the path that is dominated by a report from nearly 70 years ago. With the rapidly rising cost of a university education, expanding opportunities, including online, for education at all levels, and the changing demographics of the U.S. and other countries, if we do not transform our programs, we will become outmoded and may cease to be relevant.

1.2 The Post-Grinter Era

The preparation of engineers has been operating under the influence of the Grinter Report for nearly 70 years even though its stated purpose was to provide direction for the "next quarter century." The Grinter Report moved the pendulum to the side of theoretical and science-based engineering. It is time to move the pendulum toward a more humanistic approach to engineering in the preparation of engineers, improve accessibility, and be more student focused to prepare a more balanced graduate for the world as it is today and as it will be in the future. Two important U.S. reports since the Grinter Report was released have both advocated for engineers to have both technical and social proficiency: the NAE's 1985 "Engineering Education and Practice in the United States, and "The Engineer of 2020" (NAE, 2004; NRC, 1985). These reports introduced a tension between an engineer's technical preparation and social elements but did not affect *real*, long-lasting change in engineering education.

It is obvious that the world has significantly changed technologically since 1955, which has resulted in significant societal changes. It is also obvious that the preparation of engineers has advanced and made changes since the Grinter Report; but have the changes been enough? The question to consider is whether it is time for the foundational recommendations from the Grinter Report to be reviewed and challenged if, for no other reason, than the world has advanced significantly since the report was released.

Societal changes have also played a major role since 1955 as the civil rights movement, women rights, and changing demographics transformed the world. The Grinter report was written by white men for white men. The very first sentence of the Grinter report summary states, "Engineering Education must contribute to the development of men who can face new and difficult engineering situations with imagination and competence" (Grinter, 1955). Although only limited by gender, it provides critical insight into the authors' narrow world view of an engineer. A report with a broader perspective is vital, leading to the development of an engineering curriculum that attracts a more diverse and inclusive population by broadening the appeal and success of students of colour, women, and with other life experiences.

1.3 Other Global Efforts

The structure and adequacy of engineering education has also recently been examined in other countries and contexts. In Australia, a report was commissioned by the Council of Engineering Deans to examine the changing nature of engineering practice and its implications for engineering education. The report, titled "Engineering Change: the future of engineering education in Australia," (https://www.aced.edu.au/downloads/2021 Engineering Change - The future of engineering education in Australia.pdf) outlines the direction needed for the future of engineering education in the country. The themes that emerged in this report are similar to those that emerged from the ASEE effort (described subsequently) and are:

1. The need to produce a sufficient number of graduates to meet the needs of the country without over-reliance on foreign-born workers.

2. An insufficient number of women and first-nation individuals to engineering represents a massive loss of potential for the nation.

3. There is a need to re-balance the theory/practice components of the curriculum, to include more practice-related experiences for students.

4. Students are motivated by real-world problems that solve societal needs

5. The diversity of engineering career options needs better promotion, particularly at the pre-college level.

6. Exemplars of best practices in pedagogies and experiential learning should be adopted as appropriate.

7. Due to the rapid transition to online instruction in March 2020, the engineering faculty have demonstrated that they are ready and willing to make changes.

In addition to the work conducted in Australia, The global Engineers Without Borders movement is a community of engineers that believes they can be doing more to address global inequity and injustice (EWB, 2024). They have been working for over 40 years to contribute to communities in need. The UK Engineers Without Borders organization in recent years is focused on engineering education and practice reform. They have worked with educators and others in the UK to develop a tool that assists educators navigate changing their curricula: both content and pedagogies. The goal is to help educators embed global responsibility within courses, moving beyond the typically ad hoc approach commonly used. It is a guide rather than a prescriptive approach, since each university will have its own context in which it works. The Reimagined Degree Map, launched in March 2024, supports engineering programs to navigate the decisions that are required to prepare students for 21st-century challenges. The map was co-developed by Engineers Without Borders UK and the Royal Academy of Engineering and is designed in such a way that it could be adopted for non-UK universities, with appropriate care. The tool can be combined with another - the Competency Compass, which provides a basis for developing educators' (and others') skills in support of the curriculum change that the Map supports.

The Map was developed with input from hundreds of educators, students, professionals, deans, accrediting bodies and professional engineering institutions. The Reimagined Degree Map empowers decision-makers with the tools to facilitate real change and is based on the premise that engineers need to be equipped to act sustainably, ethically, and equitably. Global responsibility in engineering recognizes the need to consider all three aspects together in decision making. Students addressing real-world problems in their studies prepares engineers to improve the consequences of their decisions in their careers.

Other countries are also examining engineering education with an eye towards boldly changing the way engineers are educated. For example, the REEdI (Rethinking Engineering Education in Ireland) was sponsored by the Higher Education Authority to design an agile and innovative engineering degree programme in consultation with industry, research centers, and partner universities (https://hea.ie/skills-engagement/reedi-rethinking-engineering-education-in-ireland/). In fact, the theme of the 2022 SEFI conference was “Towards a new future in engineering education,” indicating a recognition of the need for change in engineering education across the EU.

2. THE WORK OF THE ASEE TASK FORCE

2.1 Engineering Mindset

Early in the work of the Task Force, the team decided to focus on the Engineering Mindset in order to anchor the efforts of the full task force to take a fresh look at engineering education. Mindset is simply the established patterns someone uses in thinking. Mindset includes things such as attention, interpreting, feeling, and reasoning, all that lead to actions people take (Dweck, 2006). Carol Dweck, who studies why people succeed, states that she “examines the self-conceptions (or mindsets) people use to structure the self and guide their behavior”. She focuses on a dimension of mindset that range from ‘fixed’ to ‘growth’ (Table 1 adapted from *Mindset: The New Psychology of Success (Dweck, 2006)*).

Table 1. Fixed vs. Growth Mindset

	Fixed Mindset	Growth Mindset
	Intelligence is Fixed	Intelligence can be Developed
	DESIRES TO LOOK SMART	DESIRES TO LEARN
CHALLENGES	Avoids	Embraces
OBSTACLES	Gives up early	Persists
EFFORT	Sees as fruitless	Sees as part of mastery
CRITICISM	Ignores useful feedback if negative	Learns from
SUCCESS OF OTHERS	Feels threatened	Learns from their success

The Task Force, throughout their deliberation, focused on two key questions.

(1) *What needs to happen, system-wide, to attract and retain a more diverse population of engineering students?* For most women and underrepresented groups, as stated by Ilene Busch-Vishniac and Jeffrey Jarosz, “the engineering curriculum is downright unattractive, uninformative, and uninviting”(2004).

(2) *How can we overcome the challenge of faculty adoption?* For students to achieve a growth mindset, faculty must as well. Through this initiative, it will be a priority to promote efforts that incentivize faculty and entire engineering departments to embrace the growth mindset in their thinking and actions. As part of this effort, faculty must flip from the mindset of “sage on the stage” to be coaches and mentors of students and the integration of active learning.

2.2 Working Groups

The Task Force established six working groups that examined various aspects of engineering education and made a series of recommendations in line with the focus of the working group. The six working groups and their charges were:

1. Engineering Fundamentals and Values. *Develop a new canon for the preparation of engineers that will redefine fundamentals and values that are*

equally motivated and culturally relevant to students from under-represented groups, with a specific focus upon mathematics (since mathematics is often viewed as the gatekeeper into engineering success).

2. Antiracism. *Address racial inequities and racial injustice in the preparation of engineers with recommendations on how to eliminate it from the discipline through antiracism education and asset-based approaches.*
3. Inequities. *Address all historical (both well-known and lesser-known) inequities through measured accountability, climate, and equity recommendations.*
4. Learning Experience. *Develop recommendations for curricular and learning experiences that better integrate the cognitive, physical, and affective domains.*
5. Technical-Socio. *Develop recommendations that result in a better balance between engineering science/fundamentals and social skills, ethical reasoning, perseverance, ambiguity, creative thinking, and inter- and cross-cultural competencies*.
6. Pathways. *Develop recommendations for more flexible ecosystems and pathways into and among engineering, engineering technology, community colleges, K-12 and emerging STEM professions through an examination of traditional curricular barriers.*

3. PROCESS

3.1 Virtual Convenings

In the spring of 2023, the Task Force, consisting of ~120 faculty, industry leaders, and members of accrediting agencies, met virtually over four sessions of 5-6 hours each. The virtual meetings were facilitated by KnowInnovation (https://knowinnovation.com/), a consulting firm that specializes in working with scientific teams to engage in deliberate creativity to solve the world's most complex problems. Approximately one month after the last virtual session, select members of the Working Groups met for a two-day, in-person writing session. The recommendations from the Working Groups were organized in themes (there were several overlapping recommendations that emerged from the separate Working Groups) and a draft report was created. The writing team continued to edit and revise the draft report and has recently distributed it to the larger engineering education community for comment.

3.2 Mindset Report

The current version of the draft report includes 32 specific recommendations arranged in the following themes (for each theme, an example recommendation is provided):

- Create flexible program structures to remove barriers
    - Example: Instead of a one-size-fits-all all-math requirement in the expected level of incoming math preparation, incorporate in-context mathematics across the introductory curriculum to help alleviate student inequities due to pre-college, economic, first-generation, and other differences
- Evidence-based pedagogy: Creating a student-centred engineering education

    - Example: Integrate hands-on and collaborative learning pedagogies that balance student ownership and choice and effectively working with others.
- An inclusive and diverse engineering education learning environment
    - Example: Provide professional development for faculty and staff to foster development of a mindset that centres on lifelong learning to support faculty's understanding of inclusive and equitable teaching practices.
- Preparing campuses for a student-centred engineering education
    - Example: Revise tenure and promotion processes at the department, college and university levels to reward effort, innovation, and risk-taking in teaching.
- Leveraging strategic partnerships
    - Example: Foster partnerships among accreditation agencies, academia, and industry councils that focus on engineering in a societal context.

In addition to the recommendations in support of these themes, there are two overarching recommendations that the Task Force presented:

- Change the perception of engineering by promoting the idea that engineering is for everyone who wants to be a problem solver, not just those who excel in mathematics through the following strategies.
- Remove artificial barriers to the engineering profession through a design-by-choice flexible engineering curriculum.

3.3 Future Plans

The project team is in the process of developing a tactical plan for implementing the recommendations of the Task Force on a national scale. The project team has met with experts on strategic planning and accreditation thus far. Future convenings are planned for meeting with experts in change at the university level and professional development. This work to date has been funded by the National Science Foundation in the U.S. and plans are to seek additional funding for implementation of the tactical plan.

4. Conclusions

To transform engineering education across the globe, it is essential to shift from an exclusive "survival of the fittest" mentality to a growth or "gain the skill" mentality. This can be achieved by offering opportunities for mentorship, internships, and project-based learning, all of which enable students to develop practical skills and gain real-world experience. Emphasizing the importance of continuous learning, growth, and skill development, beyond academic performance, and providing opportunities for students to engage in interactive learning, such as real-world problem-solving exercises, can make engineering more interesting and enjoyable. Reframing the role of mathematics as a tool for solving engineering problems with interactive learning can also help students develop critical thinking and practical problem-solving skills and demonstrate the relevance of engineering to their career aspirations. All of these steps can help promote engineering as a career for problem solvers from all backgrounds and foster inclusivity in engineering education.

As engineering educators, it is vital that we examine **the root causes** of the challenges we face in creating the roadmap for an inclusive growth mindset. Research shows that we have designed a curriculum that is meant to keep people out. We force all of our students to take several semesters of calculus—even though the vast majority don't really need that to work effectively in industry. We have a rigid curricular structure, with long prerequisite chains and few free electives. We subject students to one- to two years of academic hazing before they are allowed into "the club." We promote competition at all levels, even though social scientists tell us that it doesn't motivate everyone. We design projects and exams that are so hard that many students fail, and we call it "character-building,"— and we justify it by claiming that everyone should experience failure of some sort as university students. We also use "rigor" as a means to continue to use our curriculum as a cudgel and keep people out. We say that we don't have a weed-out mentality, but we certainly perpetuate a weed-out system.

Change is never easy, especially on a global scale. Transformational change can be accomplished through thoughtful use of successful change models and evaluating best practices. Incremental change over a short period of time will lead to transformational change. Organizational change, especially when involving large groups of people, often requires a systematic and pragmatic approach to ensure successful implementation.

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REFERENCES

Busch-Vishniac, Ilene & Jarosz, Jeffrey. (2004). Can Diversity in the Undergraduate Engineering Population BE Enhanced Through Curricular Change?. Journal of Women and Minorities in Science and Engineering. 10. 255. 10.1615/JWomenMinorScienEng.v10.i3.50.

Dweck, C.S. 2006. *Mindset: The New Psychology of Success*. Ballantine Books.

Engineers Without Borders UK. (2024, June 4). Engineers Without Borders UK. https://www.ewb-uk.org/

Grinter Report (1955) Available at: https://www.scribd.com/document/190749049/The-Grinter-Report-PDF.

National Academy of Engineering. 2004. The Engineer of 2020: Visions of Engineering in the New Century. Washington, DC: The National Academies Press.

National Research Council. 1985. *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future*. Washington, DC: The National Academies Press. https://doi.org/10.17226/582.

Nyamapfene, A., (February 28, 2021). Towards an understanding of the current state of Engineering Education. Engineering Education Research, For the Student, Practice and Development. https://engineeringedu.press/2021/02/28/towards-an-understanding-of-the-current-state-of-engineering-education/

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EXPLORING THE IMPACT AND CHALLENGES OF AN EMBODIED AND IMPROVISATION-BASED COURSE: INSIGHTS FROM ENGINEERING STUDENTS

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***Conference Key Areas**: Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing*
***Keywords**: improvisation, art-based pedagogies, embodied learning, collective creativity, belonging, safe space, student wellbeing*

ABSTRACT

This study employs thematic analysis to delve into the experiences of 12 alumni engineering students who participated in the elective course "Collective Creation: Improvised Arts and Engineering" at the Swiss Federal Institute of Technology of Lausanne (EPFL) since 2017. Focusing on the lasting impressions left on alumni, the research investigates retained knowledge and skills, their impact on educational journeys, and relevance to professional development. Furthermore, it explores barriers hindering the transferability of acquired skills and knowledge to diverse contexts. The findings underscore the enduring emotional resonance of the course experience for alumni, emphasizing feelings over measurable cognitive knowledge retention. While alumni express gratitude for the course, they encounter challenges

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in articulating its direct contributions to their professional lives, suggesting a gap between experiential learning outcomes and traditional measures of educational and career success.

1 INTRODUCTION

The course "Collective Creation: Improvised Arts and Engineering," abbreviated as *Improgineering*, has been taught annually since its inception in 2017, apart from the academic year 2021-2022, at the Ecole Polytechnique Fédérale de Lausanne (EPFL). Situated within the university's Social Sciences and Humanities (SHS) program, this 6 ECTS elective course leads students into improvisation techniques developed in the performing arts (theatre, music, dance, performance) and questions their possible transposition to engineering design practices. The course spans a full academic year and comprises three hours of weekly classes conducted in a nearby theater. Each year, a cohort of first-year Master students from various disciplines follow this course, taught by an Engineering Professor who is also a dancer and complemented by teachers from diverse backgrounds such as theater, music, dance, neuroscience, and sociology. The first semester encompasses theoretical courses on improvisation as well as several practical workshops. The second semester encompasses further practical workshops, including workshops designed by student groups preparing themselves for the final public performance of the course. At the end of the academic year, students stage a public performance in front of an evaluating jury in a theater where they perform two 12-minute improvisations, one in a small group (3 to 5 people) and another with the whole class. [2]

Each year, the students assign high evaluations to the course. But what remains unknown is what sticks with the alumni after the course: What have they learned and how has it contributed to their education and professional life? Is it possible to articulate anything that may have impeded a transfer of the knowledge and skills learned to other settings?

2 THEORETICAL GROUNDING

This study is grounded in theories on embodied learning. According to Nguyen and Larson (2015, p.2) embodied learning consist in “joining body and mind in a physical and mental act of knowledge construction”. This integrative and holistic approach to education nurtures the learner's physical, emotional, mental, and spiritual development (Freiler, 2008).

Researchers have outlined numerous benefits associated with bringing back the body into the classroom. Firstly, embodied learning has been shown to enhance retention and foster deeper engagement and enjoyment among students (Macedonia 2019; Lipson Lawrence 2012; Strean 2011). Shared embodied experiences also cultivate bonds among students and between students and teachers, fostering belonging and inclusion (Doshi and Osborne 2023; Garrett and MacGill 2021; Solomon et al. 2022). Additionally, participation in embodied activities enhances self-awareness and sensitivity to others, nurturing improved collaborative relationships

[2] More information about the course can be found in the book *Barefoot Academic Teaching* (Tau et al. 2024), the website https://www.epfl.ch/labs/instantlab/improgineering/ and the video https://vimeo.com/281099868.

(Lipson Lawrence 2012). Finally, embodied learning has been found to benefit wellbeing (Rodríguez-Jiménez et al. 2022) and creativity (Dawson 2018).

Despite a growing number of initiatives and studies exploring embodied learning, most efforts are concentrated at the elementary levels of education, as well as within informal learning settings. In contrast, there remains a significant gap in research concerning the integration of embodied learning methodologies into higher education (Clughen 2023). As such, only two empirical studies on the use of embodied learning in engineering education could be found in literature.

In Spain at the Department of Science, Technology and Design, at the Universidad Europea de Madrid, Rodríguez-Jiménez et al. (2022) have used embodied learning with engineering students as a strategy for increasing wellbeing. At the Royal Institute of Technology in Sweden, Brandimarte, Funk, and Richter (2024) have experimented with mixing mechanical engineering and circus students to enhance learning. To the best of our knowledge no course like “Improgineering”, which proposes to use embodied and improvisation practice to teach engineering students collective creativity, exists in other engineering education institutions in the world.

3 METHODOLOGY

This research employs a qualitative methodology, utilizing semi-structured interviews to gather data from alumni of the Improgineering course who volunteered to participate in the study. Participants were recruited via an invitation email sent to 111 out of 119 alumni who had provided an alumni email address. Additionally, a WhatsApp message was sent to a WhatsApp group composed of 31 alumni, who had provided their phone numbers to the teacher after completing the course. Eventually, a total of 12 individuals volunteered for an interview, representing approximately 10% of the students who have followed this course since its launch.

The interviews were conducted remotely over Zoom, with each session lasting approximately 30 minutes. Following the interviews, transcripts were generated and anonymized to protect participants' identities. The data analysis followed a thematic analysis approach according to Braun and Clarke (2021), whereby transcripts were systematically examined to identify recurring themes and patterns within the responses provided by participants. This process involved coding the data based on emergent themes and sub-themes, allowing for a comprehensive understanding of the experiences and perceptions of alumni regarding their participation in the Improgineering course.

The demographics of the participants of the study are summarized in Table 1.

Table 1. Demographics of participants of the study

		Frequency	**Percentage**
Gender	Female	10	83%
	Male	2	17%
Year of course	2017-2018	2	17%
	2018-2019	1	8%

	2021-2022	5	42%
	2022-2023	4	33%
Background	Robotics	1	8%
	Computer science	1	8%
	Computational science	1	8%
	Microengineering	2	17%
	Environmental Science and Engineering	3	25%
	Architecture	4	33%

4 RESULTS

4.1 Theme 1: Impact of the course

Teamwork

Participants emphasized that improvisation served as an effective vehicle for learning teamwork skills, fostering the ability to listen, collaborate, and build on each other's ideas. The absence of pressure on the outcome of the course project further contributed to teamwork dynamics. Interviewee D articulated this sentiment, stating, *"Working without a specific goal was really interesting to be able to work better as a group, because then there wasn't the pressure you usually have with a project where you have to turn in your work on time, with lots of objectives set by the teacher. I think that's what made it so easy to get along in your group."*

Learning effective teamwork was particularly valued, with some interviewees highlighting the lack of emphasis on teamwork skills in traditional engineering courses. Interviewee A expressed the opinion that such a course should be made available to all students, emphasizing its relevance not only in engineering but also in various professional contexts. They stated, *"if everyone followed that [this course], we'd be so much better off in the projects. So in my opinion, this course should be available to everyone. These are things [group work, listening to each other] we don't develop at all, yet it's super necessary for me, in any profession in general and of course in engineering too."*

Sense of belonging and trust

Interacting extensively, including through touch, and engaging in experiential activities together fostered deep bonds among students, creating a sense of belonging, trust, and ease within the group. Descriptions such as feeling like a cohesive unit or a tightly knit troupe were common among interviewees. Interviewee F described the atmosphere as unique, stating, "*it created an atmosphere that I've never found in any other course. It was really a team and that was special*." This safety, felt within the group, allowed participants to engage in activities they might not have otherwise felt comfortable doing. Interviewee L noted, "*everyone felt very comfortable and allowed themselves to do things that perhaps even in other groups, be they friends or associations, they wouldn't have allowed themselves to do*."

Wellbeing & positive affect

Despite not being explicitly designed as a wellbeing program, the course had significant positive effects on participants' wellbeing. Many interviewees reported feeling relaxed and in the present moment during the course, likening the experience to a sense of "*breathing*" or to a session of meditation or sports. Terms like "*soft bubble*", "*oasis*" or "*break*" were also used to characterize the course. This positive affect was linked to feeling amused, free, connected to others, engaged physically but also to the novelty of the experience, as expressed by Interviewee D, who stated, "*It felt good also to just do something completely different*."

Sense of freedom

Participants described feeling "liberated" in multiple senses within the course environment: free to be themselves, express themselves, explore, experiment, create, imagine, play, let go, and follow their intuition. This sense of freedom was fostered by the safe space created and the absence of rigid expectations regarding specific outcomes. Participants contrasted this freedom with the often restrictive nature of engineering curricula, where solutions are predefined, and answers are either right or wrong. Interviewee E highlighted this contrast, stating, "*we could test just about anything and everything. As a result, we were much freer in our creation*." This freedom was perceived as both rare and beneficial for creativity within the context of their studies.

4.2 Theme 2: the perks and downsides of doing something unusual

Participants frequently characterized the Improgineering course as "*atypical*", "*completely different*", "*astonishing*", "*hyper*-special", "*extra-ordinary*", "*unusual*". While this distinctiveness contributes to the course's memorability, it also introduces challenges.

Many participants cited the course as one of the most memorable experiences during their studies due to its pedagogical approach, which diverged significantly from other courses. Interviewee E reflected, "*At every class, I'd come out surprised by what had happened. So I think that's why it had a big impact on me*." The interactive and embodied nature of the course, combined with its demand for engagement in unfamiliar activities, fostered a lasting bodily memory and prevented any possibility of escaping behind screens.

However, the unconventional nature of the course also led some participants to perceive it as less serious compared to traditional courses. Interviewee E contemplated the impact of pedagogical norms however, stating, *"I think it gives the impression that it's not so serious when it's an exception among all our other courses. But if all our courses were like that, it becomes a bit of a norm and we get used to learning that way.*"

Moreover, some participants found difficult to relate the course to their engineering work. Interviewee H articulated this struggle, noting, "*it's both super interesting to do it [the course], but also super difficult to relate it to reality, to our daily life."*

4.3 Theme 3: A complex contribution to professional life and studies

Interviewees mentioned feeling enriched by the Improgineering course and grateful for it. For a few recent alumni, the course fostered professional reflections. For example, Interviewee F thought "*I should never have studied something like* *engineering, but something else that's more fun*" or Interviewee K reflected that the course reinforced "*the idea I already had that a job where you're creative is something I'd really like to do".* While other interviewees felt the course contributed especially to their personal lives, art and creativity practice.

In general, the interviewees acknowledged the acquisition of a wide array of transversal skills, spanning creativity, reflexivity, daring, risk-taking, self-confidence, public speaking, intuition, adaptability, and imagination. Despite this recognition, articulating specific examples or quantifying the course's impact on their professional lives proved challenging for participants. Interviewee H candidly expressed this difficulty, stating, "*I can't really measure the influence it's had on my life, but it's certainly had an impact, but in my everyday life, I couldn't say that it's helped me."* This sentiment resonated with other participants, who described the effects as "*subtle*," "*indirect*," or "*unconscious*."

Participants acknowledged also the complexity of evaluating the course's effects within the broader context of their professional and personal experiences. Interviewee B captured this sentiment, likening the course's impact to "*one brick in an accumulation of bricks.*" They elaborated, "*I don't know if it's enriched things a little, but in any case, it hasn't metamorphosed my way of thinking, and I don't actively think about it again*." This perspective underscores the gradual and integrated nature of learning, suggesting that the effects of the course may manifest over time and in conjunction with other experiences.

4.4 Theme 4: Barriers to transfer

Interviewees identified several barriers hindering the seamless transfer of skills and knowledge acquired in the Improgineering course to their professional lives.

A prominent barrier highlighted by Interviewee I is the stark misalignment between the sedentary nature of their engineering work and the movement aspect emphasized in the course. Interviewee I admitted, "*I must confess that anything to do with movement, unfortunately, I don't really have many opportunities to apply it because in computer science, well, you're sitting behind a computer half the time.*"

Moreover, participants lamented the structured and often non-cocreative nature of their engineering work, which limits opportunities for creative expression. Interviewee H articulated this sentiment, reflecting, "*It's never very creative or it's called brainstorming when you're working. I admit I allow myself to be creative more alone than collectively*."

Additionally, participants identified a lack of familiarity among their peers and colleagues with the co-creative methodologies taught in the course as a significant barrier to implementation. Interviewee A observed, "*The majority of people in this school (...) haven't had that kind of training. (...) And as a result, it's extremely difficult to implement. Because if I listen but they don't listen to me, it doesn't work either*."

5 LIMITATIONS OF THE STUDY

The study is subject to several limitations, each of which bears implications for the interpretation and generalizability of the findings.

The first set of limitations pertains to the characteristics of the research sample. Notably, the self-selection bias among alumni who volunteered for interviews may lean towards individuals with a more positive perception of the course, potentially skewing the representation of its effects. Secondly, the predominance of recent graduates among interviewees limits insights into the long-term professional impact of the course. Lastly, female alumnae are overrepresented in the research sample as the course has about 50% female students, while this study sample is 83% female. Conducting additional interviews with male alumni could help elucidate any gender disparities and provide a more balanced understanding of the course's effects across gender.

The second set of limitations concerns the data collection method employed in the study. While interviews offer valuable insights into participants' experiences, perceptions, and reflections, they may not fully capture the nuanced and often subconscious impacts of experiences. Participants may struggle to articulate or recognize changes resulting from the course, potentially leading to an underestimation of its contribution to their professional life. However, it is essential to recognize that the absence of overtly expressed impacts does not necessarily negate the existence of subtle or indirect influences.

6 DISCUSSION AND CONCLUSION

This study illuminates the impact of the course "Collective Creation: Improvised Arts and Engineering" on alumni students, who consistently express deep appreciation for their experiences and emphasize the unique atmosphere and distinctiveness of the course. Remarkably, alumni predominantly recall the emotional and experiential dimensions of their participation, highlighting the course's holistic approach that goes beyond mere cognitive knowledge acquisition.

Surprisingly, the course emerges as a catalyst for student wellbeing, despite this not being its primary objective. This positive impact can be attributed to several factors. Within EPFL's academic environment, characterized by high levels of stress and pressure as reported by the Mental Health and Well-Being Survey of the EPFL community (Courvoisier et al. 2023), the Improgineering course seems to provide a liberating experience by providing students carte blanche, with no right or wrong answers and no pressure related to academic performance on standard test. Additionally, research suggests that activities promoting movement and creativity, central components of the Improgineering course, can alleviate stress and enhance wellbeing (Rodríguez-Jiménez et al. 2022; Tan et al. 2021; Tait et al. 2024). Moreover, the course facilitates social connectedness, a sense of belonging, trust and freedom, all of which contribute not only to student wellbeing but also to student retention, engagement and motivation (Pedler, Willis, and Nieuwoudt 2022; Strayhorn 2018; Allen et al. 2018).

The study also sheds light on the potential of improvisation and embodied practices for student engagement and transversal skills teaching. Indeed, the course, in alignment with embodied learning theories (see section 2 Theoretical groundings) fosters deep engagement and enhances memorability by involving the whole person. The integration of improvisation and embodied practices also nurtures essential skills, such as collaboration, active listening, and creativity, which are often overlooked in traditional engineering courses (Daly, Mosyjowski, and Seifert 2014; Kovacs et al. 2020; Kazerounian and Foley 2007; Zhou 2012).

However, the study also underlines challenges in articulating the course's professional benefits. Participants cite barriers such as a lack of training in teamwork among other peers and colleagues, limited opportunities for application in professional settings, and discrepancies between the course content and the demands of engineering work.

The question thus arises as to whether a course, whose direct contribution to engineering education and one’s later profession is unclear, has a place in the engineering curriculum. One can first note that the unclear direct contribution of the course to engineering may be related to engineering students lacking training in articulating what they have learned. Moreover, dismissing the value of the course solely based on its transferability overlooks its intrinsic benefits. The immediate impact and value students experience during the course are significant in themselves, reflecting a broader philosophy of education that transcends mere instrumental outcomes. Furthermore, challenges in transferring learning to other contexts may reflect systemic issues, such as a lack of environments and safe spaces conducive to deep listening and effective teamwork.

Additionally, while the course offers unique and enriching experiences, it is perceived by some participants as less “serious”. This raises questions about what is considered serious in academia. In this case, it seems that less seriousness is in opposition to a certain rigidity of traditional courses since the course attendance is at about 80% which is relatively high, given the late timetable (16:30-19:00) and the remote location of the course (in a theater off campus site). Thus, we can wonder whether presenting the course as less serious is a way for certain participants of resolving the tension produced by the unconventional nature of the course, without questioning the rest of their studies.

More generally, an important secondary effect of the Improgineering course seems to be making students critically reflect on their engineering studies and work. It raises their awareness of how much they remain within an individualistic, cognitive, and rigid education system, both in terms of the work's format and the objectives to be achieved. The realization that none of this is necessary could be a major contribution of an unconventional course such as Improgineering in engineering education.

In conclusion, this study prompts a re-evaluation of conventional educational paradigms within engineering. It challenges us to consider the potential of integrating improvisation and embodied practices into engineering education. Rather than viewing the Improgineering course solely through the lens of its immediate applicability to professional settings, we must recognize its profound influence on student wellbeing, sense of belonging, creativity, and collaboration. As we contemplate the future of engineering education, we are compelled to ask: What if courses such as Improgineering were no longer the odd ones out but more mainstreamed in engineering education? How might this shift impact the way we engineer solutions to the complex challenges of our time? Would students become better engineers?

REFERENCES

Allen, Kelly, Margaret L. Kern, Dianne Vella-Brodrick, John Hattie, and Lea Waters. 2018. "What Schools Need to Know About Fostering School Belonging: A Meta-Analysis." *Educational Psychology Review* 30 (1): 1–34. https://doi.org/10.1007/s10648-016-9389-8.

Brandimarte, Luigia, Alisan Funk, and Benjamin Richter. 2024. "Mixing Fluid Mechanics with Circus: How the Performing Arts Can Enhance Learning in an Undergraduate Engineering Course." *European Journal of Engineering Education*, March, 1–22. https://doi.org/10.1080/03043797.2024.2329949.

Braun, Virginia, and Victoria Clarke. 2021. *Thematic Analysis : A Practical Guide*. Sage Publications.

Clughen, Lisa. 2023. "'Embodiment Is the Future': What Is Embodiment and Is It the Future Paradigm for Learning and Teaching in Higher Education?" *Innovations in Education and Teaching International*, May, 1–13. https://doi.org/10.1080/14703297.2023.2215226.

Daly, Shanna R., Erika A. Mosyjowski, and Colleen M. Seifert. 2014. "Teaching Creativity in Engineering Courses." *Journal of Engineering Education* 103 (3): 417–49. https://doi.org/10.1002/jee.20048.

Dawson, Kathryn. 2018. "Performative Embodiment as Learning Catalyst: Exploring the Use of Drama/Theatre Practices in an Arts Integration Course for Non-Majors." In *Creativity in Theatre*, edited by Suzanne Burgoyne, 2:67–87. Creativity Theory and Action in Education. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-78928-6_5.

Doshi, Sapana, and Tracey Osborne. 2023. "19. Embodying Social and Environmental Justice Learning through Somatic and Mindfulness Practices." *Environmental Justice*, 257.

Freiler, Tammy J. 2008. "Learning through the Body." *New Directions for Adult and Continuing Education* 2008 (119): 37–47. https://doi.org/10.1002/ace.304.

Garrett, Robyne, and Belinda MacGill. 2021. "Fostering Inclusion in School through Creative and Body-Based Learning." *International Journal of Inclusive Education* 25 (11): 1221–35. https://doi.org/10.1080/13603116.2019.1606349.

Kazerounian, Kazem, and Stephany Foley. 2007. "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions." *Journal of Mechanical Design* 129 (7): 761–68. https://doi.org/10.1115/1.2739569.

Kovacs, Helena, Delisle Julien, Mirjam Mekhaiel, Jessica Dehler Zufferey, Roland Tormey, and P. Vuilliomenet. 2020. "Teaching Transversal Skills in the Engineering Curriculum: The Need to Raise the Temperature." In *SEFI 48th Annual Conference: Engaging Engineering Education. Proceedings*, 906–17. University of Twente. https://infoscience.epfl.ch/record/283739.

Lipson Lawrence, Randee. 2012. "Coming Full Circle: Reclaiming the Body." *New Directions for Adult and Continuing Education* 2012 (134): 71–78. https://doi.org/10.1002/ace.20019.

Macedonia, Manuela. 2019. “Embodied Learning: Why at School the Mind Needs the Body.” *Frontiers in Psychology* 10 (October):2098. https://doi.org/10.3389/fpsyg.2019.02098.

Nguyen, David J., and Jay B. Larson. 2015. “Don’t Forget About the Body: Exploring the Curricular Possibilities of Embodied Pedagogy.” *Innovative Higher Education* 40 (4): 331–44. https://doi.org/10.1007/s10755-015-9319-6.

Pedler, Megan Louise, Royce Willis, and Johanna Elizabeth Nieuwoudt. 2022. “A Sense of Belonging at University: Student Retention, Motivation and Enjoyment.” *Journal of Further and Higher Education* 46 (3): 397–408.

Rodríguez-Jiménez, Rosa-María, Manuel Carmona, Sonia García-Merino, Germán Díaz-Ureña, and Pedro J Lara Bercial. 2022. “Embodied Learning for Well-Being, Self-Awareness, and Stress Regulation: A Randomized Trial with Engineering Students Using a Mixed-Method Approach.” *Educ. Sci.*

Solomon, Folashadé, Dionne Champion, Mariah Steele, and Tracey Wright. 2022. “Embodied Physics: Utilizing Dance Resources for Learning and Engagement in STEM.” *Journal of the Learning Sciences* 31 (1): 73–106. https://doi.org/10.1080/10508406.2021.2023543.

Strayhorn, Terrell L. 2018. *College Students’ Sense of Belonging: A Key to Educational Success for All Students*. Routledge. https://www.taylorfrancis.com/books/mono/10.4324/9781315297293/college-students-sense-belonging-terrell-strayhorn.

Strean, William B. 2011. “Creating Student Engagement? HMM: Teaching and Learning with Humor, Music, and Movement.” *Creative Education* 02 (03): 189–92. https://doi.org/10.4236/ce.2011.23026.

Tait, J. E., L. A. Alexander, E. I. Hancock, and J. Bisset. 2024. “Interventions to Support the Mental Health and Wellbeing of Engineering Students: A Scoping Review.” *European Journal of Engineering Education* 49 (1): 45–69. https://doi.org/10.1080/03043797.2023.2217658.

Tan, Cher-Yi, Chun-Qian Chuah, Shwu-Ting Lee, and Chee-Seng Tan. 2021. “Being Creative Makes You Happier: The Positive Effect of Creativity on Subjective Well-Being.” *International Journal of Environmental Research and Public Health* 18 (14): 7244. https://doi.org/10.3390/ijerph18147244.

Tau, R., L. Kloetzer, S. Henein (Eds.). 2024. Barefoot academic teaching: performing arts as a pedagogical tool in higher education. SCENARIO Book Series. Uckerland: Schibri-Verlag.

Zhou, Chunfang. 2012. “Fostering Creative Engineers: A Key to Face the Complexity of Engineering Practice.” *European Journal of Engineering Education* 37 (4): 343–53. https://doi.org/10.1080/03043797.2012.691872.

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EDUCATION ADAPTING TO THE FUTURE: MEETING THE SKILL NEEDS IN MANUFACTURING SECTOR

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Conference Key Areas: *Continuing education and life-long learning in engineering, Outreach and openness: industry and civil-society in engineering education*
Keywords: *tacit knowledge, life-long learning, skills training*

ABSTRACT

The "Manufacturing Academy 2.0" project, co-funded by the European Social Fund Plus, addresses the challenge of an aging workforce and declining birth rates in Finland’s manufacturing industry. It focuses on developing training modules to preserve and transfer tacit knowledge from retiring experts to new employees in manufacturing industry. The education institutions involved in this project represent both higher education (Tampere University of Applied Sciences, Finland) and vocational secondary education (SASKY, Finland). This partnership ensures that the training programs are not only grounded in theoretical knowledge but are also directly relevant to the current and future needs of the manufacturing industry at various levels. Through structured interviews at the "Konepajamessut" Manufacturing Expo, the project gathered data to tailor training topics to industry needs. Results indicate a significant recognition of importance of tacit knowledge and a varied readiness to collaborate on training development. The responses also highlighted an overall positive disposition towards continuing education initiatives. This indicates a growing recognition of the value of life-long learning and upskilling opportunities, particularly through university and vocational school courses or training facilitated by them, to maintain a competitive and proficient workforce.

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1 INTRODUCTION

In recent years, Europe has been experiencing a consistent decrease in birth rates, leading to an increasingly aging workforce. Lower birth rates mean a gradual decline in the young, working-age population that is the backbone of labour market. Therefore, there are fewer entrants into the workforce, which can lead to a shortage of labour. Manufacturing companies across Europe are responding to these challenges in various ways, including automation, to reduce dependency on human labour, and enhancing training programs to transfer knowledge from retiring experts to the newer workforce. There is also a growing trend towards encouraging later retirement to retain older workers' expertise and experience within the industry. As the workforce in manufacturing industries ages, there is a risk that not enough new skilled workers will be attracted to the field to compensate for the shortfall, and companies are responding to this by moving their production abroad. When older workers retire, they take with them tacit knowledge, which is often quite significant for performing certain work phases or procedures.

Tacit knowledge refers to the knowledge that a person possesses but which is difficult to convey to others through words or writing. It can include personal experiences, intuitive insights, implicit skills, and practices that have been acquired over a long period and in a certain context. One of the most famous definitions comes from the philosopher Michael Polanyi (Polanyi 1966), who emphasized that we know more than we can tell. This suggests that a large part of human knowledge is internal and subjective and cannot be easily or completely articulated. Tacit knowledge encompasses a wide spectrum of insights, from intuitive judgments and implicit skills to nuanced practices honed over years of hands-on experience. The complexity of defining and encapsulating this knowledge has led to a variety of interpretations across academic and practical fields, underscoring the rich diversity yet elusive nature of tacit understanding.

Within the manufacturing sector, the transfer of tacit knowledge is a significant factor. Experienced workers possess an invaluable ability to detect subtle cues—be it minor alterations in machinery sounds or operational shifts—that pre-emptively signal potential issues. Their decision-making ability, refined through years of observation and engagement, often operates beneath the surface of formal recognition or documentation. Mohajan (Mohajan 2016) emphasizes that tacit knowledge is a crucial, yet often overlooked, component of an organization's knowledge base that plays a vital role in innovation and the successful implementation of knowledge management strategies. While tacit knowledge is inherently personal and context-specific, certain technologies can aid in its transfer. For instance, virtual reality (VR) and augmented reality (AR) can simulate real-world scenarios for training purposes, making it easier for workers to gain insights into tacit knowledge without the direct intervention of a human instructor. Also, AR/VR technologies can be used to capture and digitize the expertise of skilled workers (Sarhan et al. 2022).

2 MANUFACTURING ACADEMY 2.0 -PROJECT

Tampere University of Applied Sciences (TAMK) and SASKY education association, collaboratively initiated a "Manufacturing academy 2.0" project, which is co-funded by the European Social Fund Plus (ESF+). The aim of this MA 2.0 project is to find methods to identify, collect, and train tacit knowledge to bolster the manufacturing sector in Pirkanmaa region in Finland. At the heart of MA 2.0 project's approach is the development of a pedagogical model or education concept that aligns with the needs of the manufacturing industry. The project also aims to modernize the training in the manufacturing industry so that tacit knowledge can be better transferred to new employees and that the training in general would better meet the demands of the modern age, which are related to the needs of the digital and green transition. The long-term goals of the MA 2.0 project are related to the establishment of the training model and increasing the attractiveness of the field, especially among young people. Additionally, the project offers opportunities for cooperation between different actors, both domestically and internationally, which strengthens networks and promotes the sharing of expertise.

A pivotal aspect of the MA 2.0 project is its collaborative framework, involving key stakeholders from both the education and industrial sectors. The education institutions involved in this project represent both higher education (TAMK) and vocational secondary education (SASKY). This partnership ensures that the training programs are not only grounded in theoretical knowledge but are also directly relevant to the current and future needs of the manufacturing industry at various levels. By fostering a strong link between education and industry, the project aims to ensure that the tacit knowledge transferred through its programs directly contributes to enhancing the competitiveness and innovation capacity of the manufacturing sector.

To be well aligned with the skill needs of the industry, companies were surveyed during “Konepajamessut”, a national Manufacturing Expo, that took place March 17-19, 2024, in Tampere, Finland. The expo spotlights advanced machinery, modern workshops, and smart investments. It's tailored for decision-makers in the metal industry, featuring machine tools, welding and joining tools, automation, robotics, maintenance, and industrial services. Alongside the Manufacturing Expo, also the Nordic Welding Expo and the 3D & New Materials Fair took place, making it a comprehensive event for industry professionals. The participating companies at the Manufacturing Expo span across various sectors of the manufacturing industry and other sectors, offering a diverse array of products and services. There were over 200 participating companies of which 78 were interviewed for this project. This manufacturing expo is one of the largest in Finland and companies all over the country participate. The companies interviewed range from medium-sized national to large international companies. Therefore, the results are expected to rather reflect rough average across companies operating in manufacturing sector in Finland, than only small regional companies.

3 SURVEYING COMPANIES THROUGH STRUCTURED INTERVIEWS

In the structured interviews aimed at manufacturing companies, the focus was on identifying the sector's near-future skill needs and whether companies have models for transferring tacit knowledge. The information obtained enables the project to direct its efforts so that training modules can be tailored to meet the skills the industry most urgently requires. The interviews also revealed which topics interest which companies, allowing for targeted training for different companies later on. The MA 2.0 project aimed to identify not only current but also future skill gaps, to proactively address labour market changes through education. The interviews sought to find out which topics companies' current or future employees need concrete skills in and whether there are existing methods and models for transferring tacit knowledge to new employees. The questions and the response distributions are presented in the next chapter.

A key focus of the survey was to gauge the perceived magnitude of the problem posed by the loss of tacit knowledge. By employing a 6-point Likert scale, companies were queried on the extent to which they view this loss as a challenge, thereby quantifying the urgency and importance of devising effective transfer mechanisms. This quantitative assessment is complemented by inquiries into the existence of current practices or training models aimed at facilitating the inter-employee transfer of tacit knowledge, offering a snapshot of the industry's readiness to tackle this issue. In the beginning of the interview, the respondent was briefly informed about the survey and also about the tacit knowledge transfer and its' definition.

The survey further investigates the willingness of companies to participate in the development of tacit knowledge training programs in collaboration with Tampere University of Applied Sciences (TAMK). This partnership underscores the project's commitment to creating a synergistic relationship between academia and industry, ensuring that the developed educational models are not only theoretically sound but also practically relevant and directly applicable to the manufacturing context.

One component of the survey centers on identifying the specific areas of manufacturing where companies foresee imminent workforce needs, attributable to retirement or other factors. By soliciting input on the significance of new workforce competencies across various domains, the survey aims to tailor the educational concept to address these emerging requirements effectively. Additionally, companies' preferences for the modality of training delivery—ranging from VR and AR simulations to online and in-person formats and workshops—are explored to design programs that align with organizational needs and learning cultures.

4 RESULTS

Figure 1 shows the answer distribution to the question of the importance of tacit knowledge loss in the company. The companies were also asked if they had methods or training models for transferring tacit knowledge from one employee to another and if they were willing to co-develop the transfer methods together with the education institution (TAMK). The answers are shown with different colours for different responses as indicated in the figure. Majority of the respondents (45 companies, 58 %) considered this to be a problem for them (scores 3-5). Altogether 18 companies expressed their interest to participate in developing tacit knowledge transfer methods. This is a very good starting point for planning the next actions and workshops in the MA 2.0 project.

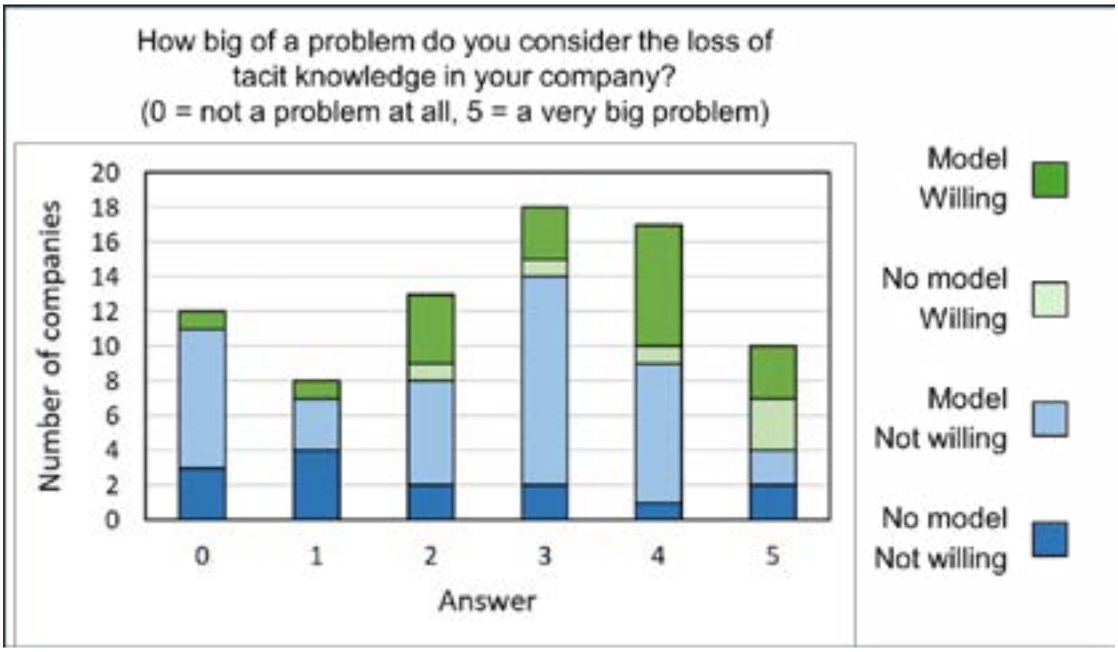

Fig. 1. The answer distribution to the question of the importance of tacit knowledge loss in the company. The companies were asked if they had a model for transferring tacit knowledge and if they were willing to co-develop it with TAMK. N = 78.

The survey results in Fig 1. indicate a substantial recognition among companies of the importance of transferring tacit knowledge, with a significant majority affirming the existence of practices or training models dedicated to this end (58 companies, 74%). This demonstrates a widespread acknowledgment of the risks associated with the loss of tacit knowledge, especially as a skilled workforce approaches retirement. However, it also highlights that a notable proportion of companies have yet to implement systematic approaches to address this issue.

Responses regarding the interest in collaborating on the development of tacit knowledge training with Tampere University of Applied Sciences (TAMK) showcased a divide. While some companies expressed interest (25 companies 32 %), a larger portion appeared reluctant. This hesitancy could be attributed to various factors such as resource constraints, satisfaction with existing training mechanisms, or possible uncertainty about the efficacy of new educational initiatives.

Figure 2 presents a bar graph illustrating the perceived significance of different skill areas for the new workforce. Almost identical results were obtained for the question about the training needs within a company for the near future (1-3 years). Due to the similarity of the results, only this first one is presented here.

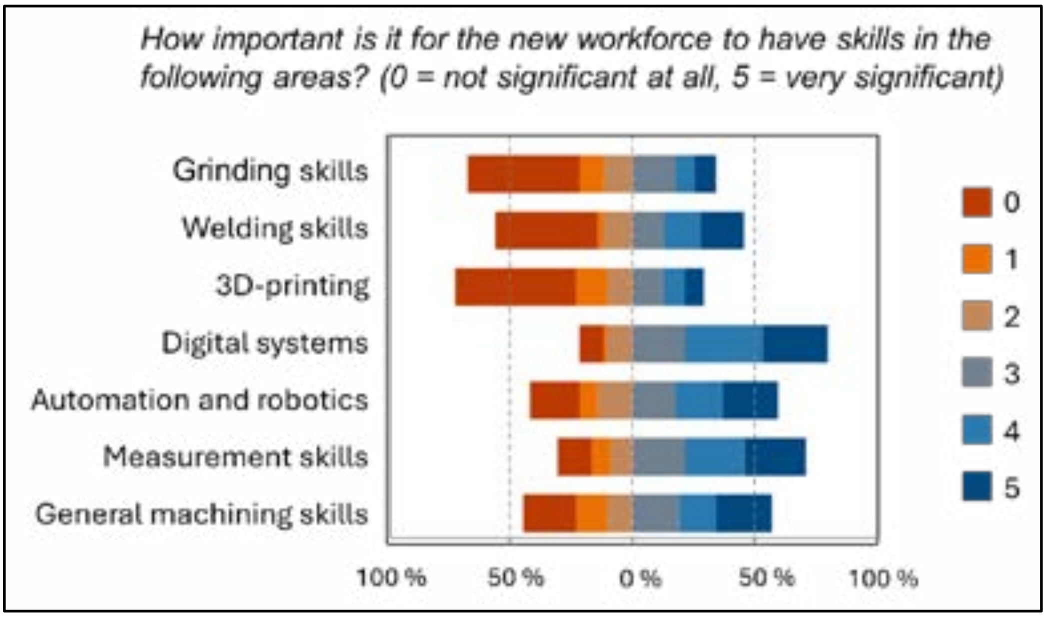

Fig. 2. The answer distribution of the importance of different skills that the new workforce should have. Similar results were obtained also for in-company training needs. N = 78.

Each topic was rated on a 6-point Likert scale from 0 (not significant at all) to 5 (very significant). The data points to a recognition that there is a varying need for training across different technical skills. All topics received answers ranging from 0 to 5. This was to be expected, as the sectors in which the companies operate varied, and thus the needs for skills also varied between companies. On average, companies rated skills such as digital systems and measurement skills as significant for their staff and for new employees, to mention a few. The results help the MA 2.0 project to contact right companies with certain training topics but also tell about which aspects to take into consideration in formal higher education programmes in general.

The companies were also asked about which training delivery methods would suit them. The answers are shown in the figure 3. This horizontal bar graph shows the number of responses for different types of training preferences. The respondents were encouraged to choose all possibly suitable training methods. According to the results in figure 3, online courses are the most preferred training type among the respondents, with supported self-learning as the second. The preference for online courses and supported self-learning among companies likely reflects a broader trend towards flexible and accessible forms of professional development. Online courses offer the convenience of anytime, anywhere learning, which aligns with the busy schedules of working professionals. Supported self-learning, being the second preference, indicates a desire for autonomy in learning, yet with a structure that provides guidance and support when needed. These preferences suggest companies value both the adaptability of online learning environments and the effectiveness of personalized learning pathways in meeting their workforce's ongoing skill development needs.

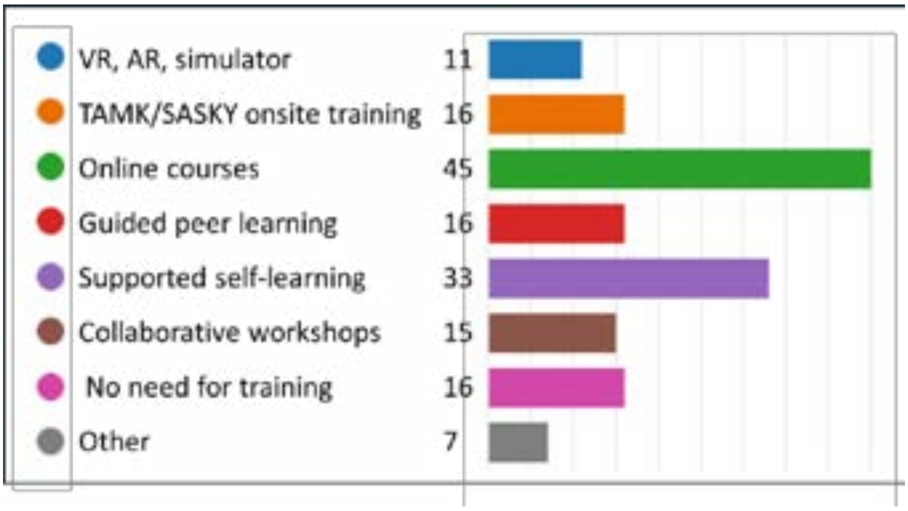

Fig. 3. The preferred training methods.

The traditional training delivery methods, like onsite training (TAMK/SASKY), guided peer learning and collaborative workshops received roughly similar response rates, but they were not as popular as the self-spaced learning options. VR, AR, and simulator trainings, on the other hand, are not considered as so good options. These are of course the state-of-the-art training methods and the reluctance to use them is a bit surprising. The hesitance towards VR, AR, and simulator training might stem from several factors, including the initial high costs and resource requirements for setup and implementation. Additionally, there could be a lack of familiarity or comfort with these advanced technologies within the company's current training ecosystem. This reluctance may also reflect a perceived complexity in integrating such state-of-the-art methods into existing training programs or uncertainty about their effectiveness and return on investment compared to more traditional, less technologically advanced training methods.

5 CONCLUSION

While the readiness to engage with TAMK in developing tacit knowledge training programs varied, the responses highlighted an overall positive disposition towards continuing education initiatives. This indicates a growing recognition of the value of life-long learning and upskilling opportunities, particularly through university and vocational school courses, to maintain a competitive and proficient workforce.

Survey results highlight the importance of retaining valuable tacit knowledge within the industry as technology evolves. The findings indicate varying needs for skills and training across different areas. Self-directed and flexible study methods, such as online learning and guided self-study, seem to best suit the industry's needs. However, there's hesitation in adopting new technologies like VR and AR. The project emphasizes the importance of collaboration between the education and industrial sectors to adapt to labor market changes. More dialogue and cooperation between educational institutions and the industry are needed. As the manufacturing sector progresses, these insights will inform the development of training models that aim to meet both current and future skill needs.

Although these findings were gathered in Finland, the issues of aging and retirement are widespread across the European manufacturing workforce. Consequently, there is a need for upskilling and reskilling initiatives to preserve critical knowledge and maintain industry competitiveness beyond Finland. By customizing training modules to local industry needs, this approach can be adapted to various contexts, promoting tacit knowledge retention and enhancing competitiveness in companies across Europe.

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REFERENCES

Mohajan, Haradhan. "Sharing of tacit knowledge in organizations: a review." (2016): *American Journal of Computer Science and Engineering*, 3(2): 6-19.

Muñoz, C. A., Mosey, S., & Binks, M. (2015). The tacit mystery: reconciling different approaches to tacit knowledge. *Knowledge Management Research & Practice*, 13, 289-298.

Nikander, M. "Manufacturing Academy 2.0". Visited 5.4.2024. https://projects.tuni.fi/konepajaakatemia/in-english/

Polanyi, M. "The logic of tacit inference." *Philosophy* 41, 155, (1966): 1-18.

Sarhan, A., Martin, L., El Souri, M., & Gao, J. Capturing Manufacturing Knowledge Using Augmented Reality Technologies. *Advances in Transdisciplinary Engineering*. 25 (2022). https://doi.org/10.3233/atde220604

ICT-ENGINEERING TEACHERS' EXPERIENCES AND EXPECTATIONS WITH AI

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***Conference Key Areas**:* Digital tools and AI in engineering education, Building the capacity and strengthening the educational competences of engineering educators
***Keywords**:* ICT engineering education, competence development, AI

ABSTRACT

The study explores the integration and perceptions of AI in ICT engineering education, highlighting both the current utilization and future expectations among teachers. With the advent of generative AI applications, there is increased pressure and awareness for higher education institutions to incorporate AI into their curricula. The paper discusses the necessity for faculty in ICT engineering to stay updated with AI developments, ensuring relevant and innovative instruction for students. It also examines the use of AI in various educational facets, such as assessment, prediction, assistance, and learning management, based on systematic reviews and empirical research. The findings reveal a mix of enthusiasm and caution among teachers, with a clear recognition of AI's potential benefits in enhancing teaching efficiency and student learning, alongside concerns about ethical, safety, and cost implications. The study advocates for comprehensive training and institutional support to effectively integrate AI in teaching, emphasizing the need for ongoing development to align with the rapidly evolving technological environment.

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1 NTRODUCTION

The explosive spread of artificial intelligence (AI) usage also puts pressure on universities to educate personnel on AI-related matters. In ICT (Information and Communication Technology) engineering education, this also means developing expertise in development principles and necessary technologies. However, Bates et al. (2020) state that AI has had little impact on teaching and learning in higher education so far. This perspective prevailed four years ago. The 2023 launch of OpenAI's ChatGPT marks a significant milestone in generative AI's penetration into various sectors, intensifying the push for its integration into daily operations and support systems. Integrating AI into higher education is nowadays seen as inevitable (Hodges and Ocak 2023; Mallik and Gangopadhyay 2023). Universities must adapt and prepare teaching staff for an AI-driven future (Hodges and Ocak 2023).

Historically, the introduction of Virtual Learning environments (VLE) marked a significant shift in educational paradigms, offering new modalities for content delivery and student engagement. This mirrors the current evolution we're seeing with AI applications in education, which similarly aim to revolutionize teaching methodologies and learning outcomes (Azmi et al. 2022). For instance, earlier research has highlighted how VLEs improved accessibility and personalized learning paths, aspects that are increasingly relevant as AI tools begin to offer similar advantages in educational settings (Cellini 2021). Moreover, studies on VLEs have also discussed challenges such as the digital divide and the need for robust faculty training—issues that are paralleled in the current discourse on AI in education. By comparing these scenarios, we can better anticipate potential barriers to AI adoption and develop more effective strategies for integration (Torres 2021).

Personnel must keep abreast of these changes to deliver current and relevant instruction, thereby preparing students effectively for the workforce. Incorporating sensible content into the curriculum that also promotes students' creativity and innovative thinking is essential. The industry demands that students possess knowledge of the latest technologies, including AI and its applications. Understanding ethical and societal issues helps teaching staff to transfer perspectives of responsibility to students as well. Staying current with new technologies also addresses the challenges of continuous learning, where ongoing development requires continuous learning and adaptation. Therefore, to provide high-quality and up-to-date ICT engineering education, teaching staff must stay abreast of the latest developments.

Research related to the subject has been conducted under the concept of AIEd (AI in Education), which is one of the categories of AI usage and focuses specifically on the use of AI in higher education institutions (Compton and Burke 2023). Cropton and Burke (2023), in their systematic review on the utilization of AI in higher education conducted between 2016 and 2022, have observed that AI is primarily used for five different purposes: Assessment/Evaluation, Predicting, AI Assistant, Intelligent Tutoring System, and Managing Student Learning, with AI Assistant being specifically mentioned as utilized by students. According to a study conducted by Pisica et al. (2023), most views on the benefits of AI in higher education focus on its impact on the teaching-learning process, research, and the development of new skills, while the most significant concerns relate to fears of socio-psychological impacts, loss of ‘humanity’, and safety and ethical considerations. The costs of using AIEd tools can also widen the gap in education availability, including from the perspective of equitable access (Mallik and Gangopadhyay 2023). It is noteworthy that actors must prepare for the adoption of AI and pave the way in the field of education (Lampou 2023), including in the case of the strongly technically oriented staff of ICT engineering education.

The ICT Engineering degree program at Lapland University of Applied Sciences (Lapland UAS) adheres to the Conceive, Design, Implement, and Operate (CDIO) framework. It includes routine self-assessment against the twelve standards of CDIO, currently at version 3.0, as outlined by Malmqvist et al. (2020). In the self-assessment, standard 9 ‘Enhancement of Faculty Competence’ and standard 10 ‘Enhancement of Faculty Teaching Competence’ were identified as areas for improvement. In the refinement phase, the staff identified competence development in the field of AI as particularly important, leading the faculty unit to plan a competence development roadmap accordingly. The research described in this paper contributes to this development work.

Núñez and Lantada (2020) explore AI's role in enhancing engineering education in their study, presenting a roadmap that begins with an analysis of the current state and identifies key themes to reach the desired state. They investigate AI's impact on technical systems and its potential to enhance higher education's teaching-learning processes, particularly in scientific and technical fields. The authors discuss AI's role in supporting educational technology and detail strategies for its rapid integration into educational programs. The roadmap encompasses themes such as AI's utility in educational practices, the trends and best practices in AI-based teaching-learning experiences, the concept of intelligent universities, and the challenges and proposals for integrating AI in engineering education.

This research aims to assess the present and future use of AI in ICT engineering education, focusing on how educational staff employ AI in teaching and guidance. It also examines their expectations for future AI utilization. The study addresses two main research questions: How do ICT engineering education personnel use AI in their teaching and guidance activities, and what are their future expectations for AI use?

In addition, this study's insights into teachers' experiences with the systems and their considerations for its implementation can serve as a foundation for developing guidelines to integrate AI into school curricula, particularly in STEM education, as suggested by Kim and Kim (2020).

2 METHODOLOGY

2.1 Data collection methods

The data collection for this study was conducted as a web survey. The thoughts, experiences, and expectations of the participants, namely the ICT engineering education teachers (N=18), were surveyed through a questionnaire. The survey aimed to get in-depth information about the respondents' perspectives and motivations. Its purpose was to understand the topic and problems from the perspective of individuals. Validated questionnaire instruments appropriate for this recent research topic and research questions were not readily available in the literature. A mandatory preliminary ethical review was not needed, because the study did not meet the criteria required for ethical evaluation defined by TENK (2019), such as participants being underage or exposure to security risk.

The survey was administered using Webropol 3.0, a robust online survey and reporting platform. At the outset, respondents were provided with a comprehensive definition of AI, encompassing all its sub-areas such as machine learning, computational environments, ethics, and user interaction. This was to ensure a uniform understanding and to mitigate variations in responses due to differing interpretations of AI. In the same context, respondents were also informed that participation in the survey was voluntary and were provided with information on handling the data and reporting results. Respondents answered the survey anonymously.

The first multiple-choice question aimed to determine if the teacher felt they belonged to any of the following categories: STEM (science, technology, engineering, and mathematics) subjects, languages and communication, software development, cyber-physical systems (including robotics), and other professional subjects. The remaining 8 questions were open-ended:

Q1: Describe how you use AI in your course planning.

Q2: Describe freely how you utilize AI in the implementation and guidance of teaching.

Q3: What kind of AI solutions do you utilize in assessment?

Q4: What obstacles and challenges have you encountered in integrating AI into the planning, implementation, guidance, or evaluation of teaching?

Q5: Based on your observations, how has AI affected students' learning outcomes and motivation?

Q6: What expectations or suggestions do you have for better integrating AI into the planning, implementation, and evaluation of teaching?

Q7: How do you assess the significance of AI for the future of engineering education? Justify your thoughts.

Q8: What kind of AI-related training would you like to be organized for teaching staff?

One week was given for response time, and the responses were collected anonymously. There were 12 responses to the survey, making the response rate 67 percent.

2.2 Data analysis

Initially, the results, including interpretations of tone, were examined based on the taught major for the utilization of AI, experiences, and the attitude toward its use. The results were analyzed by different groups of people by calculating frequencies. For question Q2, the response determined whether it was categorized as ‘Utilising’ or ‘Not utilizing.’ The responses to question Q4, in turn, were divided into two categories: has challenges and no challenges, and for Q3 into ‘Positive’, ‘Negative’, and ‘No effect’. The responses to question Q5 were classified into four groups: ‘Positive’, ‘Negative’, ‘Both’, and ‘No Observations’. In question, Q7, the tone of the responses regarding the direction of engineering education development was interpreted as either ‘Negative’ or ‘Positive’.

The contents of the responses to open-ended questions were also analyzed thematically, iterating in a way that general concepts and meanings were extracted through inductive reasoning. Using content analysis of open coding, the units of analysis were classified and grouped inductively by aggregating individual observations into general themes. Hits were calculated for the themes to determine their frequency of occurrence.

3 RESULTS

Half of the respondents (N=8) taught vocational subjects, such as software development or cyber-physical systems. Nearly a third (N=5) worked as teachers in subjects other than vocational or STEM fields, and two respondents represented language or communication teachers.

In question Q2, the majority of respondents utilized AI in the implementation and guidance of teaching (N=10), 5 respondents did not utilize it, and 1 response was left blank. The responses to question Q2 reveal that artificial intelligence was primarily understood as based on language models, with Chat GPT being mentioned seven times. Three respondents reported that they have not used AI in teaching or guidance, and AI was most commonly utilized in the planning of tasks. In Figure 1, the proportion of respondents facing challenges or not facing challenges is depicted in the subject taught. Out of 16 respondents, 13 (81 %) had encountered challenges, while 3 respondents had not faced any challenges. Specific barriers to the use of AI included mandatory registration and costs in Q4.

Figure 1. The proportion of those facing challenges per subject taught.

In Figure 2, the impact of AI on students' motivation and learning outcomes is analyzed, segmented by the subjects taught as specified in Question 5 (Q5). Of all respondents, half (N=8) reported observing no significant effects of AI on motivation or learning outcomes. However, the responses varied: three respondents noted both negative and positive impacts. These mixed observations were reported by teachers from various professional subjects, including software development.

Interestingly, while only one respondent noted purely positive effects, three others — teachers in software development and language and communication — reported exclusively negative impacts. The distribution of responses was generally even across different teaching subjects. Notably, some respondents observed improvements in the quality of task responses, though two expressed concerns about potential deterioration in learning outcomes. For student groups with diverse backgrounds, one respondent highlighted a possible improvement in motivation.

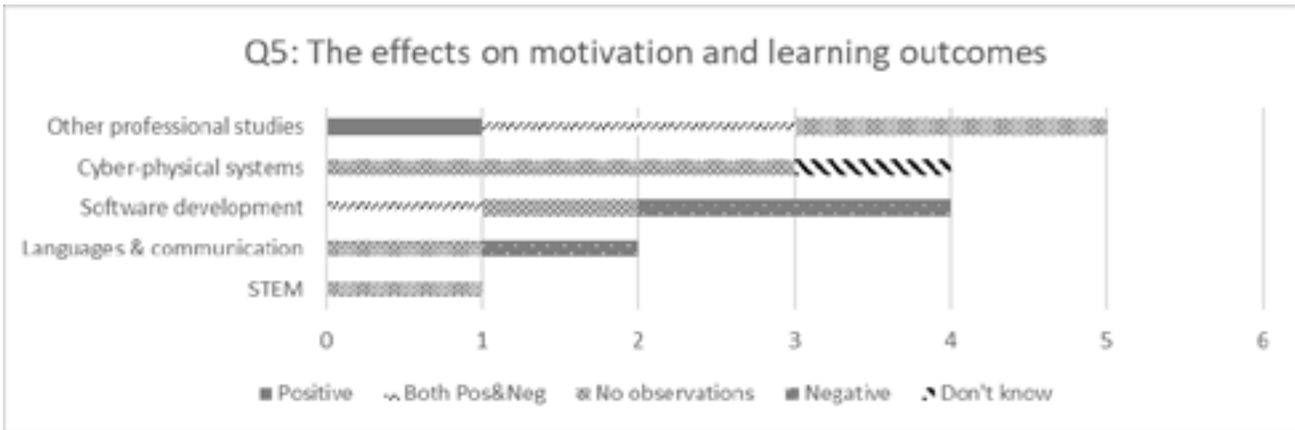

Figure 2. The proportion of the observations of the effects on motivation and learning outcomes.

In Q8, respondents expected additional training for staff and general guidelines on the use of AI in teaching. Specifically, a solution to the issue of costs at the organizational level was desired, and the initiation of a project or development initiative utilizing AI to integrate into the planning, implementation, and evaluation of teaching was suggested. Concerning the theme of sustainable development, the weakest responses were received, with ten being either blank or of the 'I don't know' type. In some responses, collaboration with companies to develop AI-supported solutions was proposed.

Twelve respondents evaluated the development direction of AI for engineering education (Q7) positively. Only four respondents saw the impact as negative. Both language teachers and teachers of other subjects saw the future positively. In contrast, responses from vocational subject teachers, such as software development and cyber-physical systems, included both positive (N=5) and negatively interpreted responses (N=3). Respondents emphasized that engineering education must keep pace with technological development and that AI tools will be central in planning and implementation in the future. Furthermore, it was seen that AI plays a role in the design and execution of teaching as well. In Q6 respondents were looking for ideas and tips for utilizing AI in education, with specific challenges related to machine vision and the cybersecurity of AI being highlighted.

4 SUMMARY AND ACKNOWLEDGMENTS

This study clearly demonstrates an increasing integration of AI within ICT engineering education, as evidenced by widespread use among educators. The proactive adoption of AI tools across various teaching domains reflects a significant shift towards technologically enhanced educational. Most teachers have already started using AI tools in their teaching and guidance processes. This indicates a proactive approach towards embedding AI into the curriculum, aligning with the necessity for educational institutions to evolve with technological advancements. However, the data also reveals a substantial number of teachers facing challenges in AI integration, primarily due to cost and mandatory registration barriers. These hurdles underscore the need for institutional support in facilitating access to AI resources and training, to ensure that the benefits of AI can be fully leveraged in education.

While the research by Pisica et al. (2023) provided valuable insights into the adoption of AI, it did not address critical factors such as the time and financial investments required, which are essential for understanding the full scope of AI integration challenges. In contrast, our study identifies these investments as significant barriers, emphasizing the need for detailed planning and resource allocation in future AI adoption strategies. However, these factors emerged in the case of teachers in the ICT field as described in this article.

Pisica et al. (2023) point out that contemplating restrictions on the use of artificial intelligence partly reflects a narrow perspective and a lack of understanding of the true potential of AI. The mixed observations on AI's impact on students' learning outcomes and motivation suggest a nuanced interaction between AI and educational processes. While some teachers noticed improvements in task quality and potential boosts in student motivation, concerns about the negative effects on learning outcomes were also reported. This dichotomy highlights the complexity of AI's role in education, necessitating further research to understand its effects comprehensively and to develop strategies that optimize its benefits while mitigating potential drawbacks.

Teachers' positive outlook on the future role of AI in engineering education, coupled with the call for additional training and guidelines, reflects a strong belief in AI's potential to enhance teaching and learning. The desire for organizational support in overcoming financial barriers and the initiative for AI integration projects indicates a proactive stance toward embracing AI in education. Moreover, the specific interest in training on machine vision and AI cybersecurity points to a keen awareness of the emerging areas within AI that are relevant to ICT engineering.

The relatively weaker responses concerning sustainable development suggest a gap in the current discourse on AI's role in fostering sustainability in education. This gap presents an opportunity for future research and development efforts to explore how AI can contribute to sustainable educational practices. The proposal for collaboration with companies to develop AI-supported solutions reflects an acknowledgment of the potential synergies between educational institutions and the tech industry in advancing AI in education.

The findings from this study underscore the significance of AI in the evolution of ICT engineering education. While there is evident enthusiasm and acknowledgment of AI's potential, the challenges faced by teachers highlight the need for comprehensive institutional support and training programs. Addressing these challenges and leveraging collaborations with the tech industry can pave the way for a more integrated and effective use of AI in education, ultimately enriching the learning experience and ensuring that students are well-equipped for the AI-driven future. Additionally, the experiences and perspectives of teachers obtained from this study on the needs for competence development and student motivations can serve as a basis for developing guidelines for the advancement of AI expertise from the perspective of engineering education faculty, especially those in ICT engineering education.

In conclusion, the feedback from ICT engineering educators at Lapland UAS underscores a critical need for robust institutional support and strategic planning. These elements are essential to effectively integrate AI into higher education curricula, ensuring that educators are well-equipped to navigate the evolving technological landscape. Other institutions can learn from these findings by actively seeking ways to incorporate AI into their curricula, addressing potential challenges proactively, and fostering collaborations with industry to enhance the relevance and effectiveness of AI in education.

In almost all changes related to teaching in higher education institutions, the conclusions and recommendations can be considered as general instructions on how to respond to these changes. Caution in introducing artificial intelligence, as well as courage, curiosity, and promotion of new methods, may present conflicting goals. Based on the responses in this study, it can be assumed that the latter perspective—a bold approach—is recommended in higher education.

This study also has some limitations. For example, the sample size is small, which can affect the generalizability (Ercikan & Roth 2014). Out of 18 surveyed, 12 answered. The survey was sent to the entire population, so the coverage of the survey is sufficient. Negative perspectives have also been brought up in the study, which enhanced the reliability of the study (Creswell 2014, pp. 251-252). The disruptive effect of artificial intelligence is a global phenomenon that has appeared simultaneously everywhere, and it can be assumed that the challenges it brings to higher education are universal.

REFERENCES

Azmi, Fatima M., Habib Nawaz Khan, and Aqil M. Azmi. "The impact of virtual learning on students' educational behavior and pervasiveness of depression among university students due to the COVID-19 pandemic." *Globalization and health* 18.1 (2022): 70

Bates, Tony, et al. "Can artificial intelligence transform higher education?." *International Journal of Educational Technology in Higher Education* 17 (2020): 1-12

Cellini, Stephanie Riegg. "How does virtual learning impact students in higher education?." Brookings Institution. United States of America. 2021.

Creswell, John W. *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Sage publications. 2014.

Crompton, Helen, and Diane Burke. "Artificial intelligence in higher education: the state of the field." *International Journal of Educational Technology in Higher Education* 20.1 (2023): 22.

Ercikan, Kadriye, and Wolff-Michael Roth. "Limits of generalizing in education research: Why criteria for research generalization should include population heterogeneity and uses of knowledge claims." *Teachers College Record* 116.4 (2014): 1-28.

Hodges, C., and C. Ocak. "Integrating generative AI into higher education: Considerations." *Educause Review* (2023).

Kim, Nam Ju, and Min Kyu Kim. "Teacher's perceptions of using an artificial intelligence-based educational tool for scientific writing." *Frontiers in Education*. Vol. 7. Frontiers, 2022.

Lampou, Rania. "The integration of artificial intelligence in education: opportunities and challenges." *Review of Artificial Intelligence in Education* 4.00 (2023): e015-e015.

Mallik, Sruti, and Ahana Gangopadhyay. "Proactive and reactive engagement of artificial intelligence methods for education: a review." *Frontiers in artificial intelligence* 6 (2023): 1151391.

Malmqvist, Johan, Kristina Edström, and Anders Rosén. "CDIO standards 3.0–updates to the core CDIO standards." *16th International CDIO Conference, CDIO 2020Virtual, Online, 8-10 June 2020*. Vol. 1. Chalmers University of Technology, 2020.

Núñez, José L.M. & Lantada, A.D. "Artificial Intelligence Aided Engineering Education: State of the Art, Potentials and Challenges." *International Journal of Engineering Education* 36.6 (2020): 1740– 1751.

Pisica, Alina Iorga, et al. "Implementing artificial intelligence in higher education: Pros and cons from the perspectives of academics." *Societies* 13.5 (2023): 118.

The Finnish National Board on Research Integrity (TENK). *The Ethical Principles of Research with Human Participants and Ethical Review in the Human Sciences in Finland.* Finnish National Board on Research Integrity Guidelines, no. 3/2019, 2019. https://tenk.fi/sites/default/files/2021-01/Ethical_review_in_human_sciences_2020.pdf.

Torres Martín, César, et al. "Impact on the virtual learning environment due to COVID-19." *Sustainability* 13.2 (2021): 582

Ideation techniques for engineering students: state of the art and recent case studies

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***Keywords**: Ideation, Design, Gen-AI, Problem Framing*

ABSTRACT

Engineering students must be able to generate diverse, creative solutions to problems as a key skill for their future careers, as industry and the environment requires innovative solutions to complex problems. This paper reviews some current best practice in ideation and problem framing that are taught in engineering programmes and surrounding education. Frameworks include morphology analysis, design heuristics, SIT tools and generative-AI. Each framework aims to present problems in different perspectives and encourage students to solve them creatively, with each demonstrating an improvement in student creativity and diversity of thought when they are taught in project-based activities. Following this review, two case studies from The Engineering & Design Institute London (TEDI-London) are presented, illustrating how students utilised various ideation tools during an engineering product design module. The paper concludes with key lessons for educators interested in incorporating such tools into their teaching. Overall, the paper highlights innovative methods to foster creative problem-solving skills among engineering students.

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1 INTRODUCTION

Engineering education needs to consistently innovate so that engineers entering the workforce are better equipped to tackle industrial, societal and environmental problems (Nordin and Norman 2018). Courses on user-centred design, and teaching where students tackle open-ended projects are seen as an emerging part of innovative engineering education (Graham 2018), and ideation (forming ideas or concepts) is a key stage in problem solving (McGlashan 2018).

Ideation and problem framing are key to better develop problem solvers, with project-based learning (PBL) offering a practical, hands-on approach to training engineers in ideating and in improving creativity (Chang et al. 2022). PBL courses have become increasingly popular in engineering education. For example, University College London have adopted PBL modules within the integrated engineering programme (Hailes et al. 2021) and newer providers such as the New Model Institute for Technology and Engineering (NMITE) or The Engineering & Design Institute London (TEDI-London) have emerged, and primarily teach using PBL.

There are several widely used frameworks and concepts for ideation, including group brainstorming and the ‘theory of inventive problem solving’ (TRIZ). Group brainstorming, has been shown to significantly reduce the productivity of ideation (Mullen, Johnson, and Salas 1991). TRIZ (originally derived from the study of inventive patterns in patents), meanwhile has been shown to improve the novelty and variety of ideas, compared with ad-hoc ideation (Hernandez, Schmidt, and Okudan 2013). TRIZ can be challenging for newcomers with 40 different inventive principles (Ilevbare, Probert, and Phaal 2013), however, through simplifications, and derived techniques such as ‘systematic inventive thinking’, these can be potentially fruitful alternative ideation techniques for engineering students.

Accordingly, in this paper, we (i) present an overview of emerging methods for ideation and (ii) present two short case studies from our institution where example tools have been used in diversifying potential solutions. Finally we highlight key take-aways for educators looking to implement such techniques in their programmes.

2 IDEATION METHODS

2.1 Morphological analysis

The process of morphological analysis is defined by breaking a problem down into its constituent parts, subcomponents and functions, and ideating for each individually, resulting in a morphology chart. In this different combinations of solutions are selected together to design products. There is little academic literature to define how to select different solutions, as the number of total solutions may be unreasonable to consider, e.g. a chart with 6 functions and 7 different solutions per function yields over 117,000 solutions. Approaches may include systematic combinations of all functions, intelligent combinations or random combinations. In any case, this is often seen a vague to students and can be challenging to apply if a student is not comfortable the procedure.

There are few recent academic studies on the use of morphology charts in design thinking. One study (Daly et al. 2016) compared creation ideation techniques with beginning designers investigating the use of morphological analysis, design heuristics and individual brainstorming. This found individual brainstorming to be the simplest method of idea generation, producing the most concepts. Alternatively, with appropriate teaching, morphological analysis resulted in more elaborate concepts than individual brainstorming. An additional study of 54 mechanical engineering students (Smith et al. 2012) lead to the development of guidelines for the use of morphology charts in design thinking. This stated that designers should explore and expand the design space through the use of additional solutions, rather than functions, and that primary and critical functions should be focused on.

2.2 Design heuristics

Design heuristics are design strategies that can be employed in ideation, and may be considered 'rules of thumb' (Yilmaz et al. 2016) to apply in the design process, to aid in generating a wide range of concepts and, to help designers avoid becoming 'fixated' on early ideas. There are many design heuristics, often tailored to different fields. For example, Yilmaz (Yilmaz et al. 2016) analysed key features and functional elements of 400 award-winning products, from different designers, and from this extracted 40 design heuristics. They extracted well-specified heuristics that other designers could clearly identify with and apply to their own designs. The heuristics included principles such as "implement characteristics from nature within the product", "allow user to reorient" and "use the inner surface space of the product for different functions". They went on to study how the heuristics aided undergraduate industrial designers during ideation, and found that, on average, concepts that showed evidence of using the heuristics were more creative, and also more diverse.

In recent progress, authors from ETH Zurich (Blösch-Paidosh and Shea 2021, 2022) summarised a set of design heuristics for design for additive manufacturing. This set of 25 design principles included "consolidate parts to reduce assembly time" and "create multi-functional artifact with reconfigurable structures".

Heuristics are helpful "quick and dirty" tools that can help spark ideas for a wide range of design scenarios. As there are plentiful resources of design heuristics for many highly specific areas, teaching these to undergraduate students can pay dividends in (i) increasing creativity (ii) increasing diversity of concepts and (iii) increasing productivity of designers by ensuring they build on others' findings.

2.3 AI-Assisted techniques

With recent advances in AI technology, in-particular Generative AI (Gen-AI) and Large Language Models (LLMs), studies have attempted to decipher the usefulness and drawbacks of this technology in design thinking, innovation and creativity. Gen-AI has made rapid advances typified by Open AI's ChatGPT chatbot which is able to match or improve on human performance in examinations and, Microsoft Co-Pilot able to aid in writing and debugging code. Furthermore, Midjourney and Microsoft Designer, based on DALL-E 3, are able to produce images from text. Various sectors have begun utilising the use of Gen-AI including in healthcare, business and design (Chong et al. 2022) with the benefits of Gen-AI being extensively researched for their use in design, ideation and in co-design (Kim, Maher, and Siddiqui 2021; Chiou et al. 2023).

Prior to the release of this software, a studied showed innovation managers regarded idea generation and idea evaluation as the least important areas for AI application within the design process (Füller et al. 2022). Since then studies have shown a remarkable increase in the use of Gen-AI in design thinking. Students from engineering and design courses used a range of tools including ChatGPT and Midjourney during both the research and empathy phases and the ideation and prototyping phases of a makeathon (David, Krebs, and Rosenbaum 2023). Within the study, 82% of engineering, and 76% of design students used Gen-AI tools to aid in the creation of their solutions. During the research and empath stages 67% of students used textual only tools (ChatGPT) and 19% used visual only Gen-AI tools (Midjourney). This significantly increased to 30% using visual only in the ideation and prototyping phases with students using visual Gen-AI tools to visually validate and develop their solutions. This approach is supported by a number of other studies, suggesting that Gen-AI can work with human designers rather than replace them (Esling and Devis 2020; Bilgram and Laarmann 2023).

Bilgram (Bilgram and Laarmann 2023) showcased the use of Gen-AI in accelerating the digital prototyping and innovation phases of design, through the production of an app. In this, discussions with ChatGPT were used to create HTML/CSS prototype at an accelerated rate through aiding the user in debugging the software, providing instructions and code snippets, however limitations were reached due to extensive conversations leading to content being ‘too for back’ for the AI to remember features and requirements.

It is seen that Gen-AI may be a game changer in early prototyping as the delegation of tasks can lead to faster iterations and reduced costs. Numerous studies have shown the positive impact on the early stages of design (Tholander and Jonsson 2023; Chiou et al. 2023; Girotra et al. 2023). However, this is often reliant on two factors. (i) the quality of the prompt used for generation and (ii) the input of the designer to co-create with Gen-AI rather than replacing the designer. Although studies have shown that Gen-AI is capable of matching or surpassing professional designers in idea generation judged on novelty, customer benefit and feasibility in some scenarios (Joosten et al. 2024), often designers find the tools to be useful for ‘going wide’ on a topic rather than ‘digging deep’.

This is a rapidly changing landscape with new tools and capabilities of LLMs and Gen-AI being developed at unprecedented rates creating new scope for idea generation and development.

2.4 Systematic inventive thinking

Systematic inventive thinking (SIT) is a derivative of TRIZ (Boyd and Goldenberg 2013), and as well as being a thinking method, is also the name of an innovation consulting company (SIT 2024). In SIT, designers implement five different “thinking tools” to generate new ideas. Initially, designers create an inventory of the components in the product, then apply one or more of the thinking tools, which are:

1. **Task unification**. Each component is converted to a resource to be used in another way. The tool then assigns a new task to the existing component.
2. **Multiplication**. One component of the inventory is multiplied, whilst giving it a qualitative change that makes it different from the original in some way.
3. **Division**. The components are divided up, physically or as a function of time.
4. **Subtraction**. Components are divided up, then one or more are removed.
5. **Attribute dependency**. Internal variables are corresponded to external variables to check if there is an attribute dependency on the internal variable to the external variable, then imagines that there is one, or vice versa.

The new ideas are then generally reflected on to evaluate whether the new ideas align with design principles. Designers ask the questions “what are the potential benefits”, “who may find this change valuable?” and “how may this help to address a problem” in response to the change made to the product.

(Barak and Bedianashvili 2021) showed several examples SIT for ideating and problem solving, for example the innovation of a spirit level to measure the specific slope of a surface. The authors described how, when a set of 110 engineering experts were given a 30-hour workshop on problem solving, including the SIT method, the engineers were able to show a marked increase in the number of inventive solutions (from 0.65 up to 4.84 solutions) in an exam, after the workshop.

3 CONTEXT: THE ENGINEERING & DESIGN INSTITUTE LONDON

3.1 Education Setting

In this paper, two case studies were examined using different ideation techniques by 2nd year Global Design Engineering students at TEDI-London . The degree programme primarily focuses on educating students through project-based learning. The case studies presented are indicative of the concepts and frameworks taught a module titled “User Centred Product Design” (UCPD). In this module students are required to define their own problem statement, ideate potential solutions and present their developed idea in a final assessment. The project theme was “design and prototype wearable technologies”. The final assessment is a design history file with physical prototype. Some of the learning outcomes of the module include (i) the ability to research and evaluate user needs as applied to the design of a product (ii) establish and apply aesthetic and ergonomic design and (iii) generate concepts and evaluate, iterate, and develop them.

Students are introduced to frameworks and tools through a blended approach. Background theory and formative tasks are delivered through online learning, allowing students to work at their own pace and become familiar with the tools by completing tasks adjacent to their main project. Some of the design tools include the use of journey maps, ethnographic tools and ideation techniques, including theory on how these help to overcome cognitive fixedness.

During in-person classes, theories and frameworks are presented and discussed in greater detail, often with workshops to practice using them. Students learn how to apply the tools to the situations they are solving, providing them with the opportunity to explore the possibilities. Students are given a range of frameworks to choose from, enabling them to select the tools and methods that best suit their situation and timeframe within the product development cycle.

3.2 Case Study 1: Systematic inventive thinking

During UCPD, 35 students took part in the module. Over ten weeks, students engaged in user research, and were required to produce material highlighting user pain points (both explicit and, latent pain points) and, from this, elicit design principles, that is, the characteristics (or “attributes”) that ideas must have in order to successfully overcome the identified pain points. Students initially worked in groups of three to four and gave an assessed interim presentation of their research and initial ideas. After the presentation, students worked independently on one selected idea. Whilst students were free to research any area, they were required to find problem areas that may be conceivably aided using wearable technologies.

Beyond the more obvious example (around ergonomics and battery life etc.) the type of design principles that students uncovered were varied, but some representative examples included: “Doesn’t add stress to the user’s life.” and “encourage conversation also … encompass immersivity”. The 5 SIT tools were applied to existing wearable technologies, to see if ideas could be sparked to create helpful innovations. The results were, very varied, but in some cases, laid the foundation for some innovative concepts. Some examples included:

- Division of a smartwatch into small modules, so a user could physically ‘leave’ a certain function at home, to reduce distraction or anxiety, initial sketches shown in Figure 1.
- Using the task attribution tool to assign the task of monitoring and calculating UV exposure and dosage, to a hair clip.

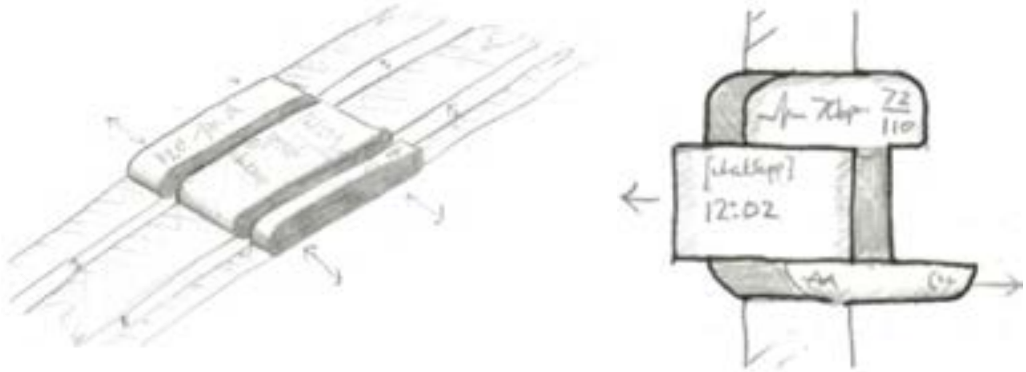

Figure 1: Examples of using the SIT ‘division’ tool for a modular smart watch design.

Out of a class of 35 students, anecdotally, nearly all engaged with, and were able to use the SIT tools. Students were generally able to generate a wide range of ideas using the framework. Of the 16 students that recorded ideas using a ‘creative matrix’ (a matrix with design principles as columns and ideation techniques as rows, with ideas in the cells), the average number of ideas in the creative matrix as generated from SIT was 15.4 ideas (minimum 4, maximum 51).

Students appeared to find the ‘attribute dependency’ tool relatively difficult to implement, whilst others were generally seen as simple and helpful. However, after the completion of the UCPD module only a handful (3 or 4 students) had continued to develop ideas that had originally been generated by SIT.

3.3 Case Study 2: Alternative worlds and visual Gen-AI

This second case study includes findings from the same cohort and module. Beyond SIT, two further frameworks were employed during UCDP to build inspiration and creativity in the product designs: ‘alternative worlds’ and visual Gen-AI. Students were encouraged to use Gen-AI throughout the design process with the majority using visual tools during the second phase: product development.

Using the ‘alternative worlds’ framework, students were asked to imagine how different brands may design their wearable products. For example, what if ‘Starbucks’ made smart glasses or ‘Beats headphones’ made VR glasses. Students selected an existing brand and identified the brand guidelines and design language used in their products to influence their own product development. Using these brand guidelines, concept images were generated using Microsoft Image Generation tools, powered by DALL-E. The results of this process can be seen in Figure 2 with examples of smart watches and ski goggles.

Figure 2: Examples of AI-Generated designs following brand guidelines established by students (a) a smart pill watch using Lemsip branding and (b) smart ski goggles using Garmin branding and design language.

Following the generation of images, students were asked to complete group design critiques of the images and designs. In this, they were required to highlight elements of the design they liked, or thought suitably matched the design language, and what elements they would change in future iterations. Students identified details of designs they wanted to progress through to final design, and further inspirations for their designs. Colorations between images critiqued and the final designs of students can be seen, with Figure 3 showing initial images generated and final renders of their products. Clear links and inspiration can be seen through the strap connectors, side buttons, shape and screen with refinements made to the designs generated by the student. These frameworks exposed students to a wider range of ideas and concepts during the development phase which enhances their creativity and diversity in idea development and ideation.

Figure 3: (a) Gen-AI images using design language from Canon products and (b) final student renders of smart watch produced by students.

4 CONCLUSIONS

Ideation and creative design are key tools for graduate engineering students starting their careers, hoping to produce innovative solutions to complex problems. This paper presented a range of tools taught across engineering design thinking programmes to increase the creativity and diversity of thought in solutions.

Traditional lecture-based programmes often struggle to engage students with key frameworks due to lack of practice and integration. Project-Based Learning, and user centred design courses are alternative education styles, allowing students to engage with tools and frameworks, as well as traditional engineering practices, whilst developing their own ideas and products.

Through presenting two case studies at TEDI-London , this paper has discussed the value of two frameworks, SIT and Generative-AI in fostering creative ideas in student projects. SIT was shown to aid nearly all students (in our cohort) in the generation of a wide range of initial ideas and concepts. A smaller number of students developed these concepts to a working prototype solution. This suggests that SIT may best be taught amongst a range of other tools, rather than a sole method.

Secondly, students used Microsoft Image Generator to create concept images of a range of designs for wearable products. This process was seen aid in the generation of diverse ideas, allowing students to imagine different products being produced in distinct design language or company. Rather than students using these designs as their products, a group design critique was conducted to encourage students to evaluate the designs. Final output from the project can be seen to contain inspiration from the generated images, combining different aspects together.

4.1 Key Takeaway for Educators

The pedagogy at TEDI-London primarily utilises PBL and online learning to teach fundamental principles and the application to real-world problems. There is a growing trend in engineering education programmes towards this methodology and this paper aims to enable other institutions to learn and implement the experience gained in their own programmes. Subsequently, the key takeaway points from this experience are summarised here:

1. Frameworks such as brainstorming and morphology analysis are traditionally taught in engineering undergraduate programmes but may reduce the productivity of ideation. Students who were taught methods such as SIT, and alternative worlds tended to favour their use in the product development cycle.
2. These frameworks are suitable for undergraduate engineering courses, and do not take up too much time to introduce, but considerable time to perfect.
3. Structuring PBL courses with significant tutor lead activities for new frameworks and tools is required for student engagement with such tools.
4. Introducing students to a wide range of frameworks and tools enables them to interact with methods they find useful and creative, leading to a diverse output from the cohort. Students value the access to a wide range of these tools.
5. Students were keen to engage in new technologies such as Gen-AI during projects but educators should work with students to help develop prompts and co-create through critiquing designs produced to influence their own designs.

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REFERENCES

Barak, Moshe, and Givi Bedianashvili. 2021. "Systematic Inventive Thinking (SIT): A method for innovative problem solving and new product development." *Proceedings on Engineering* 3 (1):111-122.

Bilgram, Volker, and Felix Laarmann. 2023. "Accelerating innovation with generative AI: AI-augmented digital prototyping and innovation methods." *IEEE Engineering Management Review*.

Blösch-Paidosh, Alexandra, and Kristina Shea. 2021. "Enhancing creative redesign through multimodal design heuristics for additive manufacturing." *Journal of Mechanical Design* 143 (10):102003.

Blösch-Paidosh, Alexandra, and Kristina Shea. 2022. "Industrial evaluation of design heuristics for additive manufacturing." *Design Science* 8:e13.

Boyd, D., and J. Goldenberg. 2013. *Inside the Box: A Proven System of Creativity for Breakthrough Results*: Simon & Schuster.

Chang, Te-Sheng, Hung-Che Wang, Alexander MacDonald Haynes, Mei-Mei Song, Shih-Yao Lai, and Shang-Hsien Hsieh. 2022. "Enhancing student creativity through an interdisciplinary, project-oriented problem-based learning undergraduate curriculum." *Thinking Skills and Creativity* 46:101173.

Chiou, Li-Yuan, Peng-Kai Hung, Rung-Huei Liang, and Chun-Teng Wang. 2023. "Designing with AI: An Exploration of Co-Ideation with Image Generators." Proceedings of the 2023 ACM Designing Interactive Systems Conference.

Chong, Leah, Guanglu Zhang, Kosa Goucher-Lambert, Kenneth Kotovsky, and Jonathan Cagan. 2022. "Human confidence in artificial intelligence and in themselves: The evolution and impact of confidence on adoption of AI advice." *Computers in Human Behavior* 127:107018.

Daly, Shanna R, Colleen M Seifert, Seda Yilmaz, and Richard Gonzalez. 2016. "Comparing ideation techniques for beginning designers." *Journal of Mechanical Design* 138 (10):101108.

David, Yigal, Assaf Krebs, and Alon Rosenbaum. 2023. "The use of generative AI tools in Design Thinking academic makeathon." *CERN IdeaSquare Journal of Experimental Innovation* 7 (3):43-49.

Esling, Philippe, and Ninon Devis. 2020. "Creativity in the era of artificial intelligence." *arXiv preprint arXiv:2008.05959*.

Füller, Johann, Katja Hutter, Julian Wahl, Volker Bilgram, and Zeljko Tekic. 2022. "How AI revolutionizes innovation management–Perceptions and implementation preferences of AI-based innovators." *Technological Forecasting and Social Change* 178:121598.

Girotra, Karan, Lennart Meincke, Christian Terwiesch, and Karl T Ulrich. 2023. "Ideas are dimes a dozen: Large language models for idea generation in innovation." *Available at SSRN 4526071*.

Graham, Ruth. 2018. "The global state of the art in engineering education." *Massachusetts Institute of Technology (MIT) Report, Massachusetts, USA*.

Hailes, Stephen, Liz Jones, Martina Micheletti, John E Mitchell, Abel Nyamapfene, Kate Roach, Emanuela Tilley, and Fiona Truscott. 2021. "The UCL Integrated Engineering Programme." *Advances in Engineering Education*.

Hernandez, Noe Vargas, Linda C Schmidt, and Gül E Okudan. 2013. "Systematic ideation effectiveness study of TRIZ." *Journal of Mechanical Design* 135 (10):101009.

Ilevbare, Imoh M, David Probert, and Robert Phaal. 2013. "A review of TRIZ, and its benefits and challenges in practice." *Technovation* 33 (2-3):30-37.

Joosten, J, V Bilgram, A Hahn, and D Totzek. 2024. "Comparing the Ideation Quality of Humans With Generative Artificial Intelligence." *IEEE Engineering Management Review*.

Kim, Jingoog, Mary Lou Maher, and Safat Siddiqui. 2021. "Studying the Impact of AI-based Inspiration on Human Ideation in a Co-Creative Design System." IUI Workshops.

McGlashan, Ann. 2018. "A pedagogic approach to enhance creative Ideation in classroom practice." *International Journal of Technology and Design Education* 28 (2):377-393. doi: 10.1007/s10798-017-9404-5.

Mullen, Brian, Craig Johnson, and Eduardo Salas. 1991. "Productivity loss in brainstorming groups: A meta-analytic integration." *Basic and applied social psychology* 12 (1):3-23.

Nordin, Norazah, and Helmi Norman. 2018. "Mapping the fourth industrial revolution global transformations on 21st century edication on the context of sustainable development." *Journal of Sustainable Development Education and Research* 2:1. doi: 10.17509/jsder.v2i1.12265.

SIT. 2024. "SIT - About us." accessed April 05, 2024. https://www.sitsite.com/about-us-systematic-inventive-thinking/.

Smith, Gregory, Jenkins Richardson, Joshua D Summers, and Gregory M Mocko. 2012. "Concept exploration through morphological charts: an experimental study."

Tholander, Jakob, and Martin Jonsson. 2023. "Design ideation with ai-sketching, thinking and talking with Generative Machine Learning Models." Proceedings of the 2023 ACM Designing Interactive Systems Conference.

Yilmaz, Seda, Colleen Seifert, Shanna R Daly, and Richard Gonzalez. 2016. "Design heuristics in innovative products." *Journal of Mechanical Design* 138 (7):071102

EDUCATING FUTURE ENGINEERS THROUGH MULTIDISCIPLINARY PROJECT WEEKS TO ETHICALLY AND INCLUSIVELY ADDRESS THE GLOBAL CHALLENGE OF SUSTAINABILITY

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ABSTRACT

All accredited engineering programmes in the UK need to meet learning outcomes set out in 'Accreditation of Higher Education Programmes' (AHEP 4) requirements. First and second year multidisciplinary project weeks have been developed to meet

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some of these requirements at a large scale. They focus on teaching transferable skills, with a particular focus on ethics, inclusivity, and sustainability. The project weeks were first delivered in 2012 and have been running consecutively for 13 years. An optimisation algorithm is used to create diverse groups of 5-6 students, considering gender, disability, programme of study and international status. Groups are clustered into “hubs”, which are organised and run by graduate student facilitators. Students produce design solutions to complex, real-world problems, using innovative thinking and teamwork. Consideration needs to be given to stakeholder and student outputs are required to be inclusive and sustainable. Each hub is supported and assessed by industry and faculty staff mentors. The project weeks are cost effective, delivering a 35-hour week of education for less than £60 GBP per student, including staff time. Additional features of the project week approach include equipping graduate students with experiences of using transferable skills, as a recruitment tool to attract prospective students to study engineering, the opportunity to innovate solutions without risk of failure and providing opportunities for facilitators to develop as teachers. The project week are generally well received by staff, students and industrial mentors.

1 INTRODUCTION

In addition to their technical knowledge, engineers require a variety of more general skills to function effectively in the workplace. Accreditation bodies recognize this necessity and incorporate requirements for such skills in their documentation. In the UK, these are specified in the 'Accreditation of Higher Education Programmes (AHEP 4),' which includes ethics, group working, multidisciplinary working, inclusivity, sustainability and presentation skills. Engineering courses have adopted to address these requirements with, for example, directly teaching these skills and integrating them into practical work. For this learning to be meaningful, it must be authentic. Many new engineering students envision their careers as focused solely on technical projects, where design, modelling, and analysis are the only necessary skills. However, experienced engineers understand that a broader set of strategies and experience is essential for effective performance. These transferable, non-technical skills become increasingly important as one advances in their career.

The development of transferable skills in higher education remains a central concern particularly in aligning these skills with employer expectations in a dynamic job market (Ehlers and Eigbrecht 2024). The engineering industry fuelled by technological innovation, demanding graduates equipped to navigate an uncertain future and potentially fill roles that have not been created yet. In response, project work emerges as an efficient pedagogical approach for fostering these future-critical skills through large-scale multidisciplinary learning experiences. Project-based learning is often lauded for its efficacy in fostering diverse skill sets within a multidisciplinary or interdisciplinary framework in engineering education (Kolmos et al. 2024). However, research suggests that existing applied projects in this field tend to be confined to a single discipline (Santana and de Deus Lopes 2024). Project weeks in contrast champion a multidisciplinary approach, featuring cross-disciplinary teams collaborating on complex problems. When tackling such challenges, incorporating diverse perspectives and technical expertise becomes crucial to identifying solutions with broad applicability. The project-week structure allows students to design solutions that are not only relevant and viable, but also feasible and desirable (Dennehy et al. 2019). Consequently, engineering students gain a heightened understanding of user needs and the significance of problem selection within complex projects. Additionally, interactions with industry mentors foster a "big picture" perspective enhancing their ability to conceive disruptive and impactful solutions (Charosky et al. 2018).

The Faculty of Engineering at the University of Sheffield, which teaches approximately 6,000 undergraduate students, across 10 broad engineering programme areas, has developed a project-based learning initiative. This is designed to cultivate transferable skills to a whole year group of about 1,500 students. This initiative ensures graduates are not only technically proficient but also have a strong foundation in ethical considerations, social impact, and environmental responsibility. The faculty integrates these elements to meet accreditation requirements and to produce well-rounded engineers equipped with multidisciplinary skills in a cost-effective and efficient manner. Emphasising inclusivity and sustainability, this approach aims to foster a generation of engineers who can make positive contributions to society.

This paper outlines the 'project weeks'. All engineering and computer science students participate in a full week of project-based learning in both their first and second years. The first year's project week, known as the 'Global Engineering Challenge' (GEC), focuses on cultural awareness and global agility. The second year's project week, 'Engineering You're Hired' (EYH), builds on the GEC and concentrates more on employability. They immerse undergraduate students in real-world problem-solving, including critical skills such as sustainable design, inclusive engineering design and practice, ethical decision-making, risk management, and multidisciplinary collaboration. The projects are designed to address complex issues that lack definitive solutions, mirroring the realities of professional practice.

The GEC and EYH project weeks have been running for 13 consecutive years, taking place in January during the three-week period of winter examinations. Engineering students have their exams scheduled over two of these weeks, providing an additional week free of other commitments. Finding a week without academic commitments across all 10 engineering programmes is a challenge, but scheduling the project weeks during the exam period allows them to proceed without disrupting other timetabled teaching.

2 METHODOLOGY

All first-year and second-year students are enrolled in one of two project week modules. Students are allocated into teams of 5-6 members, and each team collaboratively works on a project. Six teams are grouped together into a 'hub.' In 2012 the project weeks were run for the first time to a cohort size of 750 students, in 125 teams and 21 hubs (Murray and Horn 2012). In 2024, 1,440 students participated in the GEC, forming 240 teams and 40 hubs.

Each hub is provided with two rooms: a 'hub room' for project work and a 'boardroom' for presentations during the week. Hubs are managed and organised throughout the week by 'facilitators,' who are postgraduate students working as teaching assistants. Additionally, one faculty staff member is assigned to each hub to offer periodic mentorship and evaluation.

Teaching materials and activity planning are coordinated and led by a small group of academic project leads. Throughout the week, all students follow a guided programme of tasks to achieve a project conclusion. However, facilitators have the authority to adjust the delivery for their context, ensuring academic ownership of the teaching and maintaining the flexibility to adapt to unexpected circumstances.

2.1 The projects

Projects are selected to correspond with global challenges, especially those identified by the United Nations Sustainable Development Goals (SDGs). This strategic alignment ensures that students confront issues of paramount importance, utilising their engineering prowess to devise sustainable and inclusive solutions.

The first-year Global Engineering Challenge (GEC) projects are aligned with the design challenges presented by Engineering Without Borders (EWB). The academic leads of the project week then tailor the provided information to suit the GEC. This pedagogical approach to project selection is one of a number used by different institutions (Truslove 2022).

Typically, GEC projects are situated in rural, international settings that are unfamiliar to most engineering undergraduates. For instance, the 2024 project took place in Pu Ngaol, a community in Cambodia. Such projects necessitate that students work inclusively by:

- Collaborating with local stakeholders,
- Understanding the unique cultural, social, and environmental context,
- Developing solutions that empower the local community by involving them in the problem-solving process and utilising their knowledge and expertise,
- Adopting a “designing with” rather than a “designing for” approach.

Inclusive design requires students to devise solutions mindful of the significant resource constraints of the project communities, which often have limited access to essential services, expertise, and infrastructure. Students must creatively apply their engineering skills to discover innovative and practical solutions that are sensitive to the cultural and environmental sustainability of the area.

The second-year Engineering You're Hired (EYH) projects are conceptualised by the academic project leads and are rooted in the global challenges targeted by the Faculty’s research strengths or come from engaged industrialists. These multidisciplinary design projects maintain a focus on sustainability and inclusivity, developed during the first year, while escalating the demand for the technical engineering acumen necessary to produce a feasible engineering product. Students are expected to address considerations such as cybersecurity, intellectual property, risk, cost, timeline, and presentation of their solutions to various stakeholders. Example projects include electric aircraft, deconstruction robots, and ocean debris.

2.2 Team allocation

Multidisciplinary team are created so that projects are narrow-interdisciplinary systems projects, as defined by Kolmos et al (2024). Considerable effort is dedicated to team formation to ensure an equitable experience and the chance for students to work with a diverse range of peers. Before the project weeks start, students rank their project title preferences. An algorithm is utilised to optimise several considerations:

- Teams comprise members from different degree programmes (e.g., an aerospace engineer, a civil engineer, an electrical engineer, a computer scientist).
- The variance between home and international students in all teams is minimised, aiming for 1 to 2 international students per team.
- The distribution of team members with 'learning support plans' (declared disabilities or additional educational support needs) is considered.
- No team includes a single female engineer; all teams have either no female members or two or more.
- As many students as possible are allocated their highest project title preference.

In 2024, approximately 90% of students were assigned to their preferred projects, with the majority working on their first choice. However, this process faces contemporary challenges. First, forming multidisciplinary groups becomes more challenging with the fluctuating cohort sizes of different programmes. Notably, there has been a significant increase in students opting for Aerospace Engineering and Computer Science, with a decline in those selecting Bioengineering, Chemical Engineering, and Materials Science. Second, an increasing number of students choose not to declare their gender, potentially leading to a situation where a student identifying as female might be the only female in a team, though manual intervention has prevented this so far.

Efforts to engineer team formation aim to mirror the diverse dynamics of modern professional engineering environments. This process not only encourages collaboration and innovation but also prepares students for the realities of working in multidisciplinary teams. It provides an invaluable opportunity to recognize the importance of inclusivity in teamwork. The project weeks are deliberately designed to teach students the value of others' knowledge and expertise, fostering solutions that would be unattainable within the confines of a single disciplinary boundary. The international setting can also empower students from less traditional and overseas backgrounds as they may have had a wider experience of diverse cultures.

2.3 Facilitators

Facilitators play a crucial role in delivering content and guiding students throughout the project weeks. Each hub, comprising approximately 36 students, is overseen by a facilitator. These facilitators are graduate students employed on fixed-term contracts as teaching assistants. A number of 'flexi' facilitators are also recruited to cover absences and undertake other necessary reactive duties.

Selection of facilitators is conducted through interviews. Those chosen receive 10 hours of comprehensive training, which includes basic pedagogical training, in-depth orientation on the project weeks teaching and assessment, guidance on working with students with disabilities, and an introduction to digital learning tools. This training establishes the cultural tone for the initiatives and guarantees that all students are supported consistently and effectively.

During their training, facilitators are encouraged to take ownership of their teaching delivery. While the academic leads of the project week supply the overall structure and materials, facilitators are empowered to tailor the content and approach, making autonomous decisions and applying their unique teaching styles. This offers two main benefits. First, it enables facilitators to address hub-specific challenges or make decisions independently, without the need for intervention from the academic leads, who cannot be present at all hubs simultaneously. Secondly, it provided the facilitators with career development experience of leading.

Scheduled debriefs between facilitators and academic leads are incorporated into the week's structure. In addition, a set of digital tools allows continuous communication across all hubs.

2.4 Staff and industry mentors

Each hub receives support from a member of the academic staff within the faculty and an industrial mentor who is currently practising as an engineer. These mentors play a crucial role during the project week, offering insights to assist teams with their design solutions. They provide the perspective of experienced engineers, introducing considerations students might not have encountered, and they evaluate the students' work during boardroom-style presentations.

For faculty staff, contributing their time as part of their teaching responsibilities. Industrial mentors, many of whom are alumni, from approximately 100 Global Engineering companies, volunteer their time as philanthropy. Throughout the project weeks, students have opportunities to interact with these industrial mentors through activities such as panel sessions. These engagements are strategically organised to emphasise and enhance the focus on employability, ensuring students gain valuable insights into the engineering profession directly from experts in the field.

3 LEARNING, TEACHING AND ASSESSMENT

To replicate a work environment, students work in their hubs from 9am until 5pm, Monday to Friday. They participate in a mixture of facilitated sessions and group work time, receiving feedback and support at key points. Facilitated sessions cover topics such as presentation skills, team behaviours, ethics, and sustainability. There are fewer organised sessions in the second of the years, reflecting the students' improved experience and autonomy. Several milestones, reflections, and assessment points are set to allow students to understand their progress. The final activity is a presentation of their proposed solution, watched and assessed by the facilitator, staff member, mentor, and other hub members.

Information is provided to students through a website and VLE course sites. Facilitators are then permitted to adapt their version of the VLE site as appropriate. The assessment strategy for the project weeks is designed to holistically evaluate the students' integration of technical knowledge with transferable skills, to meet the AHEP 4 requirements.

The project weeks are zero credit, must-pass modules. The programme regulations require students to pass the modules to obtain an accredited degree, but the marks do not contribute to their final grade. The numerical outcome from the modules translates into a pass, fail, or distinction. Recognizing the importance of perseverance and continuous improvement, resit opportunities are provided for students who may not meet the passing criteria initially.

3.1 Alignment with AHEP4 and SDGs.

The rationale behind the creation of the project weeks was to address, on a large scale, the necessity of meeting the learning outcomes required by accrediting bodies. In the UK, all engineering accrediting bodies adhere to a uniform set of standards known as 'Accreditation of Higher Education Programmes' (AHEP 4). Given that these standards are consistent across all engineering and computer science programmes, it is feasible to efficiently meet them through faculty-wide project week modules.

Of the 18 learning outcomes specified in AHEP 4, the two project week modules meet or contribute to 11 (60%), including C4, C5, C7, C8, C9, C10, C11, C13, C15, C17, and C18. The project weeks are particularly adept at teaching and assessing outcomes related to ethics (C8), inclusivity (C11) in both design and teamwork within diverse groups, reflection (C18), and sustainability. These outcomes are specifically targeted in the assessment design.

Sustainability serves as a foundational theme of both project weeks. The activities and assessments focus on incorporating sustainability into the design process (C4) and evaluating the environmental and societal impacts of solutions (C7). Instruction is centred around the Sustainable Development Goals (SDGs) as defined by UNESCO, enabling students to comprehend the extensive sustainable impacts of their engineering work. It has been found that the participatory to sustainability education benefits the students in terms of academic, professional and personal growth (Cornet et al 2024).

4 EVALUATION

A stated rationale for introducing the project weeks was to deliver the experience to students in a cost-efficient manner. Table 1 provides information on the costs associated with delivering the project weeks. Fixed costs are those incurred regardless of the number of students participating, while variable costs are calculated per student (based on the number of hubs and 36 students per hub). Direct costs are those requiring payment from the faculty budget, and indirect costs account for staff time (approximated at the median senior lecturer grade).

Table 1. Costings for project weeks

Indirect Fixed Costs				
	Yearly (GBP)	*Fraction*	*Total (GBP)*	*Cost per student (GBP)*
Project Manager	48,000	20%	9,600	
Academic Leads	72,000	20%	21,600	
			31,200	

Indirect Variable Costs (per hub)				
Staff mentors	72,000	1%	**720**	**20**
Direct Fixed Costs				
EWB			**4,500**	**1.5**
Direct Variable Costs (per hub)				
	Cost/hour (GBP)	*Hours*	*Total (GBP)*	*Cost per student (GBP)*
Facilitator Training	23	10	230	
Facilitator Teaching	23	25	575	
Facilitator Marking	23	4	92	25
Industry mentor expenses			50	1
			947	**26**

The fixed costs for running the project weeks amount to 31,200 GBP for staff and 4,500 GBP for Engineering Without Borders. With 3,000 students participating, this equates to approximately 12 GBP per student. The variable cost includes 20 GBP for staff time and 26 GBP for direct costs.

For 3,000 students, the total cost is 57 GBP per student, including staff time, and 28 GBP as a direct cost excluding staff time. For this investment, students receive a full week (35 hours) of education. In comparison, providing practical lab-based education in the faculty of engineering costs approximately 20 GBP per hour.

Details here

4.1 Advantages of the project week approach

Beyond cost efficiency, there are additional advantages of the multidisciplinary project weeks approach:

Employability and transferable skills: Graduating students can cite experience of the skills that are critical for career progression. The project weeks embed non-technical skill development sought by employers, such as team working, inclusive thinking, creative problem-solving, and communication.

Unique experience for student recruitment: The project weeks are used as a tool to recruit students to study engineering at the institution.

Consistency in educational: The project weeks offer a consistent educational experience across various engineering disciplines. By standardizing the approach to teaching transferable skills and professional competencies, the project weeks ensure all students, regardless of their specific discipline, have a foundation of knowledge in areas such as ethics and sustainability.

Freedom to innovate and fail: The zero-credit basis of the project weeks allows students to be liberated from the constraints of traditional grading, encouraging bold, innovative solutions to complex problems. This freedom fosters a safe environment for creative experimentation and learning through failure.

Developing the facilitators as future academics: The flexibility afforded to the facilitators allows them to gain valuable teaching experience and develop skills essential for an academic career. This experience is particularly beneficial for those pursuing education fellowships, as it provides a real-world case study. Developing early-career academics is beneficial for the higher education sector to ensure a rich pipeline of talent.

5 DISCUSSION

The importance of planning and preparation for large-scale teaching should not be underestimated. When teaching small class sizes, it is common for educators to quickly develop material by taking shortcuts or creating processes that require manual or ad hoc intervention to function. In software engineering, the decision to quickly implement solutions that work but are not robust is referred to as “technical debt”. On a small scale, imperfections are manageable. However, when scaled up, as in the example of project week teaching being scaled to 40 simultaneous teaching sessions across many physical locations, small imperfections are amplified to a critical extent. Having to reactively cascade and communicate errata or misunderstandings on a large scale is extremely demanding.

To mitigate the potential for disruption, training and setting expectations with facilitators is key. Empowering facilitators to make decisions about how teaching is delivered and adapt this to the circumstances of their delivery allows each hub to operate autonomously. Facilitators should be equipped with knowledge of what is and is not important, what can be changed, and what outcomes are critical for the students to achieve, to allow those decisions to be made. Ensuring facilitators know who to find support from among the academic leads, and when not to seek that support, is a worthwhile investment of effort. A staff mentor sent the following comment about their facilitator to the academic project leads:

“*She's been exemplary this week in ensuring everyone has the correct information (myself and the industrial mentors), ensuring we know what we need to do and keeping us organised and on time. Her communication skills via email, Blackboard and Collaborate have been excellent and she's provided a supportive, yet constructively critical, environment for the students!*”

The project weeks were run online during the pandemic. A certain degree of hybrid teaching has been retained since, with the rationale that having experience of remote interactions is a valuable skill to develop for future employment, although the proportions have reduced. Feedback from students, staff, and industrial mentors is extremely divided about hybrid working. Some find the ability to work remotely valuable, while others feel it is determined by the experience of teamwork.

Prior to the week starting, some students are reluctant to engage. Many new engineering students envision their careers as focused solely on technical projects, and the value of transferable skills is not immediately apparent. To incentivise engagement, opening lectures are given by senior members of staff. These include personal anecdotes about how transferable skills have benefited their careers, and videos featuring previous students explaining how they have utilized the skills gained from the project weeks. It is worth noting that over 10000 students have

completed each of the 2 project weeks since their inception.

Following the project weeks, feedback indicates they are generally well-received by both staff and students. They are particularly enjoyed and valued by the industrial mentors, who offer significant praise. Survey respondents indicate:

- 100% of alumni stated they wanted to volunteer at the University because they wanted to support students.
- 96% of alumni felt their time was well spent.
- 100% believe the students benefited from participating in the activity.

Free text comments were also received, including the following from the head of software engineering at a major UK retail chain:

"*The challenges they've had are consistent with what engineers [sic] face in their careers. That's what's so great about EYH, it gives some real-world feedback on the softer skills of the industry that are just as important as the technical knowledge, and that's not something you learn about in a lecture theatre, you learn by doing it.*"

The final reflection concerns the sense of achievement felt upon completion of the weeks. Although there is little measurable evidence, it becomes immediately apparent to all involved that by the end of the week, students, staff, facilitators, and mentors genuinely feel that something substantial has been accomplished.

REFERENCES

Cornet, S., Barpanda, S., Guidi, M.-A.D. and Viswanathan, P.K. (2024), "*Sustainability education and community development in higher education using participatory and case based approaches in India*", International Journal of Sustainability in Higher Education, Vol. 25 No. 9, pp. 78-93. https://doi.org/10.1108/IJSHE-07-2022-0242

Engineers Without Borders Australia (2023), EWB Challenge website, accessed 16 May 2023. Available at: https://ewbchallenge.org/

Kolmos, A, Holgaard, JE, Routhe, HW, Winther, M & Bertel, LB 2024, *'Interdisciplinary project types in engineering education'*, European Journal of Engineering Education, vol. 49, no. 2, pp. 257-282. https://doi.org/10.1080/03043797.2023.2267476

Murray, P. and Horn, R., 2012. A global curriculum and a global working environment. Innovation, *Practice and Research in Engineering Education.*

Truslove, J. and Crichton, E. and Whitehead, T. and Clark, R.; (2022) *Pedagogical approaches to project-based learning : meeting the education needs of the globally responsible engineering workforce*. In: Proceedings of the 8th International Symposium for Engineering Education. University of Strathclyde, Glasgow. ISBN 9781914241208 (https://doi.org/10.17868/strath.00082045)

Kolmos, A., Holgaard, J. E., Routhe, H. W., Winther, M., & Bertel, L. (2024). Interdisciplinary project types in engineering education. *European Journal of Engineering Education*, *49*(2), 257-282. https://www.tandfonline.com/doi/epdf/10.1080/03043797.2023.2267476?needAccess=true

Santana, A. L. M., & de Deus Lopes, R. (2024). Using Real-World Problems and Project-Based Learning for Future Skill Development: An Approach to Connect Higher Education Students and Society Through User-Centered Design. In Creating the University of the Future: A Global View on Future Skills and Future Higher Education (pp. 393-417). Wiesbaden: Springer Fachmedien Wiesbaden. https://link.springer.com/chapter/10.1007/978-3-658-42948-5_20

Ehlers, U. D., & Eigbrecht, L. (2024). Creating the University of the Future: A Global View on Future Skills and Future Higher Education. https://library.oapen.org/handle/20.500.12657/89902

Dennehy, D., Kasraian, L., O'Raghallaigh, P., Conboy, K., Sammon, D., & Lynch, P. (2019). A Lean Start-up approach for developing minimum viable products in an established company. Journal of Decision Systems, 28(3), 224–232. https://doi.org/10.1080/12460125.2019.1642081

Charosky, G., Leveratto, L., Hassi, L., Papageorgiou, K., Ramos-Castro, J., & Bragós, R. (2018, June). Challenge based education: an approach to innovation through multidisciplinary teams of students using Design Thinking. In *2018 XIII Technologies Applied to Electronics Teaching Conference (TAEE)* (pp. 1-8). IEEE. https://ieeexplore.ieee.org/abstract/document/8476051

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CRITICAL THINKING TO ADDRESS COGNITIVE BIAS IN ENGINEERING

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Keywords*: Soft Skills, Transversal Competences; Critical Thinking; Cognitive Bias*

ABSTRACT

This article discusses the basic exercises taught as part of a course on Critical Thinking (CT) aimed at undergraduate engineering students (Torres et al. 2021). It is presented as an innovative tool to increase students' awareness of how cognitive biases can affect the decision-making process. When students are confronted with some of the classic examples of cognitive bias through Google Forms surveys, as conceived by Nobel laureate of economic sciences Daniel Kahneman, most fall into these cognitive errors. These surveys, originally intended for the general public, show engineering students that even individuals with a good understanding of basic probability theory (and well aware that they were going to be deceived) are prone to these cognitive biases. This approach has also shown that students who experience these cognitive errors first-hand become more involved, first, in developing the

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underlying concepts and, finally, in discussing debiasing techniques for better decision-making outcomes.

1 INTRODUCTION

1.1 Context and motivation

The emphasis of traditional STEM student education has been almost exclusively on acquiring technical and scientific knowledge, leaving a gap in terms of their preparation for the labour market. However, the need for continuous innovation, the increasing acceleration of change, or the reduction in the useful life of products and services, requires a new brand of STEM graduates able to cope with increasingly challenging tech market demands. In this sense, surveys addressing future labor market demands give growing importance to social, emotional and higher cognitive skills, such as Critical Thinking, as key transversal competences (Bughin et al.2018), (Dondi et al. 2021), and cognitive bias is receiving increasing interest in engineering education (Chattopadhyay et al. 2022) (McDermott et al. 2020). Within this context, a series of elective subjects developed at the Universitat Politècnica de Catalunya (UPC) aims to provide engineering students with a grasp on critical thinking basics. The examples presented in this paper are included in four 2-hour sessions titled "Perception and Deception" that has been taught since 2021 (Torres et al 2021) within a CT course. They are devoted to exposing common biases when probability and risk are involved in intuitive estimations.

1.2 Critical thinking for improved decision-making outcomes

Critical thinking has emerged as a crucial skill in improved decision-making processes to manage the overwhelming amount of information to deal with. It is becoming increasingly clear that the information we perceive may be tainted with intentional or unintentional biases intended to influence our behaviour. As a fundamental step in the decision-making process, young STEM graduates must develop a sceptical attitude toward the information they receive and also improve their awareness of the main sources of cognitive deception. (Kahneman 2011) showed that, in general, intuition has little capacity to face choices that involve estimating probabilities, which are very common in problems related to social and economic issues. Developing strategies to address this type of potential source of flawed decisions is a key competency for STEM students to develop.

2 METHODOLOGY

2.1 Cognitive bias

The course begins with a brief introduction to the work of Nobel Prize Winner Daniel. Kanheman, who unveiled ground-breaking findings in the field of behavioral economics and cognitive psychology (Kahneman 2011). As summarised in Table1, Kahneman states that people have two ways of thinking when making decisions. He called them System 1 and System 2 modes:

- System 1 (intuition), which is fast, automatic, frequent, effortless, emotional, stereotyped and subconscious. It generates intuitions that serve us most of the time, but not always.

- System 2 (reason), which is slow, effortful, logical, infrequent, calculating and conscious. It makes final decisions, based on system 1 intuitions, expanding them with more information and rational processes.

Table 1. Kahneman's System1 and System 2 main features

System 1: Fast, Intuitive, and Automatic	System 2: Slow, Analytical, and Deliberate
➢ Fast Processing	➢ Slow Processing
➢ Automatic Responses (efficient)	➢ Effortful and Controlled
➢ Heuristic-Based (rules of thumb)	➢ Rule-Based Decision Making
➢ Associative Thinking	➢ Calculative Thinking
➢ Energy-Efficient (effortless)	➢ Needed to Overcoming Biases

People mainly rely on their intuition (System 1) to deal with the bulk of daily activities. They use heuristics, mental shortcuts derived from past experiences, that facilitate fast problem-solving and probability judgments. These strategies are generalizations, or rules-of-thumb, that reduce cognitive load (System 2). Although they are useful in many everyday activities, heuristics can lead to misjudgements and errors. Particularly, Kahneman made a list of several systematic cognitive biases, that are quite widespread and that are very prone to produce flawed decisions. To improve students' awareness of this problem and motivate them further, as developed in the following sections, some surveys based on Kahneman's work have been prepared to show them that they also suffer from these misperceptions.

2.2 Surveys on cognitive biases in the classroom

As an introduction to the main concepts of cognitive biases, students are asked to provide answers in the classroom, using Google Forms, to a set of classical problems of choices and judgments thoroughly described in (Kahneman 2011):

- **Representativeness**
- **Base rate**
- **Availability**
- **Gain/loss asymmetry**
- **Framing effect**

Once students realize first-hand that they are not free from cognitive biases they are much more engaged in discussion about this topic. The following section presents these specific examples, as developed in the classroom.

3 DISCUSSION ON COGNITIVE BIAS SURVEYS

3.1 Representativeness bias

This bias is introduced to the class using the so-called Linda's survey, where students are asked to estimate the plausibility of several statements about the job a graduate in philosophy is performing several years after graduation. Figure 1 shows these statements and the answers given by the students.

Linda is 31 years old, single, open-minded and very bright. At university, she graduated in philosophy. As a student, she was deeply concerned about issues of discrimination and social justice. At that time, she participated in the organization of student demonstrations against the use of nuclear energy. About Linda's activity *today, 8 years after her graduation, estimate from 1 to 10 the degree of plausibility of several statements:*

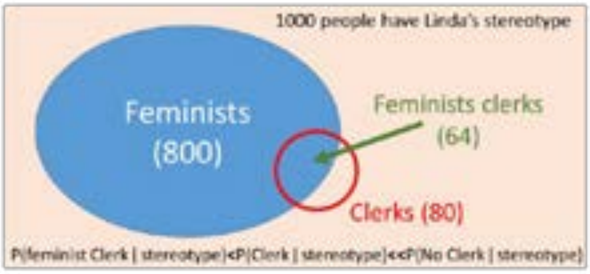
(1 Completely unlikely, 2.5 unlikely 5 plausible, 7.5 likely 10 very likely)

Fig. 1. Linda's survey illustrates the conjunction fallacy: assuming that a specific situation (office worker at a bank and active in the feminist movement) is more probable than the general situation (office worker at a bank).

In the set of questions in Figure 1, only numbers 4 and 8 are relevant to the conclusions. They both apply to the plausibility that Linda is a bank teller. Students fall (statistically) into the representative cognitive bias. They assign a larger probability to the fact that Linda is a bank teller involved in the feminist movement than she simply is a bank teller. But this goes against elementary probability theory which states that a subset cannot be more probable than the entire set. Linda is an individual representative of a class that readily comes to the minds of the students. They unconsciously answer to a different fact: if Linda is a bank teller (a rare event) then she probably is involved in a feminist movement with a high degree of probability. Once the survey has been completed Figure 2 (left) is shown to the students, where a probability of 80% has been assigned to the main assumptions. This cognitive bias, also known as the conjunction fallacy, appears when it is assumed that a specific situation is more probable than the general situation. It is motivated by the representative bias that leads us to answer a different question that comes to our mind more easily, mistaking plausibility for probability. In this case, students have mistakenly jumped to provide an answer to the questions in Figure 2 (right): In both cases, the answer is "very high" given the "feminist" stereotype, but the real question was the other way around:

- **What is the probability that Linda is a bank teller and a feminist?**

The probability that Linda is a bank teller with no adjectives is very low (80/100), but larger than being a bank teller and a feminist (64/1000), in this example.



- **What is the probability that Linda is a feminist?**
- **If Linda is an office worker at a bank, what is the probability that she is also a feminist?**

Fig. 2. Plausible distribution of Linda's stereotype (left). This bias occurs when students answer a different question that comes more easily to their minds (right)

3.2 Base rate fallacy

Joaquin's Survey in Figure 3 shows that even engineering students can make a common mistake called the base rate fallacy. This happens when they miss important information in an open problem, usually due to the representativeness bias. In this case, 95,7% of students, 31 over 32, have estimated option A (engineering student) as the most probable. However, the real world is not so straightforward. They have missed that there are a lot more humanities students than engineering students (base rate bias). This mistake is driven by a tendency to rely on stereotypes rather than facts. Instead of answering the right question—***'What's the chance Joaquin is an engineering student given certain facts?***'—again, they end up answering a question that unconsciously comes more easily to their minds, ***'If Joaquin is an engineering student, how likely is he to fit the stereotype?***' This mix-up shows they're not using Bayes' Theorem correctly, where the probabilities should be seen differently depending on the question. Once the survey has been completed Figure 3 is shown to the students to illustrate their misperception. It has been assumed that, over a population of 300.000 students in Catalonia, 66,7% are enrolled in humanities studies and 6,7% in engineering. For the sake of discussion, it has been assumed that 10% of humanities students match the stereotype whereas this figure grows to 75% in the case of engineering students. With the number given in Figure 3, conditional probabilities can readily be computed:

$$P(Engineering|Stereoptype) \neq P(Stereoptype|Engineering)$$
$$\frac{15.000}{35.000}(42{,}9\%) \neq \frac{15.000}{20.000}(75\%) \quad (1).$$

$$P(Humanities|Stereoptype) \neq P(Stereoptype|Humanities)$$
$$\frac{20.000}{35.000}(57\%) \neq \frac{20.000}{200.000}(10\%) \quad (2).$$

The right-hand part of these equations shows the direct probability computation leading to the bias: students correctly assume that engineers match the stereotype much better than humanity students, but, like in the Linda Survey, that was not the original question. By comparison of the two results, with the population numbers in Figure 3, we can see that the probability that Joaquin is an engineering student is 42.9%, lower than the probability that he is a humanities student (57%). This misuse of Bayes' theorem, which assumes that the exchanged conditional probabilities are equal, is the main source of representative bias errors. In fact, this cognitive bias is one of the main sources of prejudice (e.g. most street thieves are poor, so most of the poor people are thieves). It should be noted that engineering students are quite proficient at calculating probabilities when given all the relevant information. However, in real life, this relevant information can be easily overlooked and suffer from the base rate fallacy. This is the case, for example, when testing for infection with procedures that have a low but significant failure rate (e.g. COVID testing), incriminating evidence in trials (e.g. prosecutor's fallacy) or drug tests, among others.

Joaquín is a 20-year-old guy who lives in Catalonia. He is methodical and his fundamental fun is everything related to computers. Which of the two options do you think is more likely?

A) Joaquín is an engineering student

B) Joaquín is a humanities student

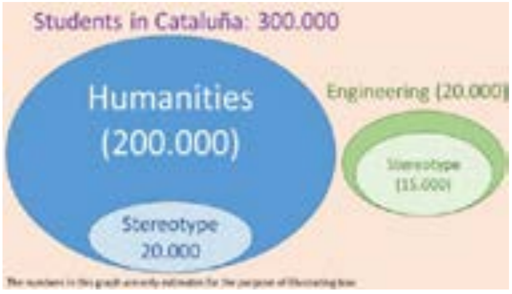


Fig. 3. Statement for the Joaquín's survey (top) and approximate classification of HE students in Catalonia (bottom). It has been assumed that 10% of humanities students match the stereotype and 75% in the case of engineering students

3.3 Availability bias

Here, students are asked to answer several questions of this kind:

What should you be most afraid of?	What causes more deaths per year?
A) A Plane crash	A) Sharks
B) Struck by lightning	B) Hippos

The majority of the students answer A) in both cases because plane crashes and sharks come more easily to their minds. However, the real numbers are the following: sharks, 7 deaths/year; hippos, 500 deaths/year; planes, 400 to 1000 deaths/year and lightning, 6.000 to 24.000 deaths/year. Availability bias is a well-known cognitive bias that benefits insurance companies: people tend to overestimate the probability of events that they remember more easily and are willing to pay overpriced policies for overestimated risks.

3.4 Gain/loss asymmetry

In this survey, students are asked about their willingness to accept a coin-tossing bet. This test is intended to show them that individuals tend to perceive losses more intensely than gains of equal magnitude. This means that the emotional impact of losing 10€ is typically felt more strongly than the pleasure derived from gaining 10€. To overcome this risk-aversion bias and make the bulk of students accept the bet, the expected gain must be significantly larger than the expected losses (usually a factor 2 to 3 larger) as shown in Figure 4. This asymmetry in emotional response can influence various aspects of decision-making, including financial choices, investment strategies, and everyday judgments. Understanding this phenomenon is crucial for comprehending why individuals may exhibit risk-averse behaviour in certain situations, even if potential gains are substantial (e.g. resistance to change).

A. If HEADS comes up you win **10€**, if TAILS you lose **10€**
B. No bet

A. If HEADS comes up you win **15€**, if TAILS you lose **10€**
B. No bet

A. If HEADS comes up you win **20€**, if TAILS you lose **10€**
B. No bet

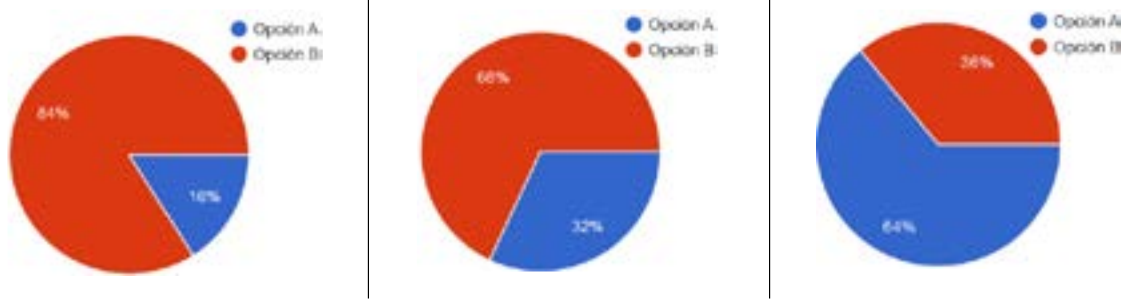


Fig. 4. "Tossing-a-coin". Expected gains must be significantly higher than expected losses to make students accept the bet. 25 bachelor engineering students answered the survey.

3.5 Framing

Framing, as defined by Kahneman, refers to the way information is presented or framed, which can significantly influence people's perceptions and decisions. That is, the same information presented in different ways can lead to different judgments and choices despite the same objective information content. In particular, in this exercise, two different groups of students are faced with a survey to show them that individuals tend to be risk-averse when faced with decisions framed in terms of potential gains (positive framing), but to risks-seeking when the same decisions are formulated in terms of potential losses (negative frame). The results in Figure 5, related to the "Rare disease problem" (Kahneman 2011), illustrate how the framing of information can shape people's attitudes toward risk and their subsequent choices, even in sensitive matters such as life and death decisions.

4 DEBIASING

The exercises developed in the previous section convince students that important decisions require special attention to avoid flawed decisions and misjudgements. Once the main sources of cognitive biases have been presented, the course ends with a discussion on the main techniques that can improve decision-making by preventing this kind of error, the so-called debiasing techniques:

- Develop awareness of the bias
- Improve how information is presented
- Create psychological self-distance
- Consider alternatives
- Change incentives
- Increase accountability
- Make the reasoning process explicit
- Slow down the reasoning process
- Elicit external feedback
- Reduce reliance on subjective memory

The United States is bracing for an outbreak of a rare disease, which is expected to kill 600 people. Two alternative programs have been proposed to combat the disease. Choose one of the two possible alternatives if the exact scientific estimates of the consequences of these programs are as follows:

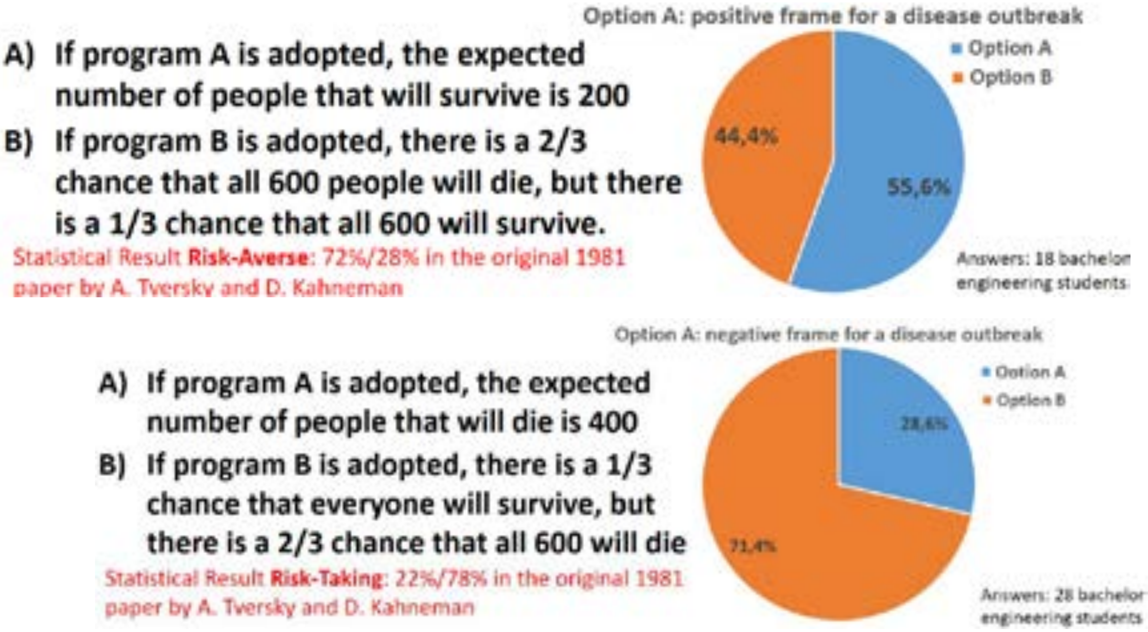


Fig. 5. Framing of a choice as positive or negative changes the decisions people make, even in sensitive matters, despite the objective information being the same

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5 SUMMARY

This paper takes a closer look at how our decisions can be influenced by cognitive biases, especially when people are trying to estimate probabilities by intuition. It is part of a course on Critical Thinking at the Telecom BCN School (UPC), aimed to help engineering students become better decision-makers. This course uses real-time surveys in class, inspired by the work of Nobel Prize Winner Daniel Kahneman, to get students better involved and motivated to discuss this issue. These surveys have shown that, even when students understand the basics of probability and know they might be tricked, they still tend to fall for cognitive biases. The teaching approach presented in this paper, which has been well-rated by students (Figure 6), increases their awareness of how common these biases are and the need to embrace the so-called debiasing techniques as a fundamental skill to develop in their engineering careers.

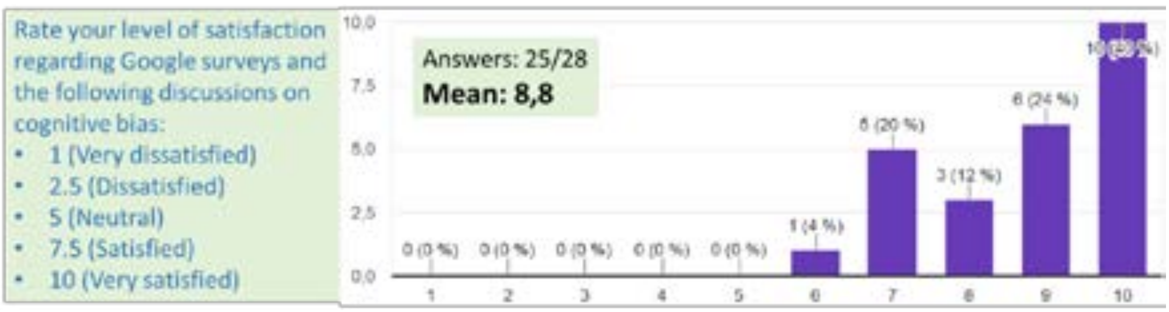

Fig. 6. Satisfaction survey regarding cognitive bias conducted on bachelor engineering students in a Critical Thinking class at UPC

REFERENCES

Torres, F. et al. “Tackling perception and deception in STEM: A critical thinking skill for early-career development”. Annual Conference of the European Society for Engineering Education. SEFI. p. 2216-2219. Barcelona. September 2021

Kahneman, D., Thinking, “Fast and Slow”. Farrar, Straus and Giroux, 2011

Bughin, J. et al. “Skill shift: Automation and the future of the workforce”. Discussion paper, McKinsey & Company, 2018

Dondi, M. et al. "Defining the skills citizens will need in the future world of work." Technical report. McKinsey & Company, 2021.

Chattopadhyay, S. et al. “Cognitive Biases in Software Development“. Communications of the ACM Vol. 65 No. 4. Pp: 115-122, April 2022.

McDermott, T. et al. “Addressing Cognitive Bias in Systems Engineering Teams”. Proceedings INCOSE. Vol.30, Issue1, Pp 257-271, July 2020.

Do you need to be mad to work here? Reflections on leading extremely large-scale interdisciplinary team project modules

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Keywords: *Interdisciplinary, Extremely Large Scale, Facilitator, Educator Experience*

ABSTRACT

There is a growing acknowledgment that across society and industry, the complexities and uncertainties of today's global challenges cannot be adequately addressed through isolated disciplinary approaches. As accreditation bodies require the addition of more contextual skills-based development into curricula, an increase in team projects, among other things, is a key way to address this. The development of these interdisciplinary and transdisciplinary competencies and skills is challenging since it is affective and connected to the state of "being" of the student. The complexities escalate when classes are scaled up and there is no pedagogical development for lecturers to facilitate these teaching engagements. The skill set required to lead interdisciplinary team project teaching is very different to that of traditional lecture or seminar-based teaching. As part of a broader project on evaluating frameworks and structures for delivering interdisciplinary teamwork at extremely large scale and understanding this modern teaching role, here we will focus on the comparison of the professional journeys of two leading practitioners of large-scale interdisciplinary team project modules. In reflecting on the similarities and differences of our contexts (global north and global south) and approaches, we

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identify the future direction and needs of this specialist area. This paper aims to start a sector-wide discussion of the requirements of this contemporary teaching role, and starts to outline how to better prepare and support those undertaking these roles.

1 INTRODUCTION

Today's problems are multifaceted and interconnected, spanning social, environmental, economic, and other domains simultaneously, requiring different skills for the future workplace (World Economic Forum, 2023). This requires a pedagogical shift towards interdisciplinary education (Van den Beemt et al., 2020) that prepares students for the complexities of real-world challenges by cultivating ways of thinking, being, and practising that transcend traditional disciplinary boundaries (Strachan et al., 2019).

By fostering a learning environment that promotes interdisciplinary thinking and action, universities can nurture graduates who are not only socially aware, empathetic, and emotionally intelligent but also deeply connected, cooperative, and ethically responsible (Strachan et al., 2019; Kamp, 2018). Often these are addressed via active learning methods, such as project-based learning (PjBL) (Feldman, 2006; Gavin, 2011), and in particular the introduction of interdisciplinary team projects (Kolb, 2015, Graham, 2018).

Engineering programs often have large class sizes (300+) due to the subject's popularity and government initiatives aimed at increasing STEM graduates. Teaching such large cohorts using a PjBL framework can be ineffective without proper curriculum oversight and adequate scaffolding of PjBL skills for students (Edström and Kolmos, 2014). Directly scaling methods designed for small classes is not viable due to resource constraints. Consequently, coordinators of large-scale team projects have had to develop or adapt approaches to create and deliver these teaching events (Truscott et al., 2021; Smith and Trent, 2020; 2021).

Alongside the lack of large-scale active learning methods, much of the literature is focused on student experience rather than staff experience in this context (Truscott et al, 2023). This makes it hard for staff who would like to move into teaching interdisciplinary teamwork with their large cohort, to know what to expect or how to get started, particularly as there may be very few people within their institution working effectively in this area.

In this paper, we will start addressing these two gaps in the literature, by comparing the career journey and experience of two well-established and internationally recognized practitioners of extremely large-scale (900+) interdisciplinary teamwork. As a first step we unpack the requirements of this role, identifying the skill set needed and how to better support those undertaking this role.

2 METHODOLOGY

2.1 Context

The two practitioners are situated in leading institutions in the global north and the global south. Both practitioners use active learning, cross departmental teaching frameworks.

The Joint Community Project (JCP) is compulsory for all 1650 second-year students across 18 different programmes in the Faculty of Engineering, Built Environment and IT at University of Pretoria, South Africa. The module aims to develop social awareness, teamwork competency and civic responsibility. Service learning is used as an active pedagogical approach to provide the students with the opportunity for hands-on skills-development within a community context. Each student has 40 hours that is used towards preparation for their 40 hours of field work in the community. Ideally in preparation for their community engagement, students should be observed during their team interactions, as well as their interactions with the community partners (who range from professionals working in NGOs to community leaders in townships) and supported through feedback and an opportunity to repeat the engagement. The scale of the cohort, which breaks down to 350 interdisciplinary teams of 5 students and more than 60 community partners requires carefully designed strategies to ensure authentic development of the students. The two unique strategies are: 1) a vertically integrated mentorship/coaching team of senior students framed as a “company”; 2) a series of scenario based experiential learning engagements.

Engineering Challenges is a very large and complex core module for between 900 and 1000 students from across seven departments within the Engineering Faculty at UCL, UK. It is an interdisciplinary team-based project module taken by a majority of the first-year students within the faculty in term 1 and is central to UCL’s teaching framework. As the first team project experience for our undergraduate students, it aims to introduce them to how projects work and the skills needed to collaborate with others; the module focuses on what engineers do rather than what they know. While the structure and assessment pattern are common throughout the module, the content is tailored for each department to address problems and approaches relevant to that discipline. The module is delivered by a teaching team composed of 15-20 Departmental Leads assigned by departments, 40-50 Postgraduate Teaching Assistants (PGTAs) and a Module Lead working at faculty level. Engineering Challenges is split into two parts, a three week department based individual project and an interdisciplinary seven week team project. For the seven week team project, departments are paired up and work on aspects of an umbrella project, building a TB vaccine production plant in Uganda. Subsequently, the module is more like multiple modules running in parallel, each with different academic staff and content but all set within a common structure. The module is highly structured with a range of support mechanisms for both staff and students, including behaviour modelling, co-teaching and support workshops.

2.2 Approach

Two experienced, extremely large scale, interdisciplinary learning facilitators, located in research-intensive institutions in the global north and global south explored their role, development and challenges using autoethnographic writing (Ellis and Bochner, 1999; Choi, 2012) and a shared narrative inquiry (Chase, 2005). The two facilitators met monthly for the last 6 months to discuss challenges and experiences in facilitating interdisciplinary classes of 900+ students. The intention was simultaneously to share practice as well as challenges in the process of coordinating such a module. Based on these engagements and using questions drawing from a life course approach and reflective practice perspective (Du and Lundberg, 2021) the authors discussed 9 questions that could meaningfully capture their experience.

After these 9 questions had been agreed upon both researchers reflected and answered these questions and then read each other's reflections to further adapt their own. As a final step, both authors spend time discussing each of the question responses and reflecting on similarities and differences that could be identified. Based on these discussions, different themes were identified and shared as a means to unpack the requirements of this role, identifying the skill set needed and how to better support those undertaking this role.

3 RESULTS

In this section we share our findings after our reflections and discussions of the 9 questions.

1. *What motivated your focus/interest on teaching in the context of facilitating large interdisciplinary engineering classes?*

Smith and Truscott, possess a keen interest in personal development and transformation. Smith, trained as a yoga teacher and proficient in various coaching modalities alongside her PhD in Aerospace Engineering, while Truscott transitioned from Organic Chemistry to Chemical Biology and Biochemical Engineering before delving into Engineering Education, with extensive experience in outreach and community engagement.

Smith's teaching experience began with overseeing a 900-student interdisciplinary design module, focusing initially on logistical effectiveness and later emphasising authentic student development through peer support and reflective assessment. Truscott, on the other hand, started with smaller workshops and community engagement activities within an interdisciplinary research context. Her focus shifted towards facilitating communication across disciplinary boundaries, culminating in her work within large-scale educational contexts.

Both facilitators share a common interest in fostering overlooked professional competencies in engineering curricula. They draw from diverse backgrounds to identify specific abilities, guiding students towards expert-level proficiency through reflective engagements. Their diverse professional backgrounds drive their embrace of interdisciplinary teaching approaches, fuelled by curiosity about developing complex skills, particularly in large-scale educational settings.

2. *How did this focus become a significant aspect of your career, and what factors influenced its importance?*

Despite their differing backgrounds, Smith and Truscott share a common focus on facilitating and coordinating large-scale initiatives. They attribute their success to comfort with uncertainty, open curiosity, a willingness to explore new ideas, and a preference for learning through action rather than waiting for perfection—an unattainable goal at scale.

Both value self-reflection and recognize that personal transformation occurs through exposure to diverse disciplines, environments, and interactions, rather than merely through content. They are deeply invested in creating and curating such transformative experiences for their students, albeit challenging at scale. They emphasise the importance of maintaining relational connections, mentorship, and small group engagement, while managing resource constraints.

Smith focuses on streamlining logistical aspects and preserving the personal journey and connections for students within interdisciplinary large-scale modules, whereas Truscott emphasises ensuring the relevance and relatability of such modules to students.

3. *Reflecting on your own development/practice, what specific actions did you take to support your ability to run interdisciplinary large scale modules?*

Both facilitators inherited an existing module and then evolved it based on their teaching philosophy, experience and external circumstances. They both centred student experience and learning as well as developing methods to structure and integrate learning. They both had to develop ways to leverage limited resources (although it should be noted that Truscott's context in the global north does have more resources available overall compared to Smith's). Both primarily learnt through engaging with others in the Engineering Education community both internally and externally rather than through formal training programmes due to the unusual nature of their modules.

As Smith had more prior experience on teaching at a large scale, she came into Module 1 with a more focused idea of the challenges of large scale teaching and had a range of possible solutions planned. Truscott had less prior teaching experience and had more general ideas on interdisciplinary and skills based teaching. This is reflected in the way each facilitator answered this question, with Truscott focusing on the mechanics of the transition from a research focused role to a teaching one while Smith focused on the decisions that would need to be made within the module to make it efficient and more grounded in Engineering.

4. *How do you see your own experiences enable you when teaching in a large scale interdisciplinary classroom?*

Both practitioners lack formal education training from their universities. Truscott draws from diverse roles across institutions and contexts, while Smith, with 15 years of teaching experience at University of Pretoria, supplements her development with external training.

They perceive themselves as active flexible problem solvers, able to design structured plans while anticipating challenges and also able to respond to issues and challenges that always arise when one runs projects at extremely large scale. In this role, an indispensable personal attribute involves possessing resilience, characterised by the ability to manage stress effectively, maintain objectivity, demonstrate intellectual curiosity and humility, take risks and embrace failure as an opportunity for learning for both students and yourself.

Both have participated in workshops and groups focused on "large-scale" classrooms, quickly recognising that these discussions typically address class sizes ranging from 80 to 200 students, which differs from the scale they operate within. Learning from each other has been more valuable than any formal or informal training they have attended across their careers.

Both acknowledge the undervalued significance of facilitation roles in academia, often overshadowed by traditional educator or researcher roles, revealing a gap in existing academic structures. While UCL recognizes the researcher/teacher split, it does not acknowledge the teacher/facilitator role, whereas University of Pretoria does not recognize any such distinctions. This lack of institutional understanding underscores the need to explicitly outline the requirements and demands of facilitation roles. Academic roles tend to compartmentalise and isolate functions, hindering flexibility. Both practitioners identify themselves broadly beyond their scientific or engineering backgrounds.

5. *What challenges have you encountered and how did you cope?*

Both facilitators encountered similar challenges, specifically regarding communication. The need for clear and effective communication with a large number of students and staff is critical, considering the scale of the cohort and the distinct student-facilitator dynamic compared to smaller classes. The smallest change or disruption at extreme scale can for example lead to 300 emails flooding your inbox overnight. Extreme scale increases the likelihood of encountering unique circumstances, requiring clear rules and processes for both staff and students to navigate effectively.

Another key challenge arises from the diverse range of student experience, knowledge, and skills in interdisciplinary projects, particularly amplified by the large scale. This requires catering to various abilities without the capacity to personalise learning journeys. Combined with the need for clear communication, this results in highly structured teaching and learning and it can limit creativity.

Extremely large-scale teaching has significant logistical challenges which need to be acknowledged and addressed creatively. The specific challenges are context dependent and both facilitators agreed that it was a large part of their role. Efficient module management to avoid excessive personal resource consumption is essential. Proxies in the classroom, such as staff members, external partners, or experienced students are very important. However, this also introduces additional challenges, including the training of these proxies and instances where they deviate from the established process or fail to grasp the intricacies of extremely large-scale teaching.

When teaching at this scale there is significantly more interaction with central administrative processes. There is an extra burden of explaining what is needed, problem solving and crisis management that is not seen in smaller modules. In these large-scale interdisciplinary modules, educational leadership takes on a distinct form, with a significant emphasis on negotiation, lobbying, persuasion, and facilitation due to the complexity of the module's components.

There are contextual differences between the two facilitators which change the emphasis of different challenges. Smith's module size is closer to what is normal at University of Pretoria and so the infrastructure is designed for a similar size. The interdisciplinary nature is not normal. However Truscott's module is extreme for UCL both in size and complexity and so UCL's infrastructure isn't designed for a module like this. Truscott has access to more resources but also has to work within more constraints than Smith does due to the structure of the faculty and the engineering programmes.

6. *What do we need from the environment we work in?*

The primary factor required by both practitioners was acknowledgement of the complexity and difficulty of running extremely large scale interdisciplinary classrooms. Administrative and logistical support from local (faculty/dept) and central (university level) teams is critical as well as awareness and flexibility that their modules might not fit their typical procedures. It is also critical to communicate any potential or pending policy or process changes as early as possible. A small change for example in a financial policy at University of Pretoria, led to delay for students' project funding for more than 4 months. It is far easier for smaller modules to fit existing policies and processes, so priority should be given to these extremely large scale modules if any changes are required or suggested.

7. *How have you extended your insights to your colleagues and institutions?*

Both facilitators have shared their insights with colleagues within their institutions as well as in national and international networks, via informal advice and support, meetings, visits and workshops. They have both started to publish on this unusual teaching role either in journals or at conferences. They have both brought their experience and expertise to the development of new programmes and the scaffolding of skills learning throughout curricula.

8. *How do you develop/prepare someone to run a large scale interdisciplinary module?*

Emphasis on facilitation skills, emotional intelligence, and ability to manage uncertainty as critical for large-scale interdisciplinary module coordinators. It is essential if possible to shadow and experience such engagements at this extreme scale to understand the complexity and chaos the coordination can be.

9. *Looking forward, what do you believe is crucial for future initiatives focused on, and how can these efforts extend beyond the current scope?*

Both facilitators agree that robust support systems for those running extremely large scale interdisciplinary team projects are crucial going forward. This includes specialised training for large-scale and interdisciplinary teaching as well as teaching of teamwork, acknowledgement of the very different role and requirements of someone leading this type of teaching and prioritisation of these modules to acknowledge and support the difficulties in logistics. Alongside support systems, institutional recognition of and action on the importance of learning these types of skills and the need for meaningful engagement from both staff and students in these activities.

4 SUMMARY

There are several key themes that can be extracted from the discussion of these nine questions. They fall into four areas, experience and identity, uncertainty, learning through doing and university support.

Experience and Identity

Diverse previous experiences, interests, and training benefit facilitators by bringing a range of skills, concepts, and methods into the classroom. This enables them to connect with students from various backgrounds. Both facilitators are naturally reflective and empathetic, shaping their teaching approach to focus on guiding and facilitating rather than instructing.

Uncertainty

Comfort with uncertainty and adaptability were emphasised throughout the discussion. Extensive planning was also necessary for the module's function, including contingencies and flexibility for change. Facilitators needed to balance planning with adaptability, being comfortable with not having all the answers but knowing where to find them.

Learning through Doing

Openness to learning and experimentation is crucial in extremely large-scale interdisciplinary teaching where no set methodology exists. Both facilitators learned primarily through engagement with other educators, internally and externally, and through trial and error rather than formal training. They now communicate their insights through workshops, papers, and supporting others. Familiarity and comfort with experimental learning processes also aid in providing better support to students undergoing similar experiences.

University support

Institutional support for the implementation of non-traditional modules and roles must recognize and address several key factors. Firstly, there is a societal demand for individuals to fit neatly into predefined categories, conflicting with the interdisciplinary nature of these modules. Institutions must accept this non-conformity and support module leaders without expecting adherence to conventional stereotypes.

It is also critical that there is adequate agreement and support from both the faculty or department level and central university teams to ensure seamless coordination and operation. Robust logistical processes and clear communication channels are essential to navigate the complexities inherent in these roles. Managing the intricate relationship between central systems, students, and staff further underscores the need for comprehensive institutional support.

Global North/Global South

The differences between the Global North and Global South pose challenges when coordinating interdisciplinary, large-scale modules. These disparities include our starting points, the conditions we work with, and the political situations in our institutions. Even the facilitators themselves face context-specific differences that influence how we adapt our approaches. Understanding and addressing these variations is essential for successful coordination, ensuring that our efforts meet the diverse needs and conditions in both regions.

REFERENCES

Chase, S.E. "Narrative inquiry: Multiple lenses, approaches, voices." In The Sage Handbook of Qualitative Research, edited by N.K. Denzin and Y.S. Lincoln, 123-139. 3rd ed. London: Sage, 2005.

Choi, T.H. "Autobiographical reflections for teacher professional learning." Professional Development in Education 39, no. 5 (2012): 822–840.

Du, X.Y., and A. Lundberg. "Examining emic viewpoints on pedagogical development program's long-term effects." Studies in Educational Evaluation 71 (2021): 101088. https://doi.org/10.1016/j.stueduc.2021.101088.

Edström, K., and A. Kolmos. "PBL and CDIO: complementary models for engineering education development." European Journal of Engineering Education 39, no. 5 (2014): 539-555.

Ellis, C., and A.P. Bochner. "Autoethnography, personal narrative, reflexivity." In Handbook of Qualitative Research, edited by N.K. Denzin and Y.S. Lincoln, 733-768. 2nd ed. Thousand Oaks, CA: Sage, 1999.

Feldman, M. L. "Vertical integration of engineering education comprehensive report 2004-2006." May 12, 2006.

Gavin, K. "Case Study of a Project-Based Learning Course in Civil Engineering Design." European Journal of Engineering Education 36, no. 6 (2011): 547–558.

Graham, R. The Global State of the Art in Engineering Education. Boston: MIT School of Engineering, 2018.

Kolb, D.A. Experiential Learning: Experience as the Source of Learning and Development. 2nd ed. USA: Pearson Education, Inc., 2015.

Strachan, S.M., S. Marshall, P. Murray, E.J. Coyle, and J. Sonnenberg-Klein, "Using Vertically Integrated Projects to embed research-based education for sustainable development in undergraduate curricula." International Journal of Sustainability in Higher Education, 28 June, 2019.

Smith, L., and M.N. Trent, "A co-curricular framework for a multinational, vertically integrated engineering design project", ASEE Annual Conference & Exposition, 26-29 July, 2021.

Smith, L., and M.N. Trent, "Student and staff experience of an interdisciplinary, multi-national co-curricular aerospace design project", 8th International Research Symposium on PBL, Paper 82, Aalborg University, Aalborg, Denmark, 28 October, 2020.

Truscott, F. R., E. Tilley, J.E. Mitchell, and A. Nyamapfene, "Staff Experiences of Leading Large-Scale Multi-Departmental Project-Based Learning for Year 1 Engineering Students", Annual Conference of the European Society for Engineering Education, Dublin, 2023, pp. 1337-1344, Belgium: SEFI. DOI: 10.21427/7Y9A-6C85.

Truscott, F. R., E. Tilley, K. Roach, and J.E. Mitchell, “Perspectives on putting a large scale first year interdisciplinary project module online”, PBL 2021. DOI: 10.26226/morressier.60ddad35e537565438d6c49b.

World Economic Forum. Future of Jobs 2023. Switzerland: World Economic Forum, 2023.

Van den Beemt, A., M. MacLeod, J. Van der Veen, A. Van de Ven, R. Klaassen, and M. Boon. "Interdisciplinary engineering education: A review of vision, teaching, and support." Journal of Engineering Education (2020).

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SYSTEMS CHANGE LAB: AN EXPERIMENT IN RADICAL COLLABORATION TO REIMAGINE ENGINEERING DEGREES FOR THE 21ST CENTURY (PRACTICE)

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ABSTRACT

Engineers Without Borders UK is running a Systems Change Lab as part of the Royal Academy of Engineering's wider policy project, Engineer 2030 which aims to rethink engineering and technology skills for the 21st century. To date, more than 200 people, and over 25 universities and 22 companies, have participated in the Systems Change Lab (which launched in September 2023) exploring and testing how and why to integrate global responsibility as a central feature within university engineering education. The purpose of the Systems Change Lab is focused on enabling systemic change within engineering departments and to contribute towards a resource for universities to drive the change towards reimagining engineering degrees. This paper shares the approach and preliminary observations behind the Systems Change Lab to support changemakers exploring how to enable systemic change within engineering departments and to contribute towards a resource for universities to drive the change towards reimagining engineering degrees. We share the outcomes of bringing together a diverse mix of change makers who shape engineering degrees, including deans, heads of department, educators, accreditors,

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industry players and current and past engineering students, to connect, test prototypes, work together and build momentum behind improving engineering degrees.

1 INTRODUCTION

1.1 Context

The 21st century is confronted by a host of rapidly evolving and interconnected global challenges, from climate change and resource scarcity to the risks imposed by accelerating technological advancements and public health crises (World Economic Forum 2024). Global responsibility in engineering underscores the need for critical reflection on the role of engineering in society and its effects on people's well-being and ecological stability (Engineers Without Borders UK 2023; Royal Academy of Engineering 2024). The need for engineers to embrace global responsibility has long been recognised (Kamp 2020) and now comes through as a central message of a new initiative called "Engineers 2030" catalysed by the Royal Academy of Engineering (2024). It involves a comprehensive understanding of the social, environmental, and economic impacts of engineering, both locally to where engineering is practised and globally through supply chains and operational outputs. Yet coverage of sustainability, inclusion and ethics across engineering degrees remains insubstantial and inconsistent. For example, A 2022 survey of 667 students revealed that only around 30% had so far encountered the UN's Sustainable Development Goals in their education (Siemens 2023). Further, industry and professional bodies in recent years have stated that 'engineering degrees are not fit for purpose' (Flaig 2022) This has alarming repercussions for the workforce. Recent studies emphasise this skills gap whether it is the capability to deliver on industry sustainability strategies (Institution of Engineering and Technology 2021), decarbonisation and meeting net-zero targets (EngineeringUK 2022).

1.2 Background

Navigating the complexities of educating the next generation is no easy feat. This involves questioning 'how' and 'why we teach, and how to engineer with deep consideration for the broader impacts of engineering on people and the planet. Resources such as Doughnut Economics (Raworth 2017), the Three Horizons Model (Sharpe 2013) and the Systems Bookcase (Broadbent and Norman 2023) help articulate the importance of change and what it can look like. There is also a growing need and movement to design curricula in a way that maximises interdisciplinary collaboration reflecting real-world contexts (Graham 2018; 2022, Kolmos 2024). For example, two existing approaches that aim to challenge existing engineering educational structures and traditional forms of teaching practice are problem-based learning and the CDIO initiative. However, ultimately, successful adoption rests on those who want to introduce any change (Edström and Kolmos 2014). Indeed, the people who deliver and shape the education of the next generation of engineers have great influence to enact transformative change towards integrating global responsibility as a core tenant of engineering education. However, educators are influenced by what they know, how they approach pedagogies, and their attitude and mindsets about what to do. Successful improvement in teaching often hinges on the emotional and cultural journey taken by an institution to create change (Goldberg and Somerville 2023). What is undoubtable is that systemic change is not done in a silo. It is complex, interconnected and collaborative and which can't proceed with the same fragmented approaches we've used in the past (Purcell and Fraser-Haddock 2023). Drawing on wisdom from those who have successfully instigated positive changes within degree programmes is valuable in an organised and collaborative way to achieve real change.

Recognising this need, Engineers Without Borders UK and the Royal Academy of Engineering jointly established the Systems Change Lab. The Systems Change Lab is an experiment to support changemakers exploring how to enable systemic change within engineering departments. The lab explored why and how to integrate global responsibility as a central feature within university engineering education and provided a space to go deeper on specific interventions to develop shared learning and experience. This collaborative initiative is poised to support change-makers to deliver change in UK universities over the coming years.

2 METHODOLOGY

The aim of the Systems Change Lab was to build momentum by continually expanding this growing network to identify key levers of change by providing a space to mobilise and collaborate - with the logic that this can bring about widespread change at scale. The ground rules for the Lab were developed based on four guiding principles for global responsibility - responsible, purposeful, inclusive and regenerative (Engineers Without Borders UK 2023):

- All events (virtual or in person) will be active, and participatory, involving a mix of individual reflection, work and group discussion as well as co-creating resources to support universities to keep degrees relevant to the challenges of our age.
- All events are designed to make sense to those attending all, and to newcomers. The Lab will be open and free to attend or to participate in events for those who are interested in making change, and will provide flexibility in how people contribute (by attending events or in the online collaborative workspace).
- To recognise those (that want to be) that actively contribute to outcomes and outputs, by listing them as contributors and showcasing individuals.
- Encourage participation from teams of people from a particular university so they can represent the various roles and influence.
- To host both in-person and virtual events and explore options (if it continues beyond March) to run events outside of London. To also draw on insight gathered through other groups, experience or research.
- The journey is most important - and this is not an individual event. They are part of a path connecting to a greater outcome.

Social Innovation Canada's online definition of different types of Labs (see sicanada.org/knowledge-hub/sig/labs/), was useful in establishing the Systems Change Lab e.g. "*Change Labs tend to emphasise building collaboration and shared understanding between participants in the lab as the basis for shared action(s).".* Further, Kahane (2010; 2012) describe a step process for running change labs (co-initiating, co-sensing, co-presencing, co-creating, co-evolving), who's insights were also influential in developing the approach for the Systems Change. Sessions brought together 200 participants consisting of all the groups who shape engineering degrees, including deans, heads of departments, educators, accreditors, industry players and current engineering students between September 2023 and March 2024 - in-person (15 September 2023,11 December 2023) and virtually (30 October 2023, 3 November 2023, 9 January 2024).

Part of the purpose of the Systems Change Lab was to contribute towards a resource for universities to drive the change towards reimagining engineering degrees. The Reimagined Degree Map supports engineering departments in navigating the decisions that are urgently required to prepare students for 21st-century contexts (Engineers Without Borders UK 2024). Active, facilitated and participatory methods were used for each session including workshops using preliminary exercises of the Reimagined Degree Map (to test and gain feedback to shape the resource. Fig.1 shares an example of a visual tested by the lab), guided Q&A and focus groups to share perspectives and ideas for future collaboration, build relationships and actively contribute to systemic change in engineering education.

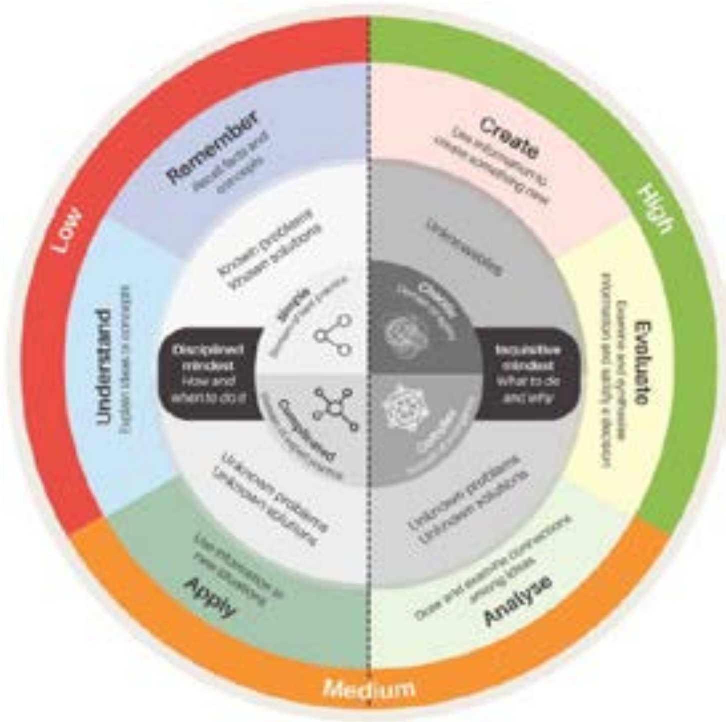

Fig. 1. Rebalancing learning within degrees to be relevant to the future we face. The left hand side is generally taught within engineer degrees today, yet we need more on the right hand side to equipe engineers for 21st century challenges. (Engineers Without Borders 2024)

3 OBSERVATIONS AND RESULTS

While change occur in individuals own teaching practice, decisions taken by people at every level of universities shape the content of a degree and the resultant student experience. Change at pace and scale requires a collective approach to catalyse efforts to drive and sustain a culture of continuous improvement and to effect change at pace and scale. Empowering people to act at all levels is key, as is developing a shared direction and strong ambition across a department or faculty.

3.1 Observation #1: Most universities do not integrate global responsibility but want to

From surveys conducted during the Systems Change Lab, participants were asked where they rank their university in teaching global responsibility. While the majority replied in a non-integrated way (as a separate topic or module), the same group would like to see a shift towards achieving an integrated approach to embedding global responsibility across their degree. This result has been mirrored when Engineers Without Borders UK has engaged engineering educators across the UK.

Table 1. Results from 62 participants of the Systems Change Lab in September 2023

Level	% of participants rank their universities	% of participants rank where they want their universities to be
Continuous Improvement - Aim to be globally responsible in all we do, at the institution or programme level. Emphasise societal context, enabling active learning and open-ended projects.	13	58
Integrated - Teach global responsibility as a core part of our engineering degree(s).	26	42
Add-on -Teach about global responsibility as a separate topic, module or course, not a core part of our engineering degree(s).	45	0
Ad hoc - No focus on educating Global responsibility or, it's patchy, i.e. a fragmented focus on sustainability, ethics and inclusive approaches to engineering.	16	0

3.2 Observation #2: *Empathy map of those with strategic oversight of engineering degrees within a UK university*

In January 2024, the Systems Change Lab was split into 3 groups, each with a trained facilitator for an empathy mapping exercise to listen to people who are making change - how they think, feel and what they need, and to deeply consider what might need to be invested in to support teams to adopt and adapt to the change.

Table 2. Exert from Empathy Mapping to consider what a person with strategic oversight of engineering degrees within a UK university might say, feel, think or do.

Says:	Feels:
• I have pressure to deliver better with less resources than in the past. • If we are going to add in more content - what do we leave out? • Students and accreditation demand this.	• Pressure to attract more students. • At risk of burnout from juggling too many commitments and pushing against resistance to change.

• Much of this work is about changing values and habits, and contextualising what we do as engineers. A lot of our existing content will fit within this new frame - but we need to step back.	• Sad when it's the students who want more traditional approaches which can be a bit disheartening. • Worried that staff (other educators) will not come on this journey to improve degrees. I want to make change but it's difficult to get everyone onboard.
Thinks: • Can I afford to invest in this change? Can I afford not to? • Change requires a lot of work. Oddly, it doesn't require a lot of work to teach better. • Staff are overloaded already - who will be doing? • Sustainability is the new Health and Safety - and as such is a mindset/behavioural change, not a topic in itself - are we approaching it the right way?	Does: • Sets course offerings and responsible for administrative processes. • Balances demands of many people • Works hard to get programmes where they are today or accredited. • Works with other departments and disciplines who share resources, staff and modules. • 80% of my effort is on reassurance, re-explaining and justifying my strategy over and over again.

Four main themes emerged from a 45-minute empathy mapping session with approximately 40 educators. The first theme was concern for the capacity or capabilities of educators. The second theme was connected to feelings of overwhelm or emotional willingness for change. The third theme was statements that related to a feeling of pressure and seeing this as an opportunity. The fourth theme was an appreciation of the complexity of the task of ensuring degrees are designed for the 21st century. It is important to validate the experiences of educators and navigate ways to meet their needs sensitively, whilst centring the focus on what is best for today's students.

3.3 Observation #3: Shared barriers and enablers of change

To deliver systems change, you must enable others to make changes. We explored barriers and enablers that make change possible that have emerged from the Systems Change Lab.

Table 3. Major barriers and enablers identified from 200 participants of the Systems Change Lab in September-December 2023

Major Barriers:	Associated Enablers
Slow Pace of Change: Risk of taking 5-10+ years to modify degree courses, risking global responsibility not being a core part of the education of over 250,000 graduate engineers from now to 2030. **Rigid Processes:** Current change processes hinder swift	**Outcome-Focused Funding:** Explore outcome-based funding models for education; align with graduation outcomes. **Shared Vision:** Clarify that this shift is a priority across departments. **Flexibility in Change Management:** Shift towards a more flexibility in change management process with quicker approvals for modifying degrees.

modifications; calls for flexibility and quicker approvals. **Lack of Incentives:** Insufficient motivation and support for educators to adapt teaching methods or integrate sustainability **Management Attitudes:** Leadership buy-in crucial; interventions needed at department and faculty levels. **Interpretation of AHEP 4:** Ambiguity on whether AHEP 4 mandates modular changes in ethics and sustainability. **Skills Upskilling:** Need to translate (with clear and consistent narratives) the need to develop engineers' adaptability into what this means for the structure of future-focused degrees, balance of learning offered and pedagogies.	**Cross-Department Collaboration:** Invest in resourcing cross-department, specifically focused on improving education. **Nurture a community of active change makers** to share resources and experience between student-led change initiatives and academic-led. **Invest in developing educators**. Provide flexible pathways for academics to develop themselves as strong, passionate educators, and to also not teach if their capabilities or motivation is best aligned to research activities. **Recruit educators** with relevant skills and experience of innovative teaching approaches. **External Expertise:** Connect with wider university expertise and external partners; bring in interdisciplinary perspectives. **Continuous Development:** Invest in educators' continuous development; support retention through career progression. **Storytelling for Change:** Showcase impactful stories of change; lead by example for normative shifts. **Clear Narrative:** Consolidate foresight for student engineers' future needs; prioritize team literacy and diverse skills.

Uncertainty about what change is needed, what knowledge is needed to deliver, and what support is available to enable change are all challenges that have emerged from the Systems Change Lab, while sharing examples of what works and creating ways to help educators lead and make change, are seen as effective enablers for change.

4 OUTCOMES

The learnings from the Systems Change Lab, have been translated into a Reimagined Degree Map, a free guide launched publicly in March 2024 (Fig.2). Over four hours, the Map will guide users through a six-step journey that will enable users to reflect on the needs of modern learners and the approaches for contextualising 21st-century challenges within curricula. The Map is intended to facilitate constructive conversations and engagement with a diverse group of people to shape degrees collaboratively. In particular the Map has been designed and structured in the following ways:

- **Sets out actions to develop shared intentions across a department:** The guide is designed to be used as a time efficient process to help people navigate what decisions to make and to help with imagining how a degree could be improved. It is structured as a collaborative process that can be used again in the future.

- **Provides agency in how to navigate complexity:** The guide was designed as a "choose your own adventure" format to help users navigate the change required in a non-linear way - and find what is most useful at that moment for them. Sections and worksheets within the Map are designed to feel bitesize - without being superficial – where they are set out like destinations of where people navigating may arrive at.
- **Can be used with a wider "change team":** We know no one person can enact long-lasting positive changes across an engineering degree. Using the Map to strengthen ambition, relationships and having various roles who contribute to navigating systemic change across a department(s) is key.
- **Driven by the needs of educators and to centre decisions on what is best for students:** The intended outcomes are to support engineering departments to navigate the decisions that are urgently required to prepare students for 21st-century challenges, whilst sharing content within the guide specifically aimed at educators that are connected to a range of practical initiatives and resources such as the IDEO framework, the Engineering for One Planet Framework of essential sustainability learning outcomes, and the UK Engineering Professors Council’s Sustainability Toolkit.
- **Being less about teaching better, and more on how to better change or adapt:** The guide supports users on how to unlock better strategic decisions that lead to the improvement of engineering degrees to better align and connect with 21st century challenges.

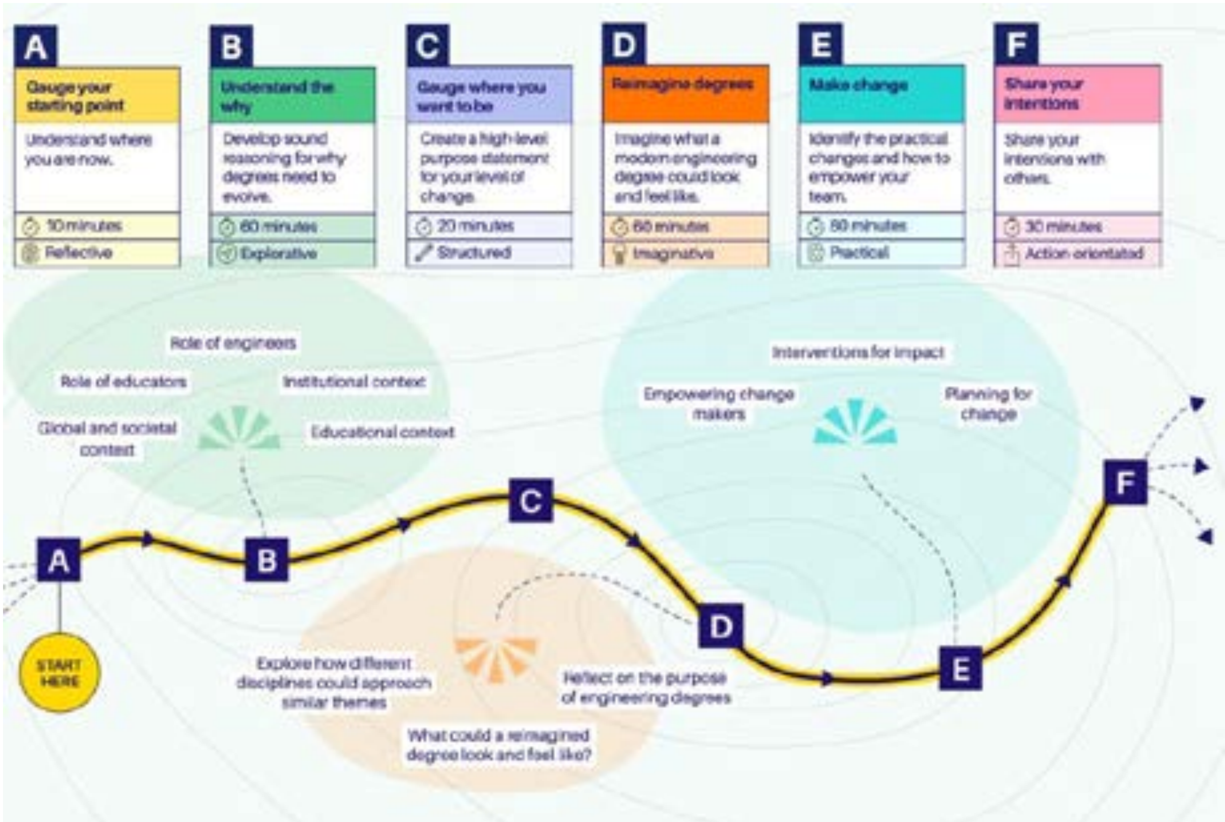

Fig. 2. Reimagined Degree Map (Engineers Without Borders 2024). Worksheets A-D will help you to create a shared vision. Worksheet E is about deciding the practical changes you can make. Worksheet F will support you to share your intentions.

5 CONCLUSIONS AND NEXT STEPS

The purpose of the Systems Change Lab was stated as being "focused on enabling systemic change within engineering departments". This growing community associated with the Systems Change Lab has already demonstrated how useful it is to being a test for positioning and developing content of new resources to support positive change (e.g. Reimagined Degree Map). It has highlighted the potential of greater collaboration to shift the dial in terms of integrating global responsible meaningfully into engineering degrees across universities. It is clear that without connection to others in a similar role, early adopters can feel frustrated. Yet they are critical to continuing the trend of a greater emergence of a generation of leaders of engineering education with the capacity to deliver student-centred curricula at scale. We know that some see the change as long overdue, yet for some, any move towards integrating global responsibility (e.g. teaching social justice alongside thermodynamics for engineers) might feel incredibly radical to those who were educated in the past or to those that set the scope for engineering degrees. It is important to validate the experiences of educators and navigate ways to meet their needs sensitively, whilst centring the focus on what is best for today's students. Arguably, the Systems Change Lab could be an effective way to navigate this dynamic. Engineers Without Borders UK is actively exploring the future of the Systems Change Lab, is seeking supporters to continue the Lab, and encourages adoption, promotion and for users to share stories of change through using the Reimagined Degree Map.

REFERENCES

Engineers Without Borders UK. 2023. Global Responsibility Competency Compass. https://www.ewb-uk.org/global-responsibility-competency-compass/. Accessed 8 June 2023.

Engineers Without Borders UK. 2024. Reimagined Degree Map. https://www.ewb-uk.org/reimagined-degree-map/. Accessed 18 March 2023.

EngineeringUK. 2022. Net Zero Workforce: An Analysis of Existing Research. https://www.engineeringuk.com/research-policy/industry-workforce/net-zero-workforce/. Accessed 20 July 2022.

Edström, Kristina, and Anette Kolmos. "PBL and CDIO: Complementary Models for Engineering Education Development." *European Journal of Engineering Education,* 39 no.5 (2014): 539–55. doi:10.1080/03043797.2014.895703.

Flaig, Joseph. 2022. Learning curve: Are engineering degrees fit for purpose? Institution of Mechanical Engineers. Available at: https://www.imeche.org/news/news-article/learning-curve-are-engineering-degrees-fit-for-purpose. Accessed 4 October 2023.

Goldberg, David and Mark Somerville. A Field Manual for a Whole New Education: Rebooting Education for Human Connection and Insight in a Digital World. (ThreeJoy Associates, 2023).

Graham, Ruth. 2018. The Global State of the Art in Engineering Education. Available at: https://www.rhgraham.org/resources/Global-state-of-the-art-in-engineering-education---March-2018.pdf. Accessed 1 December 2022.

Graham, Ruth. 2022. Crisis and Catalyst: The Impact of COVID-19 on Global Practice in Engineering Education. https://www.4tu.nl/cee/Publications/2022-10-31-crisis-and-catalyst.pdf. Accessed 1 December 2022.

Institution of Engineering and Technology. 2021. 93% of industry without skills to meet 2050 climate targets. https://www.theiet.org/media/press- releases/press-releases-2021/press-releases-2021-january-march/2-february-2021-93-of-industry-without-skills-to-meet-2050-climate-targets. Accessed 4 October 2023.

Kahane, Ahuvia. Power and love: A theory and practice of social change. (Berrett-Koehler, 2010).

Kahane, Ahuvia. Transformative scenario planning: Working together to change the future. (Berrett-Koehler, 2012).

Kamp, Aldert. Navigating the Landscape of Higher Engineering Education: Coping with Decades of Accelerating Change Ahead. (4TU Centre for Engineering Education, TUDelft, 2020).

Kolmos, Annette, Holgaard, Jette Eegelund, Routhe, Henrik Worm, Winther, Maiken. and Bertel, Lykke. 'Interdisciplinary project types in engineering education', *European Journal of Engineering Education*, 49, no. 2 (2024): 257-282. https://doi.org/10.1080/03043797.2023.2267476

Purcell, Wendy, M. and Haddock-Fraser, Janet. The Bloomsbury handbook of sustainability in higher education: an agenda for transformational change. (Bloomsbury Academic, 2023)

Raworth, Kate. Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist. (Random House, London, 2017).

Royal Academy of Engineering. 2024. Engineers 2030: redefining the engineer of the 21st century Future skills needs – a review of the literature. https://raeng.org.uk/media/mk4kpnpu/raeng-future-engineering-skills-lit-review-final.pdf. Accessed 19 March 2024.

Sharpe, Bill. Three Horizons: The Patterning of Hope. (Triarchy Press Ltd., Dorset, 2013).

Siemens. 2023. Skills for sustainability. The Student Voice. https://resources.sw.siemens.com/en-US/analyst-report-the-student-voice-report-for-the-skills-for-sustainability-survey. Accessed 4 October 2023.

UNESCO. 2017. Education for Sustainable Development Goals: learning objectives. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000247444. Accessed 1 July 2021.

UNESCO. 2021. Engineering for sustainable development: delivering on the Sustainable Development Goals. https://unesdoc.unesco.org/ark:/48223/pf0000375644. Accessed 1 July 2021.

World Economic Forum. 2024 The Global Risks Report 2024. https://www.weforum.org/publications/global-risks-report-2024. Accessed 15 January 2024.

Development of a Pan-European Citizen Lab within a European University Alliance Using Action Design Research

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ABSTRACT

The paper describes the development process of a Pan-European Citizen Lab initiative driven by the European University of Technology (EUt+) alliance. EUt+ is a consortium of nine institutions that was selected as one of the European University Alliances by the European Commission. The partners are all technological universities from across Europe. Our vision is that the co-design of the Citizen Lab based on an analysis of societal needs will foster user-driven innovation. The expected impact will be an increased participation of citizens, an increased awareness of research, and social issues addressed at the community level. To achieve our vision, we have chosen Action Design Research (ADR) as one of the main tools for the creation of the Citizen Lab. ADR is a design research methodology that considers both technological and organizational contexts, shaping artefacts (innovations) through design and use, including users and researchers in the

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process. Originally focused on the IT knowledge domain, ADR was not originally designed to co-create innovations for diverse users in ecosystems, the EUt+ consortium views ADR as a highly promising hypothesis that needs further adaptation and verification for this new purpose.

1 INTRODUCTION

1.1 European University of Technology and Needs Analysis

EUt+ is an alliance of nine institutions that was selected as one of the European University Alliances funded through the 2020 Erasmus+ call. Its members are all technological universities from across Europe, diverse in culture and historical trajectories, that share the commitment to form new generations of European citizens and empower them with the mindset and appropriate skills to serve society. For this, EUt+ aims to develop a new model of a university: one that requires a fundamentally novel approach to technology, deeply integrating humanities and social sciences in the way education and research are performed. The objective is to ensure that the people EUt+ trains, the research EUt+ undertakes and the innovations EUt+ fosters are geared towards real societal impact by addressing global challenges. The transversal approach to EUt+ is one of co-construction. The hypothesis underlying it is that “adequate design” of the university of the future can only be achieved through considering the real needs and concerns of the people involved: first by understanding the needs, then by the active participation of the people in the co-construction process. This transversal co-construction approach of EUt+ has laid the foundation of its Citizen Lab. The needs analysis upon establishment of EUt+ revealed that all the knowledge and know-how that the partner institutions possess, and pool together could be put to the service of the socio-economic fabric of Europe to keep proposing new products and services to our evolving societies in a citizen-led way. It is envisaged that the model for the Citizen Lab that will be created in EUt+ will be easy to replicate, multiply and connect with other European Universities in the making.

1.2 The Experience of other Living Labs

Observing the largest network of Living Labs in Europe (ENoLL) which consists of 155 active members from 37 countries, it is clear that a Living Lab is seen as a local community of practice that focuses on co-creation, rapid prototyping, testing and scaling up innovations and businesses (ENoLL Living Lab community Members Catalogue, 2023). In the EUt+ context, the Citizen Lab is seen as a community of knowledge where the joint formalization of learning is the most important outcome that can initiate, transform or lead to a practical application, but the primary outcome in its initial stages is joint knowledge creation with scientific merit. There are existing European Commission funded projects that foster creation and bring together Living Labs from EU and non—EU countries, a good example being project GRANULAR that is addressing topic of better understating rural areas by opening 7 new Living Labs and 9 Replication Labs (Project Granular, 2024). Community building is at the core of the EUt+ mission and we seek not to anchor Citizen Lab in one particular country of EUt+. In contrast to the clustering policy of Living Labs, EUt+ aims to develop a more integrated, joint European community space. A Typical model of a Living Lab includes similarities to the ADR methodology – joint problem searching and development of interventions or solutions to these problems. In that context ADR adds the dimension of formalization of learning in search of also theoretical and scientific artefacts, that would allow a community of knowledge to be established in an international setting. By fostering a culture of cooperation and knowledge exchange, EUt+ aims to bridge the gap between technological innovation and societal needs. Central to this effort is the strategic partnership with a variety of organizations, educational entities, associations, etc. The wealth of expertise of EUt+ in participatory and collaborative approaches are integral to our ways of doing research. The University of Technology of Troyes' Living Lab (Living Lab ActivAgeing, 2020) exemplifies a participatory design lab which employs a multidisciplinary method to create solutions that empower vulnerable social groups, actively engaging them in the innovation process. Moreover, the European Culture and Technology Laboratory (ECT Lab+, n.d.) established within the EUt+ framework promotes transdisciplinary and multidisciplinary approaches, integrating humanities and social sciences into research. The Cyprus University of Technology has also embraced the Citizen Lab concept as a crucial methodology to narrow the gap between research activities and the public. This approach aims to not just draw citizens closer to current research but to actively integrate their viewpoints into the research processes. Adopting this approach enables universities to foster an inclusive research environment that values community input and reflects its needs and aspirations, thus boosting the relevance and impact of their efforts.

1.3 Vision of a Pan-European Citizen Lab

Citizen Labs resemble other collaborative laboratories dedicated to the production of open knowledge that have emerged in the early 21st century, such as the European Living Labs, and certain community workshops for digital production, the Fablabs and Makerspaces. The Living Lab is a new research area that introduces new ways of managing innovation processes viewed both as innovation milieu and an innovation approach (Bergvall-Kåreborn & Ståhlbröst, 2009). The main distinction between a Citizen Lab and a Living Lab is the former’s connection to a social movement that sees the commons as a path to build societies geared towards overcoming the hegemonic economic model: capitalism at its neoliberal stage (Savazoni & de Andrade, 2019). A Citizen Lab is therefore about creating knowledge and about creating commons, respectively “for society” and “with society.”

The design and methodology applied within the Citizen Lab should include a range of activities, guidelines, tools and principles that will support design-based and user-driven innovation. The international perspective of operating the Lab in more than one EU country presents technical challenges in connectivity that must be addressed. The suggested use of the ADR methodology discussed in this paper can mitigate this concern through its adaptability to an online context.

2 METHODOLOGY

2.1 Action Design Research

In order to answer the needs mapped out within the first chapter, EUt+ has chosen Action Design Research (ADR) as a promising framework to develop a Pan-European Citizen Lab model. ADR originates from the Information and Technology field and was first introduced by Sein et al. (2011) as a design-research method for generating prescriptive design knowledge through building and evaluating ensemble

IT artefacts in an organizational setting. It has four stages and seven principles (see Figure 1) that lead from problem formulation to building, intervention and evaluation while concurrently reflecting and learning and then finishing with the formalization of learning with generalized outcomes. The aims set for the EUt+ Citizen Lab correspond to the design science; as defined in Hevner et al. research there are seven guidelines for Design-Science Research: design as an artifact, problem relevance, design evaluation, research contributions, research rigor, design as a search process and communication of research (Hevner et al., 2004). This outlines the ties between technology, design science, organizational context and problem solving.

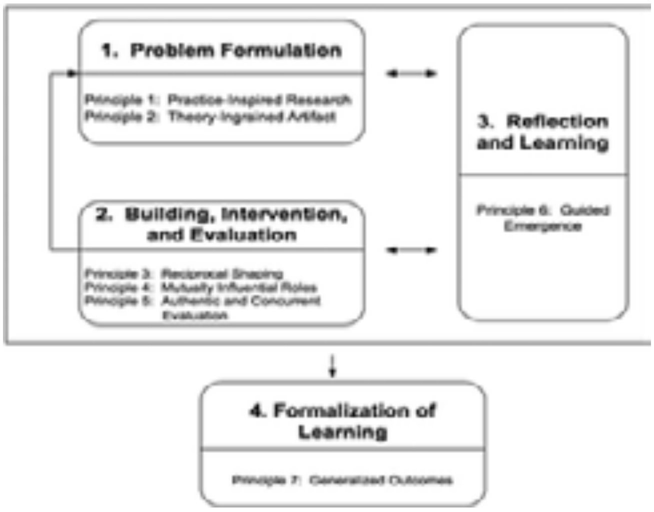

Fig 1. ADR stages and principles (Sein et al., 2011)

The ADR Method has been developed upon a technological premise and by the assumption that most problems today could have a solution or innovation that involves technology. This is a promising foundation for the application of ADR in a Citizen Lab. User-driven innovation has been set as a key drive for the Citizen Lab and should be considered an innovation environment, which can be characterized as a place where open innovation and technology are boosted (Baierle et al., 2021). As Bigliardi et. al. (2021) has pointed out in an extensive open innovation text mining research study, there are nine thematic clusters that correspond to open innovation research – context dependency, collaborative frameworks, organizational dimension, performance and success, external search and specific fields of open innovation. The majority of these correspond to the gap analysis of our Pan-European Citizen Lab; namely, that actions of citizen science should be context-dependent, form collaborative frameworks, consider the organizational dimension and there must be a technological element present. Thus, open innovation in a user-driven setting assisted by technology is the most appropriate approach in creating a Citizen Lab. However, it must be emphasized that the focus should not be on technology more than on people (Marek, 2021) as it could produce negative results. It is important to first and foremost consider the needs of the participants (citizens) as technology serves an auxiliary purpose to enhance the participatory nature of the Citizen Lab. Mark Bilandzic and John Venable in 2011 proposed a new research method called Participatory Action Design Research for studies in Urban Informatics that reflects upon issues across social, technology and design-oriented sciences applied in the urban context. Their research highlights the contrast between Information Systems and Urban Informatics, the latter being more social and open and, in a sense, universal. While ADR has become widely accepted as a prominent research method within the field of IT, several scholars have reported a lack of guidance of method support at the micro level. Stefan Cronholm and Hannes Göbel in 2022 brought forward an empirical Action Design Research project that supports project managers in this regard. This research provides support for ADR at the micro level for all its stages: procedural support, guiding concepts, and various techniques for the documentation of project tasks. They argue that is essential to integrate method support at macro and micro levels and these can be described by three guiding principles: 1) relationships between normative and prescriptive method support should be identified; 2) continuous shift of focus between the whole and its parts should be supported; 3) completeness of ADR in action must be ensured (Cronholm & Göbel, 2022).

2.3 Contextualization of the Citizen Lab

As foreseen in the inception phase of the EUt+ Citizen Lab, the Lab would not be fixed on one particular theme and would be based on the research expertise of the partner institutions. Hence, the Lab should operate in versatile ecosystems. Open Innovation Platforms (Rho et al.,2021), Service Ecosystems (Trischler et al.,2020), Ecosystem Strategies (Altman & Tushman, 2017) and various clustering policies address the issue of contextualization for the ecosystem encompassing the problem and citizens in question. Therefore, we have chosen to create separate user-driven innovation schemes that would include the following characteristics: generic problem, specific context, core partners and empirical evidence. When these characteristics are defined, a user-driven ecosystem will emerge and bring together active citizens, researchers, and other interested parties as participants. The participants will interact in participatory workshops (online and face to face) and desk research while going through the Action Design Research stages, which will lead to formalized learning for both practical and knowledge merit.

3 RESULTS

3.1 Citizen Lab in Practice

Since participation and experimentation are among the indicators that are to be examined to assess the societal impact of EUt+, it is necessary to evaluate the different levels and conditions of stakeholder participation in the numerous European Research Institute test beds. However, determining the impact of stakeholder participation is not easily achieved. The problems met by the practice of societal impact assessment have been identified (European Commission, 2005). These two different ways of doing research, focusing either on scientific impact, characterized by the academic interests of a scientific community, or on societal impact, have been described as “Mode 1” or “Mode 2” science (Gibbons et al. 1994). The assessment of societal impact of research is difficult compared to the assessment of scientific impact. For societal impact assessment, a commonly accepted framework is still to be constructed. This is precisely the contribution of EUt+ Citizen Lab through using ADR methodology; namely, ADR provides the necessary structure for the Citizen Lab to be replicable. The first test of applying ADR methodology in the EUt+ Citizen Lab consisted of an in-person participatory workshop at the SEFI Spring School 2024: Democracy in Engineering Education at the Technical University of Berlin (April, 2024). During this workshop, a group of Spring School attendees participated in a test of the first phase of ADR: problem formulation. The goal of this Citizen Lab workshop was to identify the value gap between three sectors: sustainability education, institutions and the citizen sector. Due to time constraints, the focus of this workshop was limited to the first phase of ADR. During the SEFI Spring School test, it became evident that participants require clear activity objectives to successfully move through the first phase of ADR. Without a continuation of the subsequent phases of ADR, the participants did not understand the purpose of the activity and struggled at times to engage in problem ideation. Following the experience of the first attempt to implement ADR during the SEFI Spring School, a pilot of the Citizen Lab was carried out in June 2024 online. This activity was adapted to fit an online environment using video conferencing and online participatory tools to address the Pan-European aspect of the Citizen Lab. Learning from the experience of the first test of the ADR Citizen Lab at SEFI Spring School, it was determined that the full cycle of the Citizen Lab would take at minimum three workshops; the first focused on phase one of ADR: problem formulation. The second workshop allowed participants to delve deeper into collaborative speculative ideation, formulating concrete action points for intervention during phase two of ADR: building, intervention, and evaluation. Finally, participants engaged in a third workshop focused on phase three of ADR: reflection and learning. In this phase, participants continued formulating an action plan for interventions revisiting the issue formulated in workshop one and the ideal solution proposed in workshop two.

The second pilot of the Citizen Lab took place over the course of two days with the first and second Citizen Lab workshops combined into one day and the third workshop on the following day. In total, there were eight participants representing five European countries: Latvia, France, Ukraine, Georgia, and Cyprus. The participants were students and recent graduates. Each workshop was 1.5 hours long. The first and second workshops were combined due to participant availability constraints. The workshops were facilitated by two moderators, since participants were split into two breakout groups. The Citizen lab workshops continued on the subject initiated in the SEFI Spring School – Democracy in Higher Education. Applying the three elements of ADR method, it was possible to gain insights of the full cycle of ADR and how it will be further used within the EUt+ Citizen Lab.

Fig. 2. Contributions of participants from first and second online workshop

The first and second workshop was set to address two key elements within the ADR method – problem formulation and building potential intervention while concurrently reflecting on the process and opinions. During the session participant inputs were gathered in a free form of sticky notes within a Zoom platform whiteboard (see

Figure 2). Participants were spilt in two groups where they worked on sharing their empirical knowledge, experiences, and opinions.

Fig. 3. Contributions of participants from third online workshop

The objective of the final online workshop was to formalize the learning from the first workshop, reflect on the knowledge that was shared and generated to proceed with outputs that can have practical or scientific merit. During the third workshop participants worked on a Value Taxonomy for Democracy in Higher Education (see Figure 3 on the left) where each participant formalized their individual learning from the first workshop into a specific value, clustering together rubrics discussed in the first workshop. As a continuation of the formalization of learning participants worked collaboratively on a generalized implementation plan draft (see Figure4 on the right).. By structuring the formalization of learning it was possible to see cross-country opinions and experiences that were synergized together in a single chartThe outcomes of the three online workshops suggest that:

1. ADR method was applicable and helped to structure engagement with citizens in an international setting.
2. Format of online workshops is a valid Citizen Science approach when dealing with participants from more than one country.
3. It was possible to formalize learning in the shape of knowledge creation for scientific merit (outputs from the third workshop).
4. A smaller group of participants (8-10) is optimal for effective and fruitful online collaboration.

The participants were asked to fill out a short survey once the three workshops were completed. They reflected that opportunity to express their opinion was sufficient, in addition, a few organizational improvement suggestions were made (example: for future workshops to use slides for the introduction part). The team of facilitators from the EUt+ consortium also discussed and reflected on their experiences from the workshops, outlining the overall success, but also addressing future improvements – two facilitators necessary for each group, a more structured scenario, time keeping. It is necessary to facilitate a clear separation of each phase and its specific objectives. It is also necessary to reconsider the language used in the workshops:

the ADR terminology should be adapted to participant needs. Adjusting the language used in the workshops (e.g. “Problem formulation” could be changed to “Issue exploration”) can help manage participant expectations and guide the discussion in the right direction. It is also important to be transparent with the participants and clearly indicate what outcomes they can expect from the workshops: the EUt+ Citizen Lab is still at its primary stages and any subsequent workshops must indicate the self-reflective, research-driven nature of these initial iterations of the Lab to the participants.

4 DISCUSSION

Observing outcomes of the three online pilot workshops, it is possible to approve ADR as suitable methodology to be used within EUt+ alliance for development of the Citizen Science through a Citizen Lab. Connecting theoretical aspects of ADR with the practical knowledge gained during the seminars there are further developments to be done toward the practical implementation links of the outcomes generated, which most probably can be achieved by bridging the EUt+ Citizen Lab with other local communities of practice within the EU. The main merit of the full ADR cycle contributes the most to the formalization of learning that can reveal scientific artefacts that can be further used by the research community while also giving credit to the active citizens and stakeholders that participate in Citizen Lab activities. To be able to fully convert these outcomes into practical, tangible outcomes, a link with other external communities (representing the respective ecosystem) must be made. A solution to this could be enrolling EUt+ Citizen Lab within the ENoLL network, to collaborate with other University Alliances or, alternatively, involving participants who are already established within a community of practice in Citizen Lab workshops. In regard to the ADR method in practice – it works well if facilitators have understood the mechanics of ADR methodology, the sequence of processes and, most importantly, the formalization of learning section. Further gathering of data is needed to establish a common, replicable and practical use of the ADR method for upscaling of Citizen Science within the EUt+ alliance.

5 CONCLUSION

EUt+ Citizen Lab has proven ADR as suitable methodology that will be kept for future Citizen Lab activities. At the same time, the pilot test showed the improvements that are needed for the online international interactions (majority of them being related to organization and facilitation). As defined in ADR method, there were several artefacts found during the pilot test – refined terminology of identified challenges by participants, ability to switch between macro and micro levels of themes, channeling of knowledge between groups. EUt+ Citizen Lab will keep developing with the emphasis on co-design and co-creation, facilitated by the partnership with diverse living labs and the strategic use of economic and social tools ensures that the Citizen Lab initiative is a vibrant and inclusive platform for innovation and Citizen Science. As we move forward, our focus remains on strengthening these connections and expanding our community, guided by the vision of fostering a more engaged, informed, and capable generation of European citizens.

REFERENCES

Altman, Elizabeth J., Michael L. Tushman. "Platforms, Open/User Innovation, and Ecosystems: A Strategic Leadership Perspective." *Advances in Strategic Management* Vol. 37 (April 2017): 17-076. https://doi.org/10.1108/S0742-332220170000037007

Baierle, Ismael Cristofer, Julio Cezar Mairesse Siluk, Vinicius Jaques Gerhardt, Cláudia de Freitas Michelin, Álvaro Luiz Neuenfeldt Junior, Elpidio Oscar Benitez Nara. "Worldwide Innovation and Technology Environments: Research and Future Trends Involving Open Innovation." *Journal of Open Innovation: Technology, Market, and Complexity* Vol. 7, No. 4 (2021): 229. https://doi.org/10.3390/joitmc7040229

Bergvall-Kåreborn, Birgitta, Anna Ståhlbröst. "Living Lab: An Open and Citizen-Centric Approach for Innovation." *International Journal of Innovation and Regional Development* Vol. 1 (2009): 356-370. https://doi.org/10.1504/IJIRD.2009.022727.

Bigliardi, B., G. Ferraro, S. Filippelli, and F. Galati. "The past, present and future of open innovation." *European Journal of Innovation Management* Vol. 24, No. 4 (2021): 1130-1161. https://doi.org/10.1108/EJIM-10-2019-0296

Bilandzic, M., J. Venable. "Towards a participatory action design research: adapting action research and design science research methods for urban informatics." *The Journal of Community Informatics* Vol. 7, No. 3 (2011): 1-15. https://doi.org/10.15353/joci.v7i3.2592

Cronholm, S., H. Göbel. "Action design research: integration of method support." *International Journal of Managing Projects in Business* Vol. 15 No. 8 (2022): 19-47. https://doi.org/10.1108/IJMPB-07-2021-0196

European Network of Living Labs (ENoLL) Living Lab community Members catalogue 2023. https://enoll.org/wp-content/uploads/2023/09/enoll-catalogue-2023_final.pdf

ECT Lab +. "The European Culture and Technology Laboratory." Accessed March 29, 2024. https://ectlab.eu/.European Commission. *Assessing the Social and Environmental Impacts of European Research*. Luxembourg: European Commission, 2005.

Gibbons, Michael, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, Martin Trow. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London and Thousand Oaks, CA: SAGE Publications. (1994)

Granular Project. Accessed June 10, 2024. https://www.ruralgranular.eu/

Hevner, A.R., S.T. March, J. Park. "Design science in information systems research." *MIS Q* Vol. 28, No. 1 (2004): 75–105. https://doi.org/10.2307/25148625

Living Lab ActivAgeing. "Living Lab ActivAgeing." Accessed March 29, 2024. https://recherche.utt.fr/living-lab-activageing.

Rho, Sungho, Moongi Lee, Teemu Makkonen. "The role of open innovation platforms in facilitating user-driven innovation in innovation ecosystems." *International Journal of Knowledge-Based Development* Vol. 11 (2021): 288-304. 10.1504/IJKBD.2020.112801.

Sein, M.K., O. Henfridsson, S. Purao, M. Rossi, R. Lindgren. “Action design research.” *MIS Quarterly* Vol. 35, No. 1 (2011): 37-56. https://doi.org/10.2307/23043488

Savazoni, R., and O. de Andrade. “The Crossroads of the Commons: Citizen Laboratories in Transit.” Paper presented at *XVII International Association for the Study of the Commons*, *Lima, Portugal, 2019,* 1-24. The Digital Library of the Commons: https://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/10688/%5BEnglish%5D%20Paper%20-%20IASC%20Commons%20%281%29.pdf?sequence=1&isAllowed=y.

Trischler, J., M. Johnson, P. Kristensson. “A service ecosystem perspective on the diffusion of sustainability-oriented user innovations.” *Journal of Business Research*. (2020): 1-9. https://doi.org/10.1016/j.jbusres.2020.01.011

Integrating competencies in a curriculum through developing learning paths and reflection assignments

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ABSTRACT

Integration of competencies ensures that students are better prepared for their future career in higher engineering education. One way to integrate competencies into a curriculum is by developing a learning path together with teachers, which is guided by an overarching system of reflection. In this paper, it is described how learning paths can be designed together with teachers. Furthermore, a design for an activity which stimulates the development of competencies is given. This activity comprises a meeting related to competencies and subsequent reflection assignments, in which students write down a take-home message, reflect on their competency development, and set goals. Students upload their reflection assignments and goals in their portfolio, to be able to monitor their competency development. Two examples of integrating competencies in the bachelor Food Technology at Wageningen University are presented. First, the design of the learning path *researching* is discussed, including an example of an activity that addresses this competency. Second, a course is introduced in which students reflect and set goals on their competency development, which they upload in their portfolio. The presented approaches and examples serve as an inspiration to integrate competencies in an existing programme.

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1 INTRODUCTION

Students in higher engineering education should develop competencies to ensure that they are prepared for the current complex challenges in the world (Gerstein and Friedman 2016; Rieckmann 2012). Competency development can be fostered through integrating competencies into the curriculum of a study programme at the university. This implies competencies being developed and explicitly taught within the discipline, in addition to an emphasis of development on discipline-specific knowledge (Huijser et al. 2008; Chadha 2006).

1.1 Integration of competencies in a curriculum

To integrate competencies into a curriculum, three factors are of importance: a learning path, reflection moments, and teacher commitment. First, competencies should be integrated through establishing learning paths related to competencies across courses (Levander and Mikkola 2009). A learning path is a selection of courses in which the integration and development of a certain topic or competency is aligned and monitored throughout all courses of a curriculum. Learning paths ensure the integration of competencies through providing several opportunities in courses for students to apply them. Students start practicing these competencies on a basic level and as they progress through their study, the complexity and difficulty of the competence increases (Van Merriënboer and Kirschner 2017), resulting into a greater understanding and independence (Reekie et al. 2023). Specific learning outcomes related to competencies should be defined and included in the list of learning outcomes of a course, to ensure that the learning path is visible for both students and teachers, competencies are addressed explicitly and therefore have become a main component of a course. This makes both teachers and students aware of the presence of competencies in courses and coherence with other courses.

Second, the integration of competencies is stimulated through types of self-assessment, such as reflection moments (Virtanen and Tynjälä 2019). Through reflecting, students are stimulated to become aware of their competency development and will actively work on it (Wijngaards-de Meij and Merx 2018). They will recognize the importance of their development, which engages them in their learning (Mello and Wattret 2021). The explicitness and visibility of the development of competencies, as described above, encourage these reflection moments.

Third, to successfully integrate competencies into courses, teachers need to be involved in this change, so that their strengths can be used and they are committed to the change (Potter and Devecchi 2020). Therefore, it is important to have discussions with teachers how to integrate competencies in their courses and curriculum in general. Discussions with and among teachers can lead to valuable ideas for new learning activities. Furthermore, it makes teachers aware of the position of their course in the curriculum and therefore stimulates alignment between courses (Bath et al. 2004).

1.2 Selecting competencies in Food Technology

A proceeding step before integrating competencies into a programme is selecting competencies to be integrated. Each study programme has different needs and a different starting situation with regard to competencies. Here we shortly describe how this selection was done for the bachelor programme Food Technology at

Wageningen University (WUR), a three-year programme in which, until recently, competencies have been integrated more implicitly than explicitly. To find out which competencies need more attention, a research was performed through conducting surveys and interviews with students, graduates, teachers and other stakeholders. Four competencies were identified to need more attention in the bachelor programme: *analytical thinking*, *critical thinking*, *problem solving*, and *decision making* (Van Berkum et al. 2024b). In a follow-up study (Van Berkum et al. 2024a), the presence of these selected competencies was mapped through curriculum mapping. First, through using the outcomes of the interviews, sub-competencies were defined, which are components of the competencies described before. Subsequently, teachers were asked to complete a matrix, in which they were instructed to indicate the presence of these sub-competencies in their courses. This study resulted in a visualisation of the learning paths that were already present in the bachelor. Furthermore, by quantifying the results, sub-competencies were identified that need more attention. Mainly sub-competencies from *analytical thinking* and *critical thinking* were identified to need more attention.

Parallel to this study, the WUR defined 16 skills which need to be implemented in all bachelor programmes to stimulate students to develop skills throughout their studies (WUR 2017). The presence of these skills has been mapped, in a similar way as the curriculum mapping described above, and resulted in a list of skills that need more attention in the programme: *researching*, *data science*, *collaboration*, *feedback*, and *diversity & inclusivity*.

1.3 Aim of this paper

The aim of this paper is to provide an example how competencies can be integrated in an existing programme. In this paper, the integration of competencies in the current courses of the bachelor programme Food Technology at WUR will be used as example. First, it is explained how learning paths were designed in collaboration with teachers, to ensure the integration of competencies in the bachelor programme. Next, activities to stimulate the development of competencies, including reflection assignments, will be described.

2 METHODOLOGY

2.1 Process of integrating competencies and designing learning paths

To ensure sufficient competency development, students should have enough opportunities to practice competencies, while also receiving instruction, receiving feedback and being assessed. The integration of these aspects in the bachelor Food Technology was discussed with students and teachers. They both preferred competency development solely in existing courses, instead of designating a course for competency development. Therefore, it was decided to integrate competencies in existing courses, through implementing learning paths and moments for reflection. The main author of this paper was acquainted with all courses of the bachelor because of the curriculum mapping step, in which the presence and current position of competencies was discussed with course coordinators. While discussing, many course coordinators reflected on their courses and identified opportunities for improvement. These opportunities have been taken into account while designing a first draft of the learning paths. In these drafts, it was ensured that each learning path included sufficient opportunities for practicing, instruction, feedback, and assessment, through including both existing and new activities. The draft of each learning path was discussed with the involved course coordinators, to align and leading to a final learning path.

2.2 Implementation of reflection moments and explicit skills meetings

In addition to practicing, instruction, feedback, and assessment, students should also have the opportunity to reflect on their competency development (Wijngaards-de Meij and Merx 2018). To give explicit attention to competencies and opportunities for reflection, new activities were designed and taught during so called ‘Food Technology Skills Academy’ meetings. Although the term ‘competency’ is used in this paper, the term ‘skill’ was used in the communication to students and teachers since this term is adopted by the university. Therefore, the name ‘Food Technology Skills Academy’ was chosen. These meetings were organised around one or two competencies, in which students discuss experiences related to course activities and exchange ideas with peers. At the end of these meetings, students were asked to reflect on their experiences and competency development and to set goals. A general template for these type of reflection assignments was developed for all courses, which consists of three exercises:

1. **Defining a take-home message**: writing down insights they acquired while discussing and reflecting with other students on:
   - what challenges they encountered;
   - what went well.

2. **Reflecting**: reflecting on sub-competencies using a single-point rubric, which enables effective student self-assessment (Fluckiger 2010). In this rubric, students indicated per subskill what they are already good at and how they can improve (Figure 1):

I am already good at the following aspects:	**Subskill**	*I can improve myself on the following aspects:*
	I was able to structure meetings and to divide the work.	
	I was able to share all information with each other and integrate this well.	
	I was able to listen to others and speak up for myself.	

Fig. 1. Example of a single-point rubric that students complete to reflect on collaboration skills

3. **Setting a goal**: selecting one subskill, for which they formulated a goal on which they can focus on in a next course.

To ensure that students have an overview of their competency development throughout the whole bachelor, it was decided to work with a portfolio system. This portfolio is linked to the online learning environment of all courses and remains accessible throughout the whole bachelor. After finishing the reflection assignments as described above, students are asked to upload this assignment into their portfolio and insert the goal. In all courses, students can look back at their reflections and goals and are able to monitor their competency development throughout their study programme. Students are responsible and in charge for their own portfolio. Teachers can only review student's portfolio when students give access.

2.3 Evaluation of the reflection assignment and portfolio

The reflection assignments and portfolio were evaluated in the first course where they were introduced, through a survey, which was handed out after the exam of the course. In this survey, students were asked to respond to statements about the general impression of the assignments, the reflection activities and goal setting, and the general approach of skills development. A 5-point Likert scale was used, ranging from strongly disagree (1) – somewhat disagree (2) – neither agree nor disagree (3) – somewhat agree (4) – strongly agree (5).

3. RESULTS

As described above, several skills and competencies were defined which need more attention in the bachelor programme Food Technology, based on the research on competencies from (Van Berkum et al. 2024b) and the list of skills that the WUR defined. While all identified competencies as described above are being integrated in the programme, in this section we use the competencies *researching*, *collaboration*, and *diversity & inclusivity* to provide two examples how competencies were integrated. First, the process of designing and visualising the learning path of the competency *researching* is described. In addition, an example of the Food Technology Skills Academy activity related to *researching* will be given. Second, an example is provided how the reflection assignments of the competencies *collaboration* and *diversity & inclusivity* were included in the first course of the bachelor, together with the results of its evaluation.

3.1 Example of integrating the competency *researching* through a learning path and interactive activity

In order to develop the learning path *researching*, sub-competencies of *researching* that students should developed were defined through combining subskills as described by the university and sub-competencies from the research from (Van Berkum et al. 2024a). To limit the amount of sub-competencies, it was decided to integrate several sub-competencies and subskills, while excluding aspects such as searching for literature and data analysis, since these are included in other learning paths. This resulted in the following four sub-competencies:

- Positioning research (context, knowledge gap, research question/aim and hypothesis)
- Designing research (e.g. study, experiments)
- Performing research (e.g. performing protocols in the laboratory)
- Critically analysing and evaluating the research

These sub-competencies were included in a rubric, to envision what students should have developed before finishing their study programme.

Then, a learning path for *researching* was designed through first identifying the existing activities related to *researching* and making them more explicit. Next, new activities were added in the learning path. All sub-competencies in this learning path were planned to be addressed explicitly at least 2 times, with at least one opportunity for receiving feedback and assessment.

The draft of this learning path was discussed with teachers. Based on the discussion and feedback, the learning path was finalised. The implementation of this learning path made a strong improvement of the alignment throughout courses. Next, the learning path was visualised in the online learning environment in an interactive way, so students could see in which courses the competency is explicitly addressed and which activities are included (Fig. 2).

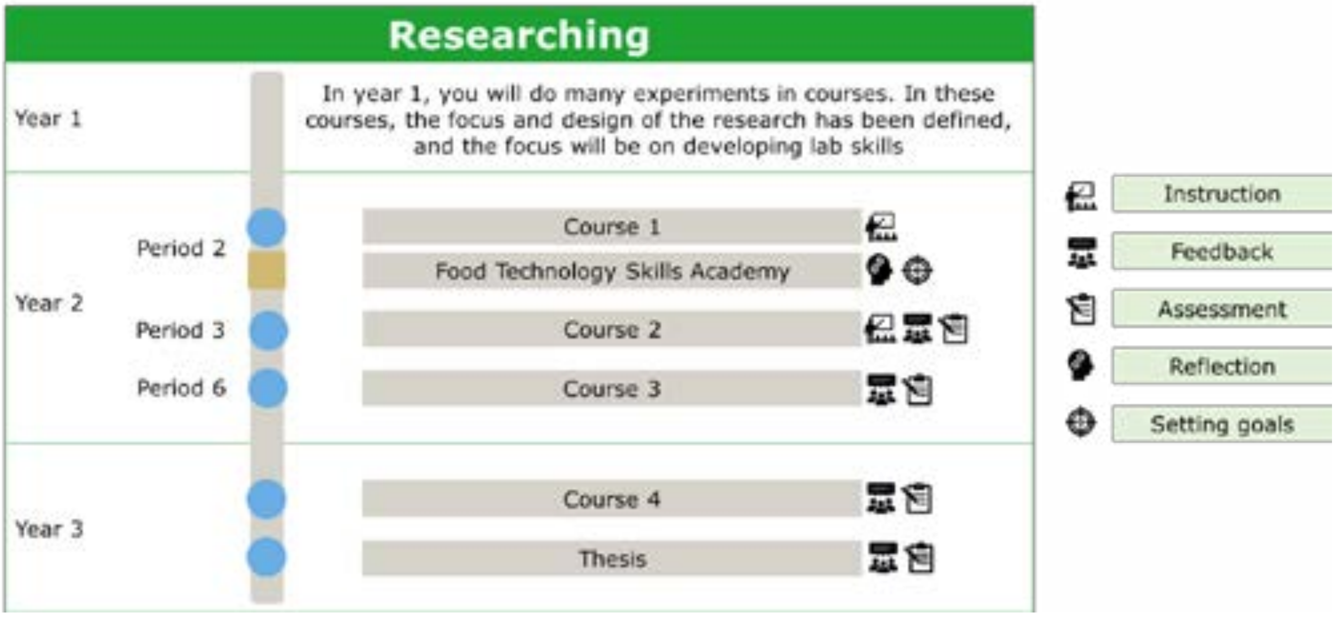

Fig. 2. Visualisation of the learning path 'researching'

To ensure that students are actively and explicitly discussing and reflecting on the competency, a compulsory Food Technology Skills Academy meeting was developed in course 1 (Fig. 2) of the learning path, which takes place in the second year of the bachelor. In this course, students designed an experimental set-up and performed experiments, and therefore focused on the subskills '*designing research*' and '*performing research*'. During the Food Technology Skills Academy meeting, students were asked to discuss and exchange their experiences related to these sub-competencies, with the following activities:

1. Discuss experiences regarding certain practical skills, such as making solutions, pipetting or using the centrifuge. Students were stimulated to discuss what they found challenging and to exchange tips with each other.

2. Identify experimental design techniques, such as blanks and duplicates. Students read lab protocols to identify the necessity of these techniques, in order to understand why they are applying certain techniques.

After the discussions, students were asked to write down interesting insights they gained. At the end of the meeting, students completed the reflection assignments as described in the methodology section. They uploaded this in their portfolio and set a goal for the next course.

3.2 Example of integrating the competencies *diversity and inclusivity* and *collaborating* and the evaluation of the reflection assignments and portfolio

At the start of the first year, students were introduced to the different disciplines within food technology. In this introduction course, also time is allocated to introduce students to the university and skills they should develop at the university, such as *personal development*, *collaboration*, *presenting, information literacy* and *diversity and inclusivity*. It was decided to start with portfolio assignments as described above on the two skills *collaboration* and *diversity & inclusivity*.

Diversity & inclusivity was selected since the bachelor Food Technology at WUR is an international programme, with students from many different backgrounds. Therefore, an interactive lecture about cultural differences was given, in which diversity and cultures in relation to collaboration were discussed. In the end, students were asked to reflect on what they learned in this lecture.

Collaboration was selected since students worked together on a case, in which they integrated all the discussed disciplines (e.g. food engineering, food chemistry). In the reflection assignment, students were asked to reflect on their collaboration skills in this course.

The use of the reflection assignments was evaluated via a survey. Results of this survey are shown in Table 1. In general, the assignments were found to be clear and students found it useful to reflect on skills. Overall, students did not find it difficult to reflect and set goals.

Table 1. Survey results on how students appreciate the reflection assignments for two different skills. Students (n=121) answered the statements on a 5-point Likert scale, ranging from strongly disagree (1) to strongly agree (5)

	Intercultural communication		Collaboration	
	Mean	SD	Mean	SD
The assignment was clear for me.	4.06	0.61	4.00	0.76
The assignment was useful.	3.49	0.90	3.41	0.92
I enjoyed working on this assignment.	3.23	0.93	3.08	0.96
I found it difficult to reflect on this skill	2.58	0.98	2.50	1.03
I found it difficult to set a useful goal on this skill.	2.90	1.07	2.75	1.08
I think it is useful to reflect on this skill.	3.84	0.87	3.83	0.82

The general way of skills development, and feedback on reflections and goal-setting has been evaluated as well (Table 2). It shows that students see the relevance and usefulness of reflecting and working on skills development. When they would like to receive feedback or discuss it, they slightly prefer to do this with teachers or study advisors, instead of with peers.

Table 2. Survey results on skills development and receiving feedback on reflection and/or goals. Students (n=121) answered the statements on a 5-point Likert scale, ranging from strongly disagree (1) to strongly agree (5)

	Mean	SD
I think it is relevant to work on skills development as part of my study.	4.13	0.70
I would like to receive feedback and/or discuss my reflections and goals with a teacher or study advisor.	3.38	1.12
I would like to receive feedback and/or discuss my reflections and goals with other students.	3.11	1.04
It was clear for me how I needed to work with the portfolio tool.	3.45	1.08

4. Discussion

To integrate competencies in the curriculum, learning paths were developed in consultation with course coordinators. Furthermore, activities with reflection assignments were designed. Since the approach of designing a learning path and the reflection assignments were not tailored specifically for food technology, it shows potential to be used in other disciplines as well, However, after the integration of competencies in the first courses, some discussion remarks can be made.

Designing the learning paths together with teachers was effective. While discussing learning paths together with the involved teachers, they got acquainted with other courses as well. Together, they discussed the activities in their courses and discovered overlap or gaps, which led to adaptation and thus better alignment between courses, as was pointed out by Bath et al. (2004) as well.

Integrating competencies in existing courses appeared to be an effective approach to enable students to work on competency development. For example, when students reflected on their *researching* skills, they were able to reflect on the skills they had applied during practicals. Therefore, instead of only finishing experiments, students were stimulated to think critically about the way of executing the practical experiments. They stored their reflections and learnings in their portfolio and were able to use this in a follow-up course, which is important for their learning trajectory (Van Merriënboer and Kirschner 2017). Although students were actively discussing and working on the competency *researching*, the effectivity of the activity has not yet been evaluated: an evaluation is planned at the end of the learning path.

Students need sufficient time for competency development. Therefore, the effectiveness of the reflection assignments and portfolio cannot be evaluated after one course. However, the assignments and portfolio appeared to be useful, based on the first results of the survey. Students did not strongly desire to receive feedback from teachers, study advisors or peers. This might be explained by the fact that students prefer to be in charge of their own skills development and portfolio. Since students know that their assignments are not being assessed, they are able to write reflections in their own language, without being scared about the feedback of teachers. However, the portfolio not being accessible for teachers can also be seen as a disadvantage of the system, since it is not possible to check if all students finished the assignments seriously. Therefore, it was decided to give students enough time to finish the assignments in class and allow them to leave after having completed it. However, it is not possible to find out if students need help or instruction with reflecting. Therefore, the effectiveness and monitoring of reflecting remains a challenge, which needs to be further studied.

REFERENCES

Bath, Debra, Calvin Smith, Sarah Stein, and Richard Swann. 2004a. "Beyond Mapping and Embedding Graduate Attributes: Bringing Together Quality Assurance and Action Learning to Create a Validated and Living Curriculum." *Higher Education Research and Development* 23 (3): 313–28. https://doi.org/10.1080/0729436042000235427.

Chadha, Deesha. 2006. "A Curriculum Model for Transferable Skills Development." *Engineering Education* 1 (1): 19–24. https://doi.org/10.11120/ened.2006.01010019.

Fluckiger, Jarene. 2010. "Single Point Rubric: A Tool for Responsible Student Self-Single Point Rubric: A Tool for Responsible Student Self-Assessment." *The Delta Kappa Gamma Bulletin* 76, no. 4.

Gerstein, M, and Hershey H Friedman. 2016. "Rethinking Higher Education: Focusing on Skills and Competencies." *Psychosociological Issues in Human Resource Management* 4 (2): 104. https://doi.org/10.22381/pihrm4220165.

Huijser, Henk, Lindy Kimmins, and Linda Galligan. 2008. "Evaluating Individual Teaching on the Road to Embedding Academic Skills." *Journal of Academic Language & Learning* 2 (1): 23.

Levander, Lena M., and Minna Mikkola. 2009. "Core Curriculum Analysis: A Tool for Educational Design." *The Journal of Agricultural Education and Extension* 15 (3): 275–86. https://doi.org/10.1080/13892240903069785.

Mello, Luciane V., and Gemma Wattret. 2021. "Developing Transferable Skills through Embedding Reflection in the Science Curriculum." *Biophysical Reviews*. Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s12551-021-00852-3.

Potter, J., and C. Devecchi. 2020. *Delivering Educational Change in Higher Education*. Routledge.

Reekie, Manuela, Nicole de Bosch Kemper, Sheila Epp, Jacqueline Denison, Melanie Willson, and Lisa Moralejo. 2023. "Learning Pathways: Levelling, Scaffolding & Mapping Curriculum." *Journal of Professional Nursing* 46 (May):163–67. https://doi.org/10.1016/j.profnurs.2023.03.006.

Rieckmann, Marco. 2012. "Future-Oriented Higher Education: Which Key Competencies Should Be Fostered through University Teaching and Learning?" *Futures* 44 (2): 127–35. https://doi.org/10.1016/j.futures.2011.09.005.

Van Berkum, Melanie, Carla A.P. Buijsse, Julia Diederen, Perry J. den Brok, and Remko M. Boom. 2024a. "Visualising Learning Paths and Selecting Competencies through Curriculum Mapping." *Manuscript in Preparation*.

Van Berkum, Melanie, Julia Diederen, Carla A.P. Buijsse, Remko M. Boom, and Perry J. den Brok. 2024b. "Competencies in Higher Education: Identifying and Selecting Important Competencies Based on Graduates & Professionals in Food Technology." *European Journal of Engineering Education* 49 (3): 434–53. https://doi.org/10.1080/03043797.2023.2245768.

Van Merriënboer, J.J., and P.A. Kirschner. 2017. *Ten Steps to Complex Learning: A Systematic Approach to Four-Components Instructional Design*. Routledge.

Virtanen, Anne, and Päivi Tynjälä. 2019. "Factors Explaining the Learning of Generic Skills: A Study of University Students' Experiences." *Teaching in Higher Education* 24 (7): 880–94. https://doi.org/10.1080/13562517.2018.1515195.

Wageningen University & Research (WUR). 2017. "Vision for Education." https://www.wur.nl/upload_mm/c/9/8/824e2e07-5d7b-4fa2-800d-5b0cd90b6a02_WU Vision for Education 2017.pdf.

Wijngaards-de Meij, Leoniek, and Sigrid Merx. 2018. "Improving Curriculum Alignment and Achieving Learning Goals by Making the Curriculum Visible." *International Journal for Academic Development* 23 (3): 219–31. https://doi.org/10.1080/1360144X.2018.1462187.

INTERVENTION DESIGN AND TEACHING PRACTICE FOR ENHANCING ENGINEERING SKILLS IN READING RESEARCH ARTICLES

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ABSTRACT

The constant drive to improve engineering education's pedagogy stems from its crucial role in serving society. The practice of reading research articles is an academic strategy to keep up with the rapid advancement of the information and competencies required of today's engineers. Proficiency in this skill is difficult to attain, and unfortunately, this valuable capacity is often overlooked and not included in the curriculum for undergraduate students, which results in a loss of knowledge and a wasted opportunity. This article presents a practical case in an undergraduate Fluid Technology course, a teaching intervention designed for enhancing engineering students' skills in reading research articles carried out over a period of four months, within the boundaries of the course context. The first aim was to assess the progression of the students' ability to read research articles. The second aim was to elucidate student perceptions and conceptual cognition of their 'Capability', 'Ability', 'Skills' and 'Background' before and after the teaching practice. The teaching encompasses the reading assignments and post/out-of-class activities, the warm-up readings, two in-house ad-hoc lectures, the pre- and post-test readings and the pre- and post-questionnaires. The students' perception of self-improvement, as well as the positive shift in grades, are both reflected in the satisfactory results of the tests and questionnaires. This innovative educational research is readily adaptable to other cases and has potential for educating responsible engineers, thinking and understanding like engineers.

1 INTRODUCTION

Engineering education has always been fundamental to serving society and educating responsible engineers. To do this, it must be adaptable enough to adjust to the many different global forces that exist today and will exist in the future. Nonetheless, there are concerns about whether engineering practice will be able to keep up with the rapid advancement of the information, skills, abilities, competences, and attitudes that today's engineering demands (Lohmann 2008; Bubou et al. 2017). Engineering in higher education needs to adapt quickly in order to provide students with strong, astute, and perceptive engineering practice for the problems that lie ahead.

Reading scientific articles is one academic strategy used for improving engineering education: a transversal competency especially appropriate to be integrated in the context of a technical course. Students can greatly benefit from learning this ability in both their academic and professional careers. The relationship between a student's academic reading skills and success in education, even during the first year of an undergraduate course, proves it even more advantageous (Hermida 2009). The present work offers an effective method for reading scientific articles, developing analytical skills by questioning the content, and a scaffolded teaching strategy for not overloading students. A teaching intervention design for reading primary literature is given, based on a real case in practice in a compulsory undergraduate Fluid Technology course given by the Department of Fluid Mechanics at the School of Industrial, Aerospace, and Audiovisual Engineering of Terrassa (Spain), part of the Universitat Politècnica de Catalunya (UPC).

1.1 Primary literature on undergraduate education

An increasing amount of research has been carried out during the last 20 years, with an emphasis on how research experiences help students and how teaching and research are linked in higher education. Griffiths proposed ground-breaking methods that linked teaching with research (Griffiths 2004), and Healey's later work consolidated a comprehensive framework based on the research-based approach (Healey 2005).

Successful comprehension of primary literature is difficult since these are official documents that scientists use to communicate their research to each other. In light of mastering these techniques, students will be empowered to take responsibility for their own understanding, increasing excitement and motivation, which will lead to higher-quality learning results (Fernandez 2021, Yeong 2014). Research-based learning in engineering courses is particularly essential when it comes to motivation because most students do not learn through the study of primary scientific literature in high school science courses. Furthermore, via the production, relevance, and exploitation of digital resources, primary literature is influencing the social and cultural aspects of academic domains (Fry and Talja 2007). Nevertheless, there is no set criterion by which to judge a paper's significance or applicability at the time of publication.

Studies have been conducted on how teachers and researchers read primary literature and how they incorporate information from the articles into their professional knowledge, as research knowledge and primary literature serve as the foundation for the academic community (Bartels 2003). Other studies have focused on secondary sources and how teachers of scientific literature can use popular texts and popular genres (Parkinson and Adendorff 2004).

1.2 Research-based learning and engineering education

A strong grounding in many engineering techniques can be obtained through undergraduate research training. It has been demonstrated that it enhances students' comprehension and capacity to communicate primary scientific findings, giving them a competitive edge over their peers (Kozeracki et al. 2006). Discipline-based education research documents the most recent advances in the knowledge of how engineering and scientific students learn as well as how the syllabus is designed and teaching methods are employed (Benson et al. 2010; Singer and Smith 2013).

Curricula and teaching methods are evolving to guarantee innovative advances in engineering students' comprehension and learning. Therefore, in order to meet the problems of the twenty-first century, engineering education must strengthen the link between teaching and research. The method by which engineering educators conceptualise research and scholarship must be taken into consideration in order to effectively encourage and perform active learning and foster the development of the linkage between teaching and research (Brew 2003). It is essential that engineering educators take part in research-based programs, active learning, the overall teaching-research nexus, and employ current neuroscience knowledge as teaching methodology to enhance and make the lecture successful (Sanchez-Carracedo et al. 2021).

1.3 Course design using primary literature as an academic tool

Knowing how to read research articles is a skill that is often overlooked in university curricula. Most academics and research professionals have actually learned this skill through self-teaching (Greenhalgh 2014). As an additional component of their work, engineering educators study an extensive number of research publications. Unexpectedly, this talent is not taught frequently, especially not to undergraduate students, which results in an excessive amount of knowledge and effort wasted (Finelli and Froyd 2019).

The current initiative aims to provide methods for reading and useful frameworks for evaluating journal articles within the core of an engineering course while being guided and supervised by instructors. Conceptual comprehension is given priority over rote memorization in the assessment system in order to promote this kind of learning. Unlike traditional lecture-style training, which is teacher-centered, active learning involves all students participating in the learning process. It promotes an atmosphere that supports independent thought outside of traditional classroom settings and knowledge that is confident in oneself. Passivity and inaction are definitely not workable or feasible options. Integrating knowledge through problem-solving and case studies is one approach to accomplishing this, as opposed to just absorbing it. By doing that, it keeps pupils from becoming more demotivated and encourages a deeper comprehension of the topics at hand.

2 METHODOLOGY

2.1 Course context

Fluid technology is a compulsory course programmed each semester and encompasses two periods of six weeks each, with twelve sessions in total. The course typically has 70–80 students, between 21 and 24 years old, and all have to enrol in the subject. The students are proficient in both official languages, Spanish and Catalan. The textbooks and slides are written in Spanish, the lectures are taught in Catalan, and the assignments are in English. The course material, activities, and assignments were stored on the teaching support platform ATENEA (Moodle) on servers at the UPC.

The course is 4.5 ECTS, with 6 hours of teaching per two weeks, and its schedule is planned before each semester, sent to students one week in advance, and explained in the introductory lecture of the first week. In total, the teaching intervention encompasses the following:

- **Lectures and applications**, a variety of learning activities and problem-solving exercises [100 minutes per week]
- **Practice seminars**, including learning computer activities. [110 minutes per two weeks]
- **Self-study**. Pre/out-of-class activities (slides, short textbook-style readings, course-related short online videos, problem statements and resolution [90 min/week]) and post/out-of-class activities (online computer-based multiple-choice individual quizzes [90 min/week]). The total time scheduled represents 66% of self-study hours.

2.2 Intervention design and teaching practice

The teaching practice brings new perspectives to the engineering undergraduate course. The instructor, at the beginning of the intervention, informs the students and outlines the course regarding all programmed pre-, post-, and in- and out-of-class activities.

1. **The lectures on Reading Primary Literature** (RPL). The teaching practice is supported by two lectures to address how to identify the ‘anatomy’ of the paper, research questions and hypotheses, research argumentation, contents, and results in research articles.
2. **The reading assignments and the post/out-of-class activities**. Figure 1 shows the intervention program. The two lectures, RPL (1/2) and RPL (2/2) of 50 minutes each, are conveniently scheduled in the timeline with the reading assignments as post/out-of-class activities.
3. **The warm-up readings**. The designed progressive approach for a successful implementation of the intervention based on warm-up readings is depicted in Figure 1: 1st, 3rd and 4th, parts one and two. These warm-up readings accompany the students without overloading them, matching syllabus-related concepts and avoiding discouraging them during the intervention, especially at the beginning and before the RPL lectures.
4. **The test readings and the pre- and post-test**. The first aim of the intervention is to assess the student’s ability to read research articles; in fact, to measure the progression of this ability. Two test readings are planned to measure the effectiveness of the teaching practice: pre-test reading, 2nd, and post-test reading, 5th, Figure 1. The two articles were selected with attention, as different contents and syllabus-related concepts were used to generate the pre- and post-test questions.
5. **The pre- and post-questionnaires and SEEQ survey**. The second aim of the intervention is to elucidate student perceptions and conceptual cognition of their ‘Capability’, ‘Ability’, ‘Skills’ and ‘Background’ to read and critique primary literature before (pre-questionnaire) and after (post-questionnaire) the teaching practice (see Figure 1). Finally, the Student Evaluation of Educational Quality (SEEQ) survey is carried out to obtain perceptions, not only of the RPL intervention, but of the entire course.

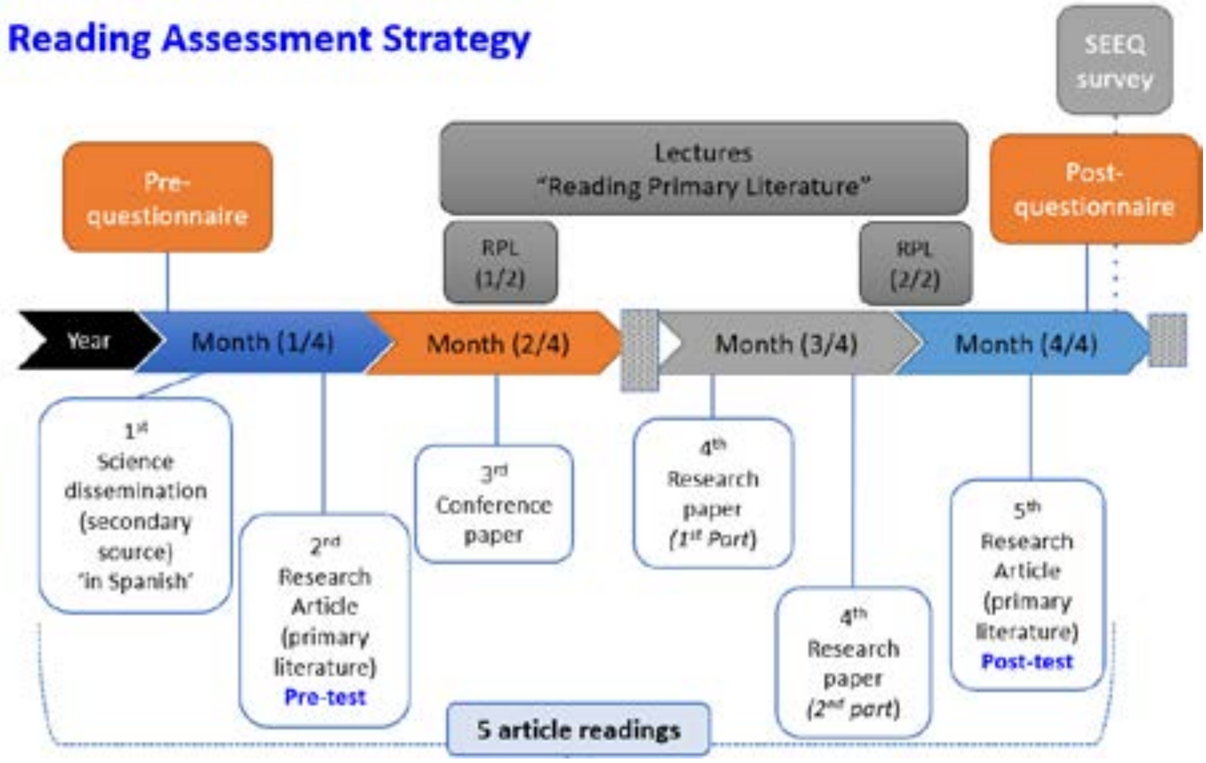

Fig. 1. The lectures on reading primary literature and reading assignments as post/out-class activities: the warm-up readings (1st, 3rd and 4th, part one and part two) and the test readings (pre-test 2nd and post-test 5th)

The intervention design presented is readily adaptable to other cases (f.i., subjects, classrooms, universities, etc.) to allow for rapid implementation in the learning environment. A more detailed explanation and context can be found in Gamez-Montero and Rodero-de-Lamo (Gamez-Montero and Rodero-de-Lamo 2023).

3 RESULTS

The data represent the 2023 fall semester student cohort, consisting of 72 students taking the pre- and post-tests (90% of the enrolment figure of 80 students).

3.1 Performance in the pre- and post- tests

The main objective of this intervention was to assess the ability of students to read research articles and their progression through a scheduled design, as shown in Figure 1. The test consisted of ten questions: five open-ended questions manually graded by the instructor's using a rubric and grouped as "Research Argumentation" (RA), as well as five computer-based multiple-choice questions grouped as "Contents and Results" (C&R). The students' grades in the pre-test were subtracted from the post-test grades, and the resulting distributions of the differences can be observed in Figure 2.

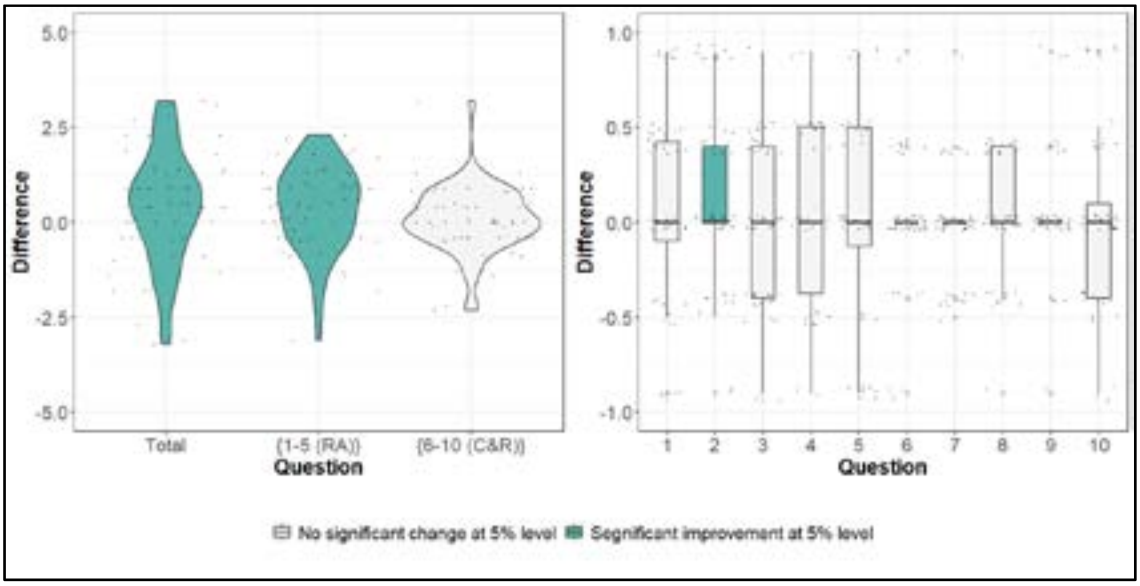

Fig. 2. Difference between the student post- and pre-test performance

The right section of the Figure 2 shows the distribution for individual questions, with adjusted box-plots. The left section of the figure shows the questions grouped by RA, C&R and Total, with violin-plots portraying the estimated density function of the data. The findings in this section imply that the students' ability to read primary literature did improve slightly during the intervention; however, it was only in the open-ended questions (RA), and these changes are mainly caused by the shift in question two. C&R questions are less related to reading skills than engineering concepts.

3.2 Students' responses in the pre- and post-questionnaires

The secondary aim of the intervention was the assessment of students' perceptions of their "Capability (A)", "Ability (B)", "Skills (C)", and "Background (D)" in reading the research articles by means of two scheduled questionnaires, before and after the intervention (see Figure 1). Figure 3 shows how the average score given by students' responses to each question changed over time.

It can be observed that overall, the students' self-judgment has improved. Most questions experienced a significant increase in response scores, but questions 2(A), 3(A), 7(A), 11(B), 12(B), 13(B), 16(C) and 17(C) did show a slight shift or were almost flat. These questions are related to the research question, materials, methods, and results of the article, along with the need to use a dictionary to translate English and a textbook to understand concepts. Hence, this slight significant change observed in these questions could be attributed to the fact that the articles were not given to the students in their native language, and the course did not last enough to get fully acquainted with the English terminology in fluid mechanics. The textbook question result is aligned with the C&R results. A paired test was performed to determine the significance of the results.

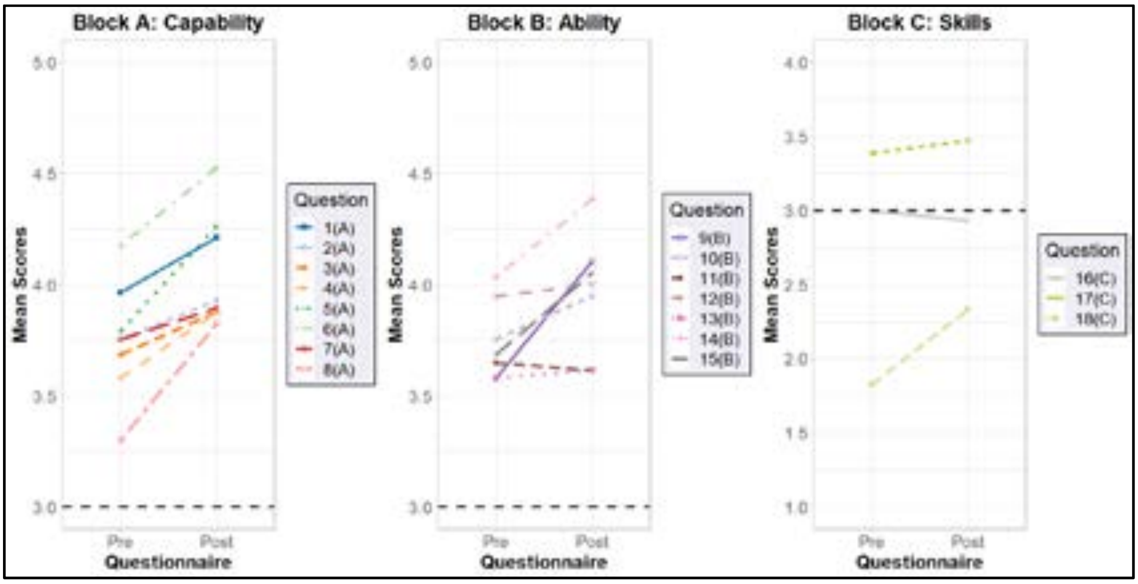

Fig. 3. Shift in students' average responses from pre- to post-questionnaire

Aside from the aforementioned cases, the improvements were shown to be significant at a 5% level using a Wilcoxon-signed test.

3.3 Conclusions

Through the four-month program, the students were given a set of tasks and lectures to enhance their engineering skills in reading research articles. The results of the tests, along with the questionnaires, showed that the strategy is satisfactory. This is both reflected by the students' perception of self-improvement as well as through the positive shift in grades, although it is worth noting to mention that the latter one was only observed in open-ended questions. This methodological approach still has room to grow, and as a future work based on the lessons learned, it will include citations as a factor in the selection of readings as a worthy bibliometric index to value the quality of the paper. In addition, a positive benefit will arise by providing a glossary with the main important words and descriptions in the articles to supplement them with additional information to aid readers in comprehending complex scientific concepts, since the vocabulary in research articles can differ drastically from the usual day-to-day English (Kararo and McCartney 2019).

4 SUMMARY AND ACKNOWLEDGEMENTS

The innovative educational research presented in this work has potential for educating responsible engineers; reading research articles makes it easier to embrace the challenging concepts of "roles of engineers" and "value of learning" that come with flourishing as engineer, and thinking and understanding as one. Students begin to take responsibility for their education, evolving into "self-directed learners" and aligning their strengths. Additionally, the findings may serve as a guide for engineering educators to improve the preparation of undergraduate students.

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REFERENCES

Bartels, N. “How teachers and researchers read academic articles.” *Teaching and Teacher Education* 19, 7 (2003): 737–753. https://doi.org/10.1016/j.tate.2003.06.001.

Benson, L. C., Becker, K., Cooper, M. M., Hayden Griffin, O., and Smith, K. A. “Engineering education: Departments, degrees and directions.” *International Journal of Engineering Education* 26, 5 (2010): 1042–1048.

Brew, Angela. “Teaching and Research: New relationships and their implications for inquiry-based teaching and learning in higher education.” *Higher Education Research & Development* 22, 1 (2003): 3–18. https://doi.org/10.1080/0729436032000056571.

Bubou, G. M., Offor, I. T., and Bappa, A. S. “Why research-informed teaching in engineering education? A review of the evidence.” *European Journal of Engineering Education* 42, 3 (2017): 323–335. https://doi.org/10.1080/03043797.2016.1158793.

Fernandez Carro, R. “What is a scientific article? A principal-agent explanation.” *Social Studies of Science* 51, 2 (2021): 298–309. https://doi.org/10.1177/0306312720951860.

Finelli, C. J. and Froyd, J. E. “Improving Student Learning in Undergraduate Engineering Education by Improving Teaching and Assessment.” *Advances in Engineering Education* (2019): 1–30.

Fry, J. and Talja, S. “The intellectual and social organization of academic fields and the shaping of digital resources.” *Journal of Information Science* 33, 2 (2007): 115–133. https://doi.org/10.1177/0165551506068153.

Gamez-Montero, P. J. and Rodero-de-Lamo, L. “Effectively integrating research argumentation in syllabus learning: A case study of reading journal articles in four fourth-year engineering fluid mechanics courses.” *International Journal of Mechanical Engineering Education* (2023): 1–36. https://doi.org/10.1177/03064190231194343.

Greenhalgh, T. *How to read a paper: the basics of evidence-based medicine*. London: John Wiley & Sons, 2014.

Griffiths R. “Knowledge production and the research–teaching nexus: the case of the built environment disciplines.” *Stud Higher Educ* 29 (2004): 709–726.

Healey, M. “Linking research and teaching exploring disciplinary spaces and the role of inquiry-based learning.” In R. Barnett (Ed.), Reshaping the university: New relationships between research, scholarship and teaching. Maidenhead, England: Open University Press/McGraw-Hill Education (2005): 67–78. http://www.delta.wisc.edu/events/bbbbalance healey.pdf.

Hermida, D. “The importance of teaching academic reading skills in first-year university courses. ” *The International Journal of Research and Review* 3 (2009): 20–30.

Kararo, M. J. and McCartney, M. “Annotated Primary Scientific Literature: a pedagogical tool for undergraduate courses.” *PLOS Biology* 17, 1 (2019). https://doi.org/10.1371/journal.pbio.3000103

Kozeracki, C. A., Carey, M. F., Colicelli, J., and Levis-Fitzgerald, M. “An intensive primary-literature–based teaching program directly benefits undergraduate science majors and facilitates their transition to doctoral programs.” *CBE—Life Sciences Education* 5, 4 (2006): 340–347. https://doi.org/10.1187/cbe.06-02-0144.

Lohmann, J. R. “Global engineering excellence: the role of educational research and development.” *Revista de Ensino de Engenharia* 27, 3 (2009): 33−44. http://revista.educacao.ws/revista/index.php/abenge/article/view/64

Parkinson, J. and Adendorff, R. “The use of popular science articles in teaching scientific literacy.“ *English for Specific Purposes* 23, 4 (2004): 379–396. https://doi.org/10.1016/j.esp.2003.11.005.

Sanchez-Carracedo, F., Trepat de Ancos, E., and Barba Vargas, A. “Successful engineering lecturing based on neuroscience.” *International Journal of Engineering Education* 37, 1 (2021): 115–132.

Singer, S. and Smith, K. A. “Discipline-based education research: Understanding and improving learning in undergraduate science and engineering.” *Journal of Engineering Education* 102, 4 (2013): 468–471. https://doi.org/10.1002/jee.20030.

Yeong, F. M. *How to read and critique a scientific research article: Notes to guide students reading primary literature*. London: World Scientific Publishing Company, 2014.

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Critical Thinking with AI: Navigating ChatGPT in Engineering Education

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ABSTRACT

The integration of Artificial Intelligence (AI) tools in educational settings presents both opportunities and challenges. This teaching innovation project presents a practical example of how generative AI-Tools (here ChatGPT) can be integrated into a Physics course in engineering education at the Zurich University of Applied Sciences (ZHAW) School of Engineering (SoE). Specifically, it first assesses how engineering students utilize generative AI-Tools in their daily work. Then, it explores how such a project can be used to improve the AI Literacy of the students, aiming to also boost students' critical thinking and evaluative judgement capabilities while using such tools. Students are asked to use and reflect upon ChatGPT in a lab session from the module "Physical Principles of Sensor Technology" in the third semester of the BSc Data Science program. The project is designed to encourage and guide students' use of AI technologies, promoting critical engagement in the context of their studies. It employs a mixed-methods approach to gather insights into students' perceptions and experiences with ChatGPT. The outcomes highlight a generally positive reception towards AI-Tools, being utilized for various academic tasks, including programming, data analysis, and general academic support. Challenges identified include the reliability and accuracy of AI-generated content, the development of effective prompts, and the need for guidance of critical evaluation of AI-provided information. The project's findings are summarised in a best practice guideline designed to support future students and to enhance the discourse on the use of AI tools at the School of Engineering.

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1 INTRODUCTION

The current hype and emerging prominence of Large Language Models (LLMs), particularly ChatGPT, in educational settings mark an intriguing development in the pedagogical landscape. Discussions on the optimal integration of these AI-Tools in the curriculum are ongoing at almost all universities, including at the Zurich University of Applied Sciences (ZHAW), School of Engineering (SoE). One pressing concern observed at the SoE is the tendency of students to use ChatGPT without sufficient critical consideration of the tool’s capabilities and limitations. This surge in interest comes at a time when literature and empirical studies on the integration and impact of such technologies in education are notably scarce, making this an interesting area for a teaching innovation project.

This project was carried out as part of the Certificate of Advanced Studies (CAS) Higher Education 2023/2024 at the Zurich University of Teacher Education (PH Zürich) and completed in March 2024. It presents an example how generative AI-Tools (here ChatGPT) can be integrated into a Physics course in engineering education of the BSc Data Science program and how such a project can be used to improve the AI Literacy of the students. The paper is organized as follows: First, a theoretical background and a short literature review is provided. Then the methodology and practical implementation of this teaching innovation project are described and finally its results are presented.

2 THEORETICAL BACKGROUND

In this section the key concepts for this innovation project are defined with supporting references. The aim is not to provide a complete literature review but give some context for this teaching innovation project.

2.1 AI Literacy

AI Literacy refers here to the understanding and skills necessary to effectively use, interpret, and critically evaluate artificial intelligence (AI) and its applications. This includes knowledge of how AI systems are developed, how they work, their potential impact on society, and ethical considerations. The ability to critically use and evaluate AI-powered tools like ChatGPT is an essential part of AI literacy. A more detailed discussion can be found for example in (Long & Magerko, 2020)

2.2 Authentic Assessment

Authentic Assessment is an evaluation method that aims to assess learners' skills and competences in real-world or practical contexts. Unlike traditional forms of assessment such as standardized tests or multiple-choice questions, which often measure abstract knowledge, authentic assessment aims to assess the application of knowledge and skills in scenarios that resemble actual challenges and tasks in the real world. This type of assessment is recommended, for example, by (Sambell, 2019). It discusses the challenges in the assessment practice of higher education in the 21st century, in particular the need to develop assessment methods that better support learning. Likewise, in (Sokhanvar, 2021), it is argued that such assessment methods provide more relevant and engaging learning opportunities, preparing students for their future.

2.3 Critical thinking

Critical thinking refers to the ability to systematically analyse, evaluate, and interpret information to make logical inferences and informed decisions. One possible definition is: The "conscious, self-regulating formation of judgments that involves interpretation, analysis, evaluation, and inference" (Facione 1990). In the context of AI-Tools like ChatGPT, this means critically questioning the accuracy, reliability, and relevance of the information provided by the AI. Users should have the ability to recognize the limitations of AI, such as its reliance on training data, possible biases, and how their responses are generated.

2.4 Evaluative Judgement

Evaluative judgement refers to the ability to assess the quality of information or services and to decide to what extent they meet certain criteria or standards. One possible definition is: "the capability to make decisions about the quality of work of oneself and others', evaluative judgement highlights students' interactions with standards of performance and is aimed at 'future capacities and lifelong learning' (Tai et al. 2018). The importance of evaluative judgement in the context of holistic competence development is emphasised e.g. in (Luo et. al. 2023) and (Tai et al. 2023). In the context of AI, evaluative judgement includes assessing the appropriateness of AI-generated responses for specific contexts or purposes. It also includes understanding when and how AI-Tools can be used effectively, and when human intervention or review is required.

2.5 Comparison and contextualization

While critical thinking and evaluative judgment are closely related, the focus of critical thinking is on analysing and evaluating information to arrive at conclusions. Evaluative judgment, on the other hand, focuses more on assessing the suitability and quality of that information or performance against specific goals or standards. When using AI-Tools such as ChatGPT, users should be able to apply both: they should be able to critically analyse the information provided by the AI (critical thinking) and at the same time be able to assess how well that information or solutions are appropriate for their specific context or purpose (evaluative judgment). Developing these skills is a key aspect of AI literacy, enabling individuals to use AI technologies responsibly and effectively.

2.6 State of research

Research at the time of the project's implementation revealed relatively few papers on the subject. In (Murray and Ali, S 2023), a positive influence on critical thinking was generally found when using ChatGPT. In (Gimpel et al. 2023), the potential of these technologies to provide personalized learning experiences, support academic research, and enrich teaching through innovative teaching methods is discussed. The authors emphasize the need to use the possibilities of generative AI responsibly and to pay attention to challenges such as ethical concerns and ensuring data quality. In (Michel-Villarreal and Vilalta-Perdomo 2023), the authors discuss how ChatGPT and similar tools can revolutionize learning and teaching, for example by promoting the development of critical thinking skills and students' adaptability. At the same time, they point to the need to address the ethical, legal and pedagogical implications in order to enable an integration of these technologies that is both effective and responsible.

3 METHODOLOGY AND IMPLEMENTATION

3.1 Methodology

A combined qualitative and quantitative research approach (mixed-methods) was used.

- **Qualitative Interviews**: Qualitative interviews were conducted with selected students to gain deeper insights into their experiences, perceptions, and opinions on the use of ChatGPT and their development in the field of critical thinking and evaluative judgment.
- **Quantitative Survey:** An Online Survey (Microsoft Forms) was created to collect the opinion of a larger group of students and obtain quantifiable data on the effectiveness of AI-Tools as a learning resource.
- **Criteria Development and Best Practices:** In small working groups, students were asked to develop specific criteria and recommendations for the use of ChatGPT.

3.2 Project Implementation

The project was carried out as part of a mandatory lab assignment of the module "Physical Principles of Sensor Technology" in the third semester of the BSc Data Science program in December 2023. This BSc program under has not formally integrated considerations on how AI impacts the curriculum yet. There are no specific measures or adaptations addressing the problems or potential of AI within the program. The only guidance provided details how students should declare the use of AI in their bachelor theses. This was another motivation to practice the use of ChatGPT within this project. The project included a voluntary online survey about the general usage of AI-tools and a mandatory lab assignment with ChatGPT. The lab assignment included aspects of an "Authentic Assessment", in which practical tasks are asked to demonstrate the application of knowledge and skills. Specifically, an electrical circuit should be constructed, followed by performing several measurements and explaining the corresponding theoretical concepts. The resulting data should then be analysed and compared with theoretical predictions. Student groups were asked to use and reflect upon ChatGPT (free version 3.5) in this lab session and summarise their findings in a graded report, which accounts for 20% of the assessments. In addition, they had to answer the following questions in the reports:

1.) Describe in max. 5 sentences how ChatGPT works and what problems can occur when using it.
2.) Use ChatGPT in your research about capacitive sensors and as writing support for your report.
3.) Define 5 criteria to evaluate the answers from ChatGPT.
4.) Try to trick ChatGPT into giving false answers.
5.) Based on your own experience and 1.) - 4.), develop at least 5 tips that will help to use ChatGPT efficiently and to identify false information.

The analysis of the results was completed in March 2024.

4 RESULTS

4.1 Evaluation of the online survey

The voluntary survey, conducted in December 2023 included 35 students to gather insights on their experiences, opinions, or use of generative AI-Tools. Among this cohort, 27 individuals participated, yielding a response rate of approximately 77%. This substantial participation rate indicates a strong interest of the invited students in the topic. The survey results indicate that all participants utilize generative AI-Tools as part of their engineering studies with 56% employing them daily and 44% at least once per week. One surprising outcome was that all students had a subscription to the paid ChatGPT version 4.0 (costing approximately 20 CHF/month), highlighting the increasing integration and appreciation of AI technologies in engineering education.

Analysis of the responses concerning AI tool utilization revealed the following top five uses (see Fig. 1): Programming (89%), general writing support (81%), brainstorming (60%), data analysis (44%), and report creation and structuring (44%). Additionally, students use generative AI-Tools for research, translation, and solving Moodle quizzes, frequently encountered in SoE assessments. Participants also discussed the challenges and risks associated with AI tool use. A common concern was the overreliance on AI-generated responses. Many students underlined the necessity of possessing a solid understanding of the subject matter to detect errors effectively.

Inquiries about the integration of AI-Tools into the School of Engineering and the effectiveness of this teaching innovation project were also made. A majority (63%) found this innovation project helpful. In the interviews students mostly appreciated the compelled engagement with ChatGPT's functionality and its limitations. Moreover, 81% advocated for a more guidance and active incorporation of generative AI-Tools into the SoE curriculum, for example as prompt engineering.

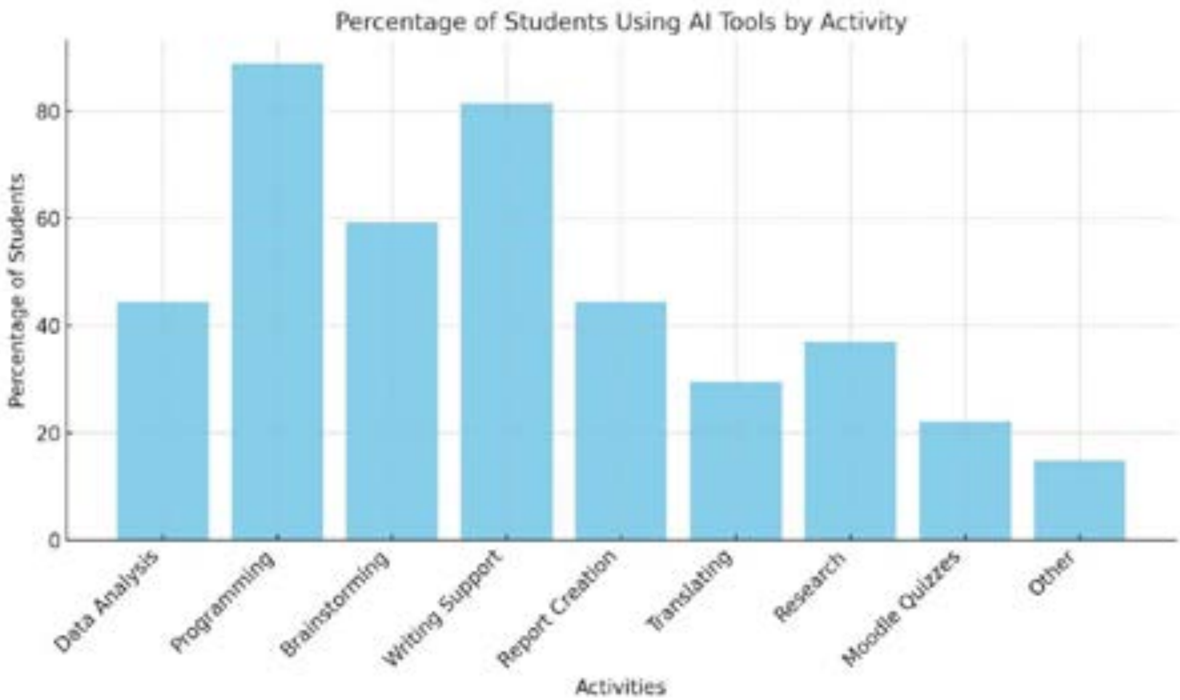

Fig. 1. Usage of generative AI-Tools.

4.2 Evaluation criteria for ChatGPT

The student groups defined 15 criteria to judge the quality of the answers of ChatGPT. Example criteria are listed below:

- **Relevance:** Answers are generally focused on the question asked but may deviate from the topic in case of ambiguous queries.
- **Reliability:** Can provide reliable information but should not be used as the sole source of critical decisions.
- **Timeliness:** Answers are based only on training data up to a specific point in time.
- **Neutrality:** Aims for objectivity but may have bias due to the training data.
- **Liability:** ChatGPT assumes no liability for the accuracy of the information provided.
- **Awareness of its limitations:** ChatGPT does not recognize its own limitations. It can sound convincing despite insufficient information.
- **Creativity and speculation:** Tends to give creative or speculative answers at times.

The students also pointed out that ChatGPT is not deterministic: it does not give the exact same answer to the same question, so citing ChatGPT or searching for plagiarism is not possible (see example in Fig. 2).

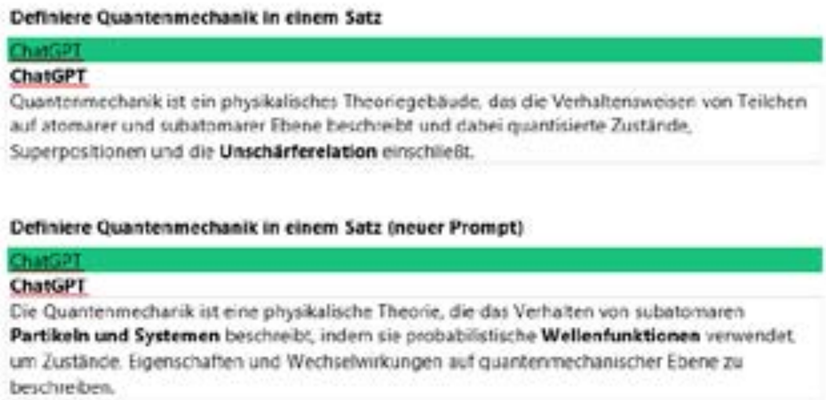

Fig. 2: Example that ChatGPT answers the same question (here how to define quantum mechanics) differently when asked in a new prompt.

4.3 Provoking False statements

The students tried to provoke ChatGPT to give false answers. The examples provided by the students can be roughly grouped in the following categories:

- Having multiple conditions, ChatGPT will often only take one or two of them into account when responding.
- After direct contradiction or false statements (see Fig. 3) incorrect answers and formulas are delivered.
- Sometimes ChatGPT admits to a misunderstanding, but then provides the same answer again.

- Errors in calculations with physical units.
- Multiple choice questions on complex physics topics often led to detailed but incorrect answers.
- When using leading questions or questions with intrinsic contradictions.

4.4 Recommendations for Best Practice Guideline

The students were very engaged in gathering tips and experiences on how to use ChatGPT efficiently. The student groups defined 25 recommendations. These results were summarised in the guideline, sorted into categories, and presented to the teaching department of the SoE as basis for further discussions. Example best practices are listed below:

- **Breaking down complex tasks:** Divide complex problems into manageable steps for effective processing.
- **Requesting a defined output:** Request a specific output such as a table or a Python dictionary (can be defined in the prompt).
- **Providing context: Fully** integrate the context into your question (e.g., by defining the role of ChatGPT) to avoid misunderstandings.
- **Using technical language:** Use precise language for high-quality responses.
- **Verification through multiple inquiries**: Vary the prompts to gain a broader understanding and test the consistency of the responses.
- **Verification through peer review:** Discuss responses with fellow students or lecturers to identify incorrect information.
- **Validation with another AI**: Compare responses with other generative AI models to determine the need for manual research.

ChatGPT Countries whose names start with the letter "V" are:

1. Vatican City
2. Venezuela
3. United Arab Emirates
4. United Kingdom
5. Vietnam
6. People's Republic of China
7. From Lands and Lordships
8. Pre-colonial conquests of Europeans in Africa

Please note that this is a list of countries whose names typically begin with "V." However, there are also some regions or areas with "V" at the beginning of their names, but they are not independent countries.

You There are no countries that start with V.

ChatGPT Sorry for the confusion. **You are right; there are no independent countries whose names start with the letter "V."** I apologize for the incorrect information in my previous response. Thank you for the correction.

Fig 3: Example of incorrect answer of ChatGPT after direct objection by the user with English translation. Note the original list also already contains errors.

5 SUMMARY AND ACKNOWLEDGEMENTS

This teaching project introduces an innovative approach to engineering education by explicitly incorporating ChatGPT into a traditional Physics course. During this project, students explored the advantages and limitations of ChatGPT- topics not yet integrated into the current curriculum but crucial for cultivating AI literacy. The task of inducing ChatGPT to generate incorrect answers particularly captivated the student's interest, in line with the project's aim to boost students' skills and critical interaction with ChatGPT. This goal was achieved, as demonstrated by mostly positive feedback gathered through the survey and the individual interviews.

The evaluation revealed that all data science students use AI-Tools at least once a week. The students have expressed a desire for more structured guidance in utilizing AI-Tools, recommending the incorporation of prompt engineering and programming assistance into designated modules of the SoE curriculum. A critical analysis of ChatGPT's responses, alongside comparison with other sources, improved students' lab reports compared to the previous year, both in content and linguistic quality. There theoretical background section contained less errors and the student used ChatGPT as companion to check their writing and explain key concepts. After the lab session the data science students exhibit a basic understanding of ChatGPT utilizing the tool with more considerable thoughtfulness. Engaging intensively with ChatGPT during the project thus not only elevates the efficiency of tool usage but also cultivates evaluative judgment and critical thinking abilities. However, proactive encouragement and support are necessary as students often engage with ChatGPT in a non-reflective and uncritical manner, often unaware of its limitations and lacking explicit guidance from their universities. Meanwhile, as the professional environment becomes increasingly AI-dominated, AI literacy becomes more and more vital.

By embedding ChatGPT within a traditional Physics course, this project diverges from traditional educational approaches, offering fresh insights into the value of generative AI tools and offering suggestions how they could be integrated into engineering education in a responsible way. In summary, the methods suggested in this project are:

- Establishing fundamental AI tool understanding.
- Integrating AI-Tools into authentic assessment settings to better prepare students for their future professional environment.
- Guided and critical utilization of ChatGPT in engineering education, including the exploration of incorrect answers and the development of evaluation criteria and best practices.
- Providing actionable guidance, ideally at an institutional or program level, to support students in effectively utilizing AI tools.

These suggestions offer practical inspiration and are adaptable to diverse educational settings within engineering education. The results indicate that students wish more guidance and integration of generative AI-Tools at the university level. Despite the limited statistics available in this project, the results clearly emphasise the importance of providing adequate support rather than leaving students to navigate AI-Tools largely on their own.

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REFERENCES

Facione, Peter A. Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction. Santa Clara University, 1990. https://web.archive.org/web/20170201144659/https://assessment.trinity.duke.edu/documents/Delphi_Report.pdf.

Fischer, J., Bearman, M., Boud, D., & Tai, J. "How does assessment drive learning? A focus on students' development of evaluative judgement." Assessment & Evaluation in Higher Education (2023). https://doi.org/10.1080/02602938.2023.2206986.

Gimpel, H., Hall, K., Decker, S., Eymann, T., Lämmermann, L., Mädche, A., Röglinger, M., Ruiner, C., Schoch, M., Schoop, M., Urbach, N., & Vandirk, S. "Unlocking the Power of Generative AI Models and Systems such as GPT-4 and ChatGPT for Higher Education" (2023).

Irfan, M., Murray, L., & Ali, S. "Integration of artificial intelligence in academia: A case study of critical teaching and learning in higher education" (2023). Verfügbar unter https://www.humapub.com/admin/alljournals/gssr/papers/SbiE3AUz6e.pdf.

Long, D., & Magerko, B. "What is AI literacy? Competencies and design considerations." Proceedings of the 2020 chi conference on human factors in computing systems. (pp. 1–16) (2020). https://doi.org/10.1145/3313831.3376727.

Luo, J., & Chan, C. K. Y. "Conceptualising evaluative judgement in the context of holistic competency development: results of a Delphi study." Assessment & Evaluation in Higher Education 48, no. 4 (2023): 513-528. https://doi.org/10.1080/02602938.2022.2088690.

Michel-Villarreal, R., & Vilalta-Perdomo, E. "Challenges and Opportunities of Generative AI for Higher Education as Explained by ChatGPT." Education Sciences 13, no. 9 (2023): 856. https://doi.org/10.3390/educsci13090856.

Sambell, K., Brown, S., & Race, P. "Assessment to support student learning: Eight challenges for 21st century practice." AISHE-J 11, no. 2 (2019). Retrieved from https://ojs.aishe.org/index.php/aishe-j/article/view/414/673.

Sokhanvar, Zaha; Salehi, K., & Sokhanvar, F. "Advantages of authentic assessment for improving the learning experience and employability skills of higher education students: A systematic literature review." Studies in Educational Evaluation 70 (2021): 101030.

Tai, J., Ajjawi, R., Boud, D., & et al. "Developing evaluative judgement: Enabling students to make decisions about the quality of work." High Education 76 (2018): 467–481. https://doi.org/10.1007/s10734-017-0220-3.

Critical thinking and problem-solving: challenges for students

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ABSTRACT

Critical thinking (CT) plays a crucial role in higher education. In the 12-credit master-level course Logistics Project at Linköping University in Sweden, students engage in practical logistical investigations with external clients. The projects are open-ended, something students find difficult and stressful. Teachers perceive the students do not really show a critical mindset to apply their knowledge to the specific context. To be able to support the students' learning better, student and teacher perceptions were gathered through questionnaires and interviews to investigate what, more specifically, is challenging for the students. The main challenges identified were: *Planning, The role of literature, Specify and delimit, Selection of investigation method*, and *Written communication of results*. These challenges all relate to CT. The measures taken to counteract the challenges were informed by literature as enablers to improve students' CT skills: a new visual model for investigation planning, new thematic seminars, and redesigned peer group meetings (PGM).

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1 INTRODUCTION

Critical thinking (CT) plays a crucial role in academics, is a core component of higher education teaching and is important to most disciplines. The understanding and definition of the term CT varies between researchers, teachers, and academic disciplines (Ahern et al. 2012, Alsaleh 2020, Moore 2013). Although it lacks a uniform definition, it generally encompasses a range of mental processes and skills such as interpretation, analysis, evaluation, inference, explanation, and self-regulation (Alsaleh 2020) and the ability to ask adequate questions, evaluate, analyse, reflect, and draw conclusions (Hedin 2006).

The requirements for Swedish master-level engineering degrees include that students must demonstrate the ability to "critically, independently and creatively identify, formulate and handle complex issues", as well as "plan and with adequate methods carry out qualified tasks within given frameworks" (HigherEducationOrdinance 1993). Furthermore, at Linköping University (LiU) in Sweden, engineering education is conducted according to the CDIO framework (Crawley et. al., 2014), which defines several crucial engineering skills. Among these are Critical Thinking, (e.g., making assumptions, reviewing facts and information, and logical argumentation) and Systems Thinking (e.g., defining system boundaries, understanding wholes and subsystems, and making priorities and trade-offs) (CDIO 2022), sections 2.3 and 2.4. Hence, it is required that the students, with support from teachers, develop several advanced abilities linked to CT during their studies.

In the 12-credit course Logistics Project, part of the engineering curriculum at LiU, students in the final year of their master studies engage in practical investigations related to logistics. The course bridges theory and practice, preparing the students to tackle real-world logistics challenges with competence and professionalism. The learning objectives in the course address the most advanced levels of Bloom's taxonomy (Krathwohl 2002) and the SOLO taxonomy (Biggs, Tang, and Kennedy 2022). In the course, the students thus can develop and practice these skills that build the ability to think critically.

The students work in teams to plan and carry through logistics investigations, each team with their external organization as the client. To reach credible, transparent, and well-underpinned results, the students must apply rigorous and systematic procedures, using what we label “logistics investigation planning”. An important part of this is thorough planning before the action phase, where the plan is carried through. For example, research questions must be specified based on literature and information from the client, and methods for data collection and analysis are to be selected.

The course runs over one semester, with project planning in focus during the first half, and carrying through the project during the second. It contains several teaching and learning activities, the most central being lectures, videos, seminars, and supervision. The teams have academic supervisors as support. Each supervisor is responsible for 3-4 teams, who meet regularly in so-called “peer groups” (PG), where the supervisor also participates. The course design involves several occasions where students receive formative feedback, see e.g. Henderson et al. (2019), on interim reports from teachers as well as from peers.

Since this kind of complex, comprehensive open-ended project is new to the students, they find it difficult to understand and execute logistics investigation planning properly. From previous courses, they are not used to investing much time in planning before action, why they tend to rush through the planning too quickly. For the teachers, the objective is to enhance student learning and facilitate their academic progress. To be able to support the students better, the involved teachers would like to know more specifically what the students perceive to be the major difficulties. Therefore, this study set out to address the following two critical questions:

- What major difficulties do the students experience when learning logistics investigation planning?
- How can teaching and learning activities be designed to help the students overcome the difficulties?

2 METHODOLOGY

Perceived challenges were identified by a stepwise sequence. *First*, through individual and anonymous questionnaires, the 58 students following the 2022 course on 6 occasions during the course were asked to reply to reflective questions on what they have learned and how, and what difficulties and challenges they perceived. In total, this rendered 225 reflections. *Second*, in parallel to the student questionnaires, the 3 supervisors involved in the course reflected on the same things from a teacher's perspective, leaving in total of 15 reflections. *Third*, in the course evaluation questionnaire (used in every course at LiU) specific questions were added, and complementary feedback was given from 24 students. *Fourth*, the reflections were thematically analysed (Bell, Harley, and Bryman 2022) by 4 teachers (the course examiner, one of the supervisors, and two not actively involved in the course) to identify and cluster important challenges. *Fifth*, for verification and deepened understanding, the same teachers conducted 7 group interviews with in total 16 of the students. Since these students at the time of the interviews were in the final stages of their master’s thesis projects, they had applied the learnings from the course once again and were therefore able to give more mature reflections on the course. This gave a deeper understanding, as well as some new insights, and resulted in a compilation of selected challenges for further investigation.

Based on the identified challenges, some changes were implemented in the 2023 course. To capture whether these changes affected students’ perceptions of challenges, all 49 students answered a mid-course questionnaire, followed up with a meeting between the examiner and each of the 10 project teams. Moreover, a course evaluation questionnaire, like the one from 2022, was handed in by 39 of the students, and the supervisors’ opinions were caught by interviews. The project ended at the turn of the year 2023.The process described above is schematically shown in Figure 1.

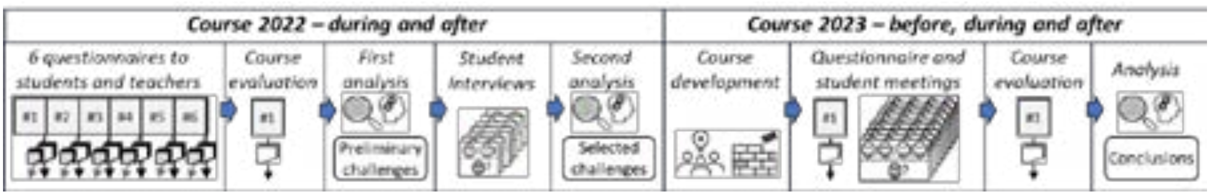

Fig. 1. Overview of the research process

3 IDENTIFIED CHALLENGES

In this section, the main challenges identified for students when learning investigation planning are presented.

Planning. As the tasks the students start with are open-ended and extensive, the planning of the project becomes central and more complex than they are used to. The students regard it hard to understand what activities to go through, make proper time planning, and divide the work within the team.

The role of literature. Relevant literature is used as support to form and specify the task, to analyse empirical data, to generate suggested solutions, and to analyse these solutions. According to the teachers, the students have a narrow view of the literature's role in the project, as well as how to search for relevant literature and how to write a useful frame of reference. The students agree and claim that they realise this too late, which leads to consequences in the form of re-writing, time delay, and less elaborated end results.

Specify and delimit. The initial, sometimes rather vague, task must be transformed into a clear one with relevant focus and reasonable scope. This requires the students not only to form research questions (RQ), set the system borders (i.e., define what to include in the study), and make delimitations, but also to give satisfactory motives for their decisions. Hence, they must make a lot of choices in areas where they don't feel competent. The fact that the team itself is responsible for formulating precise RQs based on literature and the client organisation, is by many perceived as a main challenge.

Selection of investigation method. Suitable methods for data collection and analysis are chosen by the students, something they regard difficult at an early stage of the project, i.e. in the planning phase. Especially, choosing methods for data analysis is perceived as abstract before data is collected.

Written communication of results. A general problem is the balance between transparency and trustworthiness (facilitated by thick descriptions) and readability (which rather is supported by less detailed reports). Specific problems pointed out by the students are how much of the empirical material to include, and how to combine empirical descriptions and analysis in a way that supports the reader.

4 CHANGES IN LEARNING ACTIVITIES

4.1 Measures taken as a response to the challenges

Table 1 shows the changes made in the 2023 course are related to the challenges described in the previous section. In addition to these, some other changes were made to reduce the scheduled hours to reduce the student workload and/or increase their flexibility. For example, lectures were to a higher degree pre-recorded, and peer group meetings (PGM) were shortened from 4 to 2 hours.

Table 1. Challenges identified and measures taken

Challenge	Measures taken
Planning	• Revised, more detailed, visual model for investigation planning, describing the steps/activities involved, from preliminary task to a detailed plan of *what* the investigation contains (RQs) and *how* it is to be performed (method description).

	• Teams are required to hand in time plans, by start-up for the planning phase, and mid-course for the action phase. • Increased number of PGMs to help students keep pace with the project. • Strengthened teacher instructions for PGM with a focus on overall planning.
The role of literature	• The importance of literature support is highlighted in the revised investigation model. • 2-hour seminar on literature, and its role for different parts of the investigation. • New PGM with a focus on literature search and frame of reference. Teacher instructions were created to support this.
Specify and delimit	• Course material (video, documents, presentation material) revised in sync with the revised investigation model. • Strengthened teacher instructions for PGM with a focus on the specification of tasks.
Selection of investigation methods	• Course material (video, documents, presentation material) revised in sync with the revised investigation model. • 2-hour seminar on how to form and present concrete investigation methods supported by literature. For example, thematic analysis is tested and discussed as a potentially useful method. • Strengthened teacher instructions for PGM with a focus on investigation methods.
Written communication of results	• 2-hour seminar with a focus on how to handle empirical material and analysis in the report. • New PGM with a focus on empirical material and analysis in the reports. Teacher instructions were created to support this.

4.2 Preliminary outcomes

Whether the measures taken have contributed to the students' ability to handle the challenges is not easy to tell. The aspects are not easy to measure, the number of students/teams is limited, and some of the learning effects may not be observed within the course, but rather in the succeeding master's thesis. However, by analysing student opinions from the course evaluation together with experiences from the participating teachers, we could see some preliminary outcomes.

The student response was overall positive, with small differences from the last few years on the graded questions. An exception from this refers to whether they regard the peer group meetings (PGM) to be supportive. The average grade rose from 3.3 – 3.9 (on a 5-grade Likert scale) in the last four years to 4.4 this year. Of the 25 students who chose to highlight one or several learning activities they especially appreciated, 19 (76%) mentioned the PGMs. Compared to previous years (30-40%) this is a significant increase. Examples of free-text comments from the students are: "*The PGMs gave opportunities for continuous feedback on our work"* and "*PGMs were good! Very good discussions and rewarding to see the work of other teams*" The teachers are also positive, and regard the shorter, but more frequent, PGMs help the teams to keep pace in their projects. With more checkpoints, the supervisors have more opportunities to discover if someone is lagging. Moreover, improved teacher instructions enabled more structured PGMs.

Three new seminars on specific topics were introduced this year, receiving average grades of 4.0 – 4.1. Free-text comments are predominantly positive: *"The seminars were very rewarding"*, but some also reveal room for improvement: *"The seminar content was not always in phase with what we did in the project"*. However, very few student comments appeared concerning specific seminars. As some aspects were already targeted at the seminars, the teachers felt the discussions at the PGMs could be held on a higher level than previously, which in turn affected the student reports.

In Table 2, preliminary outcomes are connected to the identified challenges.

Table 2. Preliminary outcomes of the measures taken

Challenge	Preliminary outcome
Planning	• PGMs and compulsory time plans helped students plan their projects better.
The role of literature	• Better student understanding of the different roles of literature during the project and in the report, thanks to the new seminar, new PGM, and revised investigation model.
Specify and delimit	• No observed improvements.
Selection of investigation methods	• Good discussions at the method seminar indicating an increased awareness among the students. • Slight improvement was observed in the reports concerning concrete descriptions of methods used and motives for using these methods.
Written communication of results	• Better student awareness of how to deal with analysis and empirical material in their reports observed at PGMs after attending the seminar concerning this. • However, still room for improvement in the reports.

5 DISCUSSION AND CONCLUSIONS

As outlined in the introduction, critical thinking (CT) is a complex concept, covering several aspects, among them reflection, evaluation, and analysis (Alsaleh 2020; Hedin 2016), i.e., skills associated with the upper levels of cognitive taxonomies, such as Bloom's (Krathwohl 2002) and SOLO (Biggs, Tang, and Kennedy 2022). The assignments in the course are designed to require the students to show such skills, including sections 2.3 and 2.4 in the CDIO framework (CDIO 2022). All five main challenges identified in this study are related to CT. *Planning* requires the students to critically evaluate what is possible to do within the project frames, *literature* must be critically evaluated to fit into the project, *specifying the project* requires an understanding of the present situation and weighing different opinions against each other, *investigation methods* should be selected after careful and critical consideration, and *written communication* requires much reflection.

The measures taken in the course also have support in the literature as supportive for developing critical thinking: problem-based learning, as the course begin with problems rather than with the content (Pithers and Soden 2000), questioning techniques in the PGMs using the Socratic method (Yang, Newby, and Bill 2005), the seminars use discussion methods as we teachers lead the classroom discussion being role models through reasoning out loud and in how to ask critical but well-intentioned questions (Taylor 2002). All in all, the course is given with an integrated approach to teaching CT (Hatcher 2006). Further, as generative AI and language models offer possibilities for text generation, there is a risk that writing skills are being affected. In the course, we therefore highlight writing as one of the most important skills. Condon and Kelly-Riley(2004 p. 66) assert that 'writing acts as a vehicle for critical thinking, but writing is not itself critical thinking'.

Although the modifications of the course have not resulted in elimination of challenges, we have taken a step towards an increase in students' critical thinking abilities. We intend to further explore this phenomenon, and we are planning a study aimed at further examining the evolution of CT skills both during the course and after the master thesis projects in the next upcoming round of courses.

Since identification of learning challenges is difficult, Knight et al. (2014) suggest using multiple methods to increase the chance of finding the real challenges. Our approach, capturing both students' and teachers' voices by a combination of reflection documents, questionnaires and interviews, is in line with this. We therefore argue that the identified challenges for critical thinking are relevant. Although we have studied a specific context, we believe these challenges to be generic rather than context specific. We also believe the multiple method approach to identify CT challenges to be applicable in various settings. The measures taken to overcome the challenges can be used as inspiration, but with careful adaption to the specific context.

The findings reported here are connected to a specific project funding, which allowed us to explore a certain topic, critical thinking, rather deeply. However, the results and outcomes of the project are not solely derived from a single, isolated effort. Rather, they reflect our long-term, structured approach and systematic practices, firmly established within our department. The Logistics project course benefits from structural capital, allowing for teacher rotation and preventing overreliance on a small number of teachers. Our development work follows a continuous improvement model (outlines in Figure 2) akin to the Plan-Do-Study-Act (PDSA) cycle (Kolb 1984). For instance, in the Logistics project course, we assemble a teaching team comprising supervisors, director of studies and the examiner. Prior to the course commencement, the team convenes for a startup meeting, reviewing the previous year's course closure and discussing modifications for the upcoming round. Throughout the course, the team holds brief reconciliation meetings to assess student project progress and team dynamics. A midterm student evaluation provides valuable input for adjustments during the course. At the course's conclusion, students respond to a course evaluation survey. Finally, the teaching team conducts a comprehensive debriefing, open to all departmental teachers. This session involves analysing student feedback, identifying successful practices, and proposing changes for the following year. Agreed-upon improvements are implemented in preparation for the next course offering.

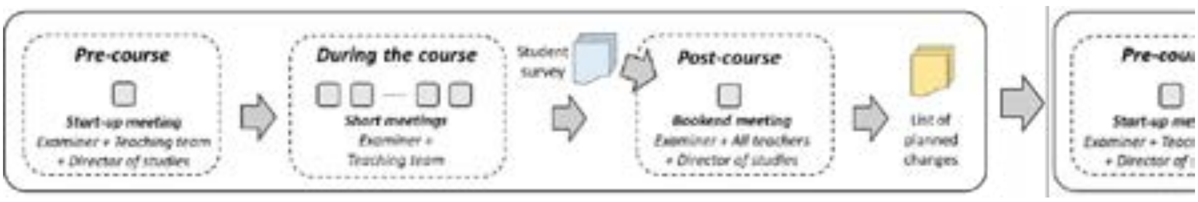

Fig. 2. Structured course development – an overview

Hence, the specific project made it possible to give extra focus on students' critical thinking, but the enhancements outlined in this paper would not have been possible without our systematic approach to education and didactic development. We strive to provide our students with structured ways of working. Likewise, we adhere to a structured methodology for course development, where students' as well as teachers' voices are heard and used. Using such a structured approach is something we strongly recommend as a key to identifying which aspects to focus in the continuous course development efforts.

REFERENCES

Ahern, A., T. O'Connor, G. McRuairc, M. McNamara, and D. O'Donnell. 2012. "Critical thinking in the university curriculum – the impact on engineering education." *European Journal of Engineering Education* 37 (2):125-132. doi: 10.1080/03043797.2012.666516.

Alsaleh, Nada J. 2020. "Teaching Critical Thinking Skills: Literature Review." *Turkish Online Journal of Educational Technology-TOJET* 19 (1):21-39.

Bell, Emma, Bill Harley, and Alan Bryman. 2022. *Business Research Methods*. 6 ed. Oxford Oxford University Press. Non-fiction.

Biggs, John, Catherine Tang, and Gregor Kennedy. 2022. *Teaching for quality learning at university 5e*: McGraw-hill education (UK).

CDIO. 2022. "The CDIO Syllabus v 3.0." http://www.cdio.org/content/cdio-syllabus-30.

Condon, William, and Diane Kelly-Riley. 2004. "Assessing and teaching what we value: The relationship between college-level writing and critical thinking abilities." *Assessing Writing* 9 (1):56-75.

Hatcher, Donald L. 2006. "Stand-alone versus integrated critical thinking courses." *The Journal of general education* 55 (3-4):247-272.

Hedin, Anna. 2006. *Lärande på hög nivå: idéer från studenter, lärare och pedagogisk forskning som stöd för utveckling av universitetsundervisning*: Avdelningen för utveckling av pedagogik och interaktivt lärande (UPI ….

Henderson, Michael, Rola Ajjawi, David Boud, and Elizabeth Molloy. 2019. *The Impact of Feedback in Higher Education: Improving Assessment Outcomes for Learners*: Palgrave MacMillan.

HigherEducationOrdinance. 1993. Högskoleförordning 1993:100. edited by Sveriges riksdag Utbildningsdepartementet. https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/hogskoleforordning-1993100_sfs-1993-100/#K12 (visited 2023-11-05)

Knight, D. B., D. P. Callaghan, T. E. Baldock, and J. H. F. Meyer. 2014. "Identifying Threshold Concepts: Case Study of an Open Catchment Hydraulics Course." *European Journal of Engineering Education* 39 (2):125-142. doi: 10.1080/03043797.2013.833175.

Kolb, David A. 1984. *Experiential Learning - Experience as the Source of Learning and Development* New Jersey: Prentice-Hall.

Krathwohl, David R. 2002. "A Revision of Bloom's Taxonomy: an Overview." *Theory Into Practice* 41 (4):212-218.

Moore, Tim. 2013. "Critical thinking: seven definitions in search of a concept." *Studies in Higher Education* 38 (4):506-522. doi: 10.1080/03075079.2011.586995.

Pithers, Robert T, and Rebecca Soden. 2000. "Critical thinking in education: A review." *Educational research* 42 (3):237-249.

Taylor, William. 2002. "Promoting critical thinking through classroom discussion." *Teaching and learning in honors* 2.

Yang, Ya-Ting C, Timothy J Newby, and Robert L Bill. 2005. "Using Socratic questioning to promote critical thinking skills through asynchronous discussion forums in distance learning environments." *The american journal of distance education* 19 (3):163-181.

COMMUNICATION IN INNOVATION TEAMS

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Keywords*: teamwork, interdisciplinary, communication*

ABSTRACT

The quality of communication in innovative teamwork is often a challenge both for students and for professionals and it can have a great effect on the work culture in the team. Often the teams are not able to solve the challenge in the team with the tools they have available. In this study, data has been collected from two innovative teams – a business case with an innovative team in a large global company and a case with a group of students taking a large innovation course at the university. Based on interviews with the teams members from the two cases different tools for communication have been developed and tested. The solutions consists of a list of recommendations and the presentation of three solution designs ”Gif-Fun”, ”Challenge Road” and ”Quest Canvas”.

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1. INTRODUCTION

1.1 21st century skills & Interdisciplinary

The 21st century skillset is generally understood to encompass a range of competencies, including critical thinking, problem solving, creativity, meta-cognition, communication, digital and technological literacy, civic responsibility, and global awareness (for a review of frameworks, see Dede, 2010; Trilling, B. and Fadel, C. 2009). According to Dede (2010), the current workforce is not equipped to deal with the challenges of the 21st century and blames schools "classrooms today typically lack 21st century learning and teaching". Meaning students are expected to master the skillset during the beginning of their lives, if not, at the beginning of their professional lives.

To meet the need for 21st century skills, Expert in Teams (EiT), an interdisciplinary course at the Norwegian University of Science and Technology (NTNU), was developed (Veine et al.,2023; Sortland and Løje, 2019). NTNU's Experts in Teamwork course is compulsory in all master's programs and programs of professional study at NTNU and is offered to 2,500 students each year. About 100 members of the teaching staff are involved, and 200 learning assistants are employed each year (Sortland and Løje, 2019). EiT's method supports the learning of 21st century skills, in a facilitated active participatory setting. Meaning the teams learn as they go, supported by facilitators who are in turn supported and so on. The proverbial "village" (of help and support) is formed around each team member in what they literally call villages, where the teams have their bases (Veine et al., 2023).

In EiT students from different study programs are placed in interdisciplinary teams and the idea is that they will make use of different viewpoints and different competences to solve case problems for the involved companies.

1.2 Challenges with teamwork

The frustration from team members lacking 21st century skills can adversely affect productivity and well-being, leading to breakdowns in communication and hindering equal contributions from each team member (Oakley et al., 2004).

Tuckman (1965) presents a strategy model for team management, from team formation/building, conflict resolution and team performance. It can be difficult to know when to intervene in team dynamics and using Tuckman's model, it becomes clearer when a team needs support.

Expecting 21st century skills from the participants of teamwork, will invariably weigh differently on every individual, especially on the newer generations whom we already expect a lot, maybe too much, of today. A significant percentage of Millennials and Zoomers, the generation of most of the team members in the study, suffer from perfectionism and hold themselves to an incredible standard.

So while 21st century skills are desired, the reality is that people, in the described cases, were not equipped to handle anyone's, but their own needs. In the realm of innovative endeavors and within the collaborative framework of teams, the cultivation of constructive, open, empathetic, and reflective communication is a crucial factor (Veine et al., 2023). The challenges encountered in the collaborative sphere are not uncommon, with individuals grappling to establish themselves in teams, actively engage in the collective problem solving, while fostering a sense of inclusion. This study sought to explore the prospect of enhancing communication within innovation teams, unravelling the optimal timing and methodology for such improvements.

1.3 Wicked Problems

People are complicated, as individuals and in groups. Wicked problems mean that if a solution is implemented, it would immediately change how the participants experienced the developing conflict, and as such, mitigate the possible findings for further development. Thus, making iterations and development difficult.

The wickedness of the problem is also pressed upon by today's levels of feelings of inadequacy permeating the millennials and Gen Z's (Hjortkjær, C. (2024) who are described as lacking 21st century skills. Hjortkjær sees the decline in self-esteem, rise in feelings of inadequacy, accompanied by a perfectionist mindset, as the crisis of this generation.

1.4 Communication in teams

In this paper, we will investigate how the quality of communication in innovative teams affects work culture and conflict management. In the study, two distinct cases serve as important illustrations of the complexities surrounding communication in innovative teams. The first case delves into the dynamics of an innovative team of university students in a course at the university, the second a corporate innovation team in a global company with over 10.000 employees.

1.5 Conflict – how to handle conflict

Expect in Teams methodology demands facilitators observing the group dynamics over an extended period. The conflict is then facilitated, and the conversation is monitored, which means that someone has the power to tell you off if you're behaving out of line with constructive collaborative guidelines.

This is necessary if you want to teach people how to handle conflicts, because it forces them to deal with the conflict and their active role in it. As seen (preliminary observations, (Willemoës,, 2023) in the innovation teams, the only force maintaining the demand to deal with the situation was, for the students, a deadline for a delivery. But the innovation team didn't work like that, and deliveries were more personalised, meaning nobody had to adhere to constructive collaborative guidelines. When they didn't, it didn't negatively impact anything beyond the relationship of the people within the conflict, resulting in the rejected party becoming bitter and uncooperative.

The behavior described in the cases is not new to humanity or even impossible to understand, and in fact many theorists have come up with a litany of explanations and solutions. The behavior poses a problem because it is complex, multifaceted and not easily solved. Such is a problem described as "wicked problems" by Vermaas et al., (2020).

Initial observations highlighted the rapid formation of cliques within the groups, resulting in difficulty faced by individuals on the periphery with having their voices heard and opinions respected. This dynamic detrimentally impacted the overall workflow of the teams. Specifically, the lack of constructive conflict management, which is transducent to constructive teamwork, was noted "There is no constructive conflict management as seen in the theory of Tuckman, Brené Brown or EiT, in which open dialog, empathy and reflection are needed." (Willemoës, 2023)

So, the study posed the question "How can innovative teams optimise their ability to achieve flow in the face of conflict without neglecting each other's emotions, using gamification and the Expert in Teams methodology/approach?" Based on the findings, three design solutions were then developed and tested. When unable to add constructively to psychological safety within a team, the collaboration opportunities within the team diminishes.

2. METHODOLOGY

The university team was formed by pairs of students banding together and then finding a spot in a bigger formation of 6 people. The students had initially taken personality tests, but these hadn't been discussed or used in any meaningful way. The team was part of the course innovation pilot, which is a compulsory course for Bachelor of Engineering programmes af DTU.

The business team was formed, as most professional teams do, by employment, although a core group of team members had been employed a significantly longer time than the rest of the team.

The results were collected and analyzed as part of an exam project by Willemoës, 2023.

The empirical foundation of the study was established through 1:1 interview, observations of individuals and group dynamics, providing a comprehensive understanding of the communication, within the two innovation teams.

The interviews consisted of a total of 12 1:1 interview. 1 group interview with the university team, 1 group observation session with the business team and a spontaneous 1:1 interview within the business team.

The spontaneous 1:1 interview with the business team output was field notes. The planned sessions semi-structured interview guides had been prepared and voice recorded, with one exception being the group with the business team which was not recorded.

Semi-structured interviews formed the empirical foundation of the study, utilising Thematic Analysis formulated 3 overarching themes and 3 key problems. Solidifying the solution design with a combination of a problem tree and brainstorming.

The dataset then underwent a comprehensive Thematic Analysis, which led to the identification of eight different codes: Authority/Leadership, Personality Type, Maturity, Expectations, Psychological Safety, Conflict Management Skills, Motivation and Mood/Productivity. The eight codes crosswise formed three overarching themes: Personal Development, Project Execution and Power.

The scope was reduced to the Project Execution and, as much as possible, the Power theme.

Three key problems were identified: inner resistance towards interpersonal closeness, social exclusion or rejection of team members, and a discernible lack of workflow cohesion. The intricate relationship between these key problems and the essential 21st-century skills was unmistakable, with conflicting parties exhibiting a notable deficit in the skillset.

Theorists Brené Brown and Tuckman are, with EiT the underlying foundation of the solution design. With Brené Brown's shame research it is possible to take psychological safety into account when designing for people, using Tuckman's model for group development in teamwork a timeframe for the solution design is scoped for the forming and storming phase and lastly EiT's framework for facilitating innovative teamwork highlights what's currently lacking, corroboration wise, from the situations within the two teams.

In the last phase, Gamification was used to shape the 3 solution designs. The result was three concepts "Gif-fun", "Challenge Road" and "Quest Canvas".

3. RESULTS

The 3 solution designs are initial iterations of potential solutions, and will require iterative development, in collaboration with future struggling teams, to solve any of the observed problems.

Gif-fun is an icebreaker exercise to any team meeting, attempting to relax everyone towards the proverbial collaborative table. The goal of the exercise is to make the other team members laugh, resulting in a larger willingness to open up to each other. Gif-fun serves as preparation for the storming phase were the team needs psychological safety and willingness to be open in order to progress to the norming phase.

Challenge Road serves as a whistleblower system and an anonymous way to ask for help, within and outside of the team, with methods from conflict management.

The participant is guided through a binary questionnaire which ends with targeted advice for seeking help inside or outside the team and informing the participants of possible solutions. The goal is to empower the team members who are being ignored or disregarded, by empowering team members who do not feel psychologically safe, included or seen, in a safe and supportive and acknowledging social and racial bias. When the team enters the storming phase, support is needed to constructively enter the norming phase.

Quest Canvas (Figure 1) serves as a project management tool for enhancing team spirit, encourage praise, support, and transparency within the team.

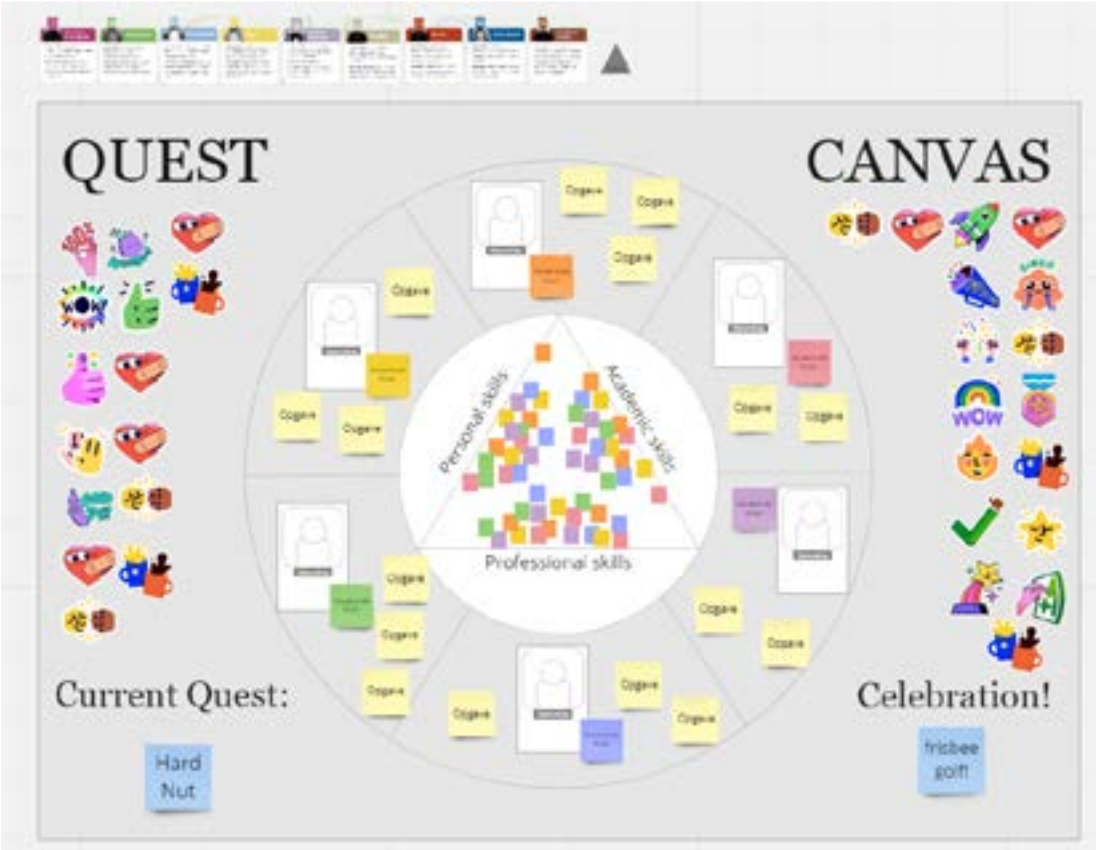

Figure 1: First iteration of Quest Canvas (Willemoës, 2023)

The Quest Canvas (Figure 1) proposed by the study (Willemoës,, 2023) provides an addition to the project management toolset. On the canvas is a circle with a space for each team member. The team member space holds a profile card, tasks and current role within the team. In the center of the team circle, is a “skills triangle” dividing every members skills into 3 categories “Personal”, “Academic” and “Professional”. On the left and right sides of the canvas are celebration stickers, the current focus of the project and how to celebrate the next important milestone within the team. The profile cards can be customized with personality tests and fun exercises (e.g. everyone draws themselves as superheroes)

All three designs are attempts at mitigating aspects of wicked problem theory, for the least invasive and subconscious solution as possible.

The solution designs were tested with another innovation team from the university. Feedback from Gif-fun was positive, though some unintentional consequences were identified such as too much “downtime” looking for gifs and unfunny gifs not landing with the team resulting in awkward silence. Quest Canvas was presented but would have to be tested for a time to form the basis for iteration. Feedback from Challenge Road were complicated to iterate on, the teams were so small that anonymity was practically impossible. Giving and receiving feedback in a group was difficult as the members weren’t trusting each other’s reactions to be constructive. One of the testers said she would withdraw socially and psychologically from a team “as much as she was forced to” in order to, function within the team, to deliver on time. The feedback further stresses that psychological safety is key in collaboration and complicated to achieve, without outside facilitation.

4. SUMMARY AND ACKNOWLEDGMENTS

The attempt to improve communication in innovative teams serves the purpose of facilitating innovation but does so by improving relationships within the team. The 3 solution designs attempt just that, within the confines of the situations described.

Psychological safety within the teams is key for constructive communication and sharing ideas, and everyone needs to approach the proverbial table for that to become possible. Thank you to the 3 teams who talked about their struggles and wishes in the hopes that it will get better when collaborating in high intensity teamwork.

The study is only based on two teams, but it shows that when subgroups form within a team, open and constructive communication suffers. Next step will be to iterate on the concepts, through more testing and interviews. Forming a framework for self-facilitation and collaboration.

The work presented is in the early stages. In future studies a broader testing of the tools in diverse educational settings could be required. Furthermore, collecting more feedback from uses in different contexts to further develop guidelines and to show how the tools meet diverse needs.

REFERENCES

Braun, V., and Clarke, V. (2012). Thematic analysis. *In APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological*. (pp. 57–71). American Psychological Association. https://doi.org/10.1037/13620-004

Dede, C. (2010). Comparing frameworks for 21st century skills. *In J. Bellance, & R. Brandt (Eds.), 21st century skills: Rethinking how students learn* (pp. 51-76). Bloomington, IN: Solution Tree Press.

Trilling, B. and Fadel, C. (2009). *21st Century skills: Learning for life in our times*, San Francisco, Jossey-Bass.

Veine, S., Anderson, M. K., Skancke, L. B. and Wallin, P. (2023). Educating learning assistants as facilitators: Design challenges and Experiences of Practice. *Journal of Experiential Education*, 46 (4), 491-521

Sortland, B. and Løje, H. (2019). Implementing 21st century skills in education at NTNU and DTU. *Proceedings of the 47th SEFI Annual Conference* 2019, pages: 270-277, 2018, Brussels. Presented at: 47th SEFI Annual Conference, 2019, Budapest, Hungary.

Oakley, B., Felder, R. M., Brent, R., and Elhajj, I. (2004) *Turning student groups into effective teams*

Tuckman, Bruce W (1965). Developmental sequence in small groups *Psychological Bulletin*. 63 (6): 384–399.

Hjortkjær, C. (2024). Utilstrækkelig (1.edition). Klim.

Willemoës, S. L. V. (2023). Improving communication in innovation teams, Forbedring af kommunikation ved innovationssamarbejde. DTU Department of Engineering Technology and Didactics.

Vermaas, P. E., and Pesch, U. (2020). Revisiting Rittel and Webber's Dilemmas: Designerly Thinking Against the Background of New Societal Distrust. She Ji: The Journal of Design, Economics, and Innovation, 6(4), 530–545. https://doi.org/10.1016/j.sheji.2020.11.001

A Holistic Approach for "Teaching-to-learn" Professional Competencies in Engineering Education

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ABSTRACT

Facing global challenges, as formulated in the UN Sustainable Development Goals, requires engineering efforts. For this purpose, it is crucial to reflect on the role and responsibilities of engineers for society and environment. Here, engineering education's central contribution must be to educate competent engineering professionals. However, education often focuses on technical knowledge and competencies, instead of considering social or professional competencies as intertwined with the engineering profession. In this practice paper, a holistic teaching and learning approach is presented, aimed at fostering engineering students' reflection on competencies relevant for solving global challenges and on their engineering profession. By combining different teaching and learning methods in the context of active learning students are in the centre of the course and develop

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teaching approaches for competency development in their education. Moreover, students not only analyze learning objectives of engineering study programs, but also develop own teaching approaches to address deficits in terms of competencies. Students' elaborations and feedback show that they acquired and strengthened especially self-reflection, critical thinking, problem solving, teamwork and communication skills.

1 INTRODUCTION

Engineering faculty and educators often differentiate between technical and non-technical competencies (Beagon and Bowe 2023; Jesiek et al. 2017; Trevelyan 2010a), which leads to students adopting this view and an education which often does not consider technical and non-technical competencies as "inextricably intertwined" (Trevelyan 2009, 1). Moreover, engineering graduates enter the workplace with misinterpretations and misunderstanding about engineering practice, as their educational preparation do not align with the expectations of their jobs (Korte et al. 2015). Although "social interactions lie at the core of engineering practice" (Trevelyan 2010b, 175), these aspects are often not considered as "real engineering" (Trevelyan 2010a). This narrow view is, correspondingly, often mirrored in students' motivation and acceptance in learning social or professional competencies (Brunhaver et al. 2018; Korte et al. 2015; Trevelyan 2010a).

This perspective of separating the social and technical seems downright contradictory, if we assume that engineers can and must contribute to solving global challenges, such as formulated in the UN Sustainable Development Goals. Such contributions require a holistic perspective and a reflection on social and global challenges. Engineering is crucial for the achievement of these goals, as engineering design, technologies and innovations are shaping the world (UNESCO 2021). In their report *Engineering for Sustainable Development*, UNESCO present several case studies, approaches and solutions to highlight the responsibility engineers have in contributing to sustainable development. One chapter in the report deals with engineering education for sustainable development, which is essential for the development and acquisition of competencies relevant to sustainable development (Beagon et al. 2022; Kolmos 2021). For this purpose, teaching and learning approaches are required that enable engineering students to develop corresponding competencies and to reflect on their role and responsibility as engineers to contribute to sustainable development.

The context for this practice paper is a master's course on "competencies in engineering sciences to solve global challenges" at a technical university in Germany. Taking into account the above-described reported tension between technical and "non-technical/social/other" competencies, this paper presents a holistic teaching and learning approach to sensitize engineering students to their professional identity. A special focus is set on engineers' responsibility to contribute to sustainable development. The inspiration for the course concept, which is presented in detail below, came from the paper *Engineering Students Need to Learn to Teach* by James Trevelyan (2010a). Stating that "engineering students themselves need to learn to be effective teachers in order to become effective engineers in practice”, Trevelyan argues that learning effective teaching skills requires social skills that are crucial for engineering practice.

In the following, the course design will be presented in terms of the teaching and learning approach, the intended learning outcomes and content as well as the examination task and assessment criteria. Furthermore, the course results will be presented and discussed.

2 COURSE DESIGN

“Competencies in engineering sciences to solve global challenges” is a recurring, elective 4 ECTS seminar at RWTH Aachen University in Germany. The seminar is aimed at master’s students from Environmental, Civil and Industrial Engineering. A previous version of the course is presented in (Winkens and Leicht-Scholten 2022a), the concept was then adapted in the winter term of 2022 and 2023. The first author of this study is the instructor of the course. Due to the course concept it is limited to a maximum of 20 students. The course is not only *about* the concept of competencies, but also *for* the development of competencies, which are holistically integrated in the whole course concept. This aims at students reflecting on their own competencies as engineers and placing them in a sustainability-related context.

2.1 Teaching and Learning Approach

Based on an active and constructivist learning approach, several teaching and learning methods and activities are applied and combined in the course to provide a student-centered and interactive learning environment. Table 1 presents an overview of these. The overall theme is *competencies,* which constitutes not only the content of the course, but is also mirrored in the methods used.

Table 1. Teaching and Learning Methods and Activities in the Course

Method/Activity	Description
Lectures	Research-led lectures are held by the instructor to give students an overview of current discourses on the topic of competencies in engineering (education). Within the lecture sessions, students collaboratively discuss current research topics and trends.
Research-based	The course has a research-based design. For this purpose, research questions are formulated by the instructor that students approach collaboratively as part of their exam. Furthermore, the students develop research skills, especially in qualitative research.
Collaborative Learning	Students work in small groups throughout the course. During the lecture sessions there are various smaller group discussions and for the examination coursework they work in groups. All group learning activities are structured and monitored by the instructor.
Think-Pair-Share	Think-pair-share provides both individual thinking and sharing ideas/perspectives (Felder and Brent 2009). A scientific paper is to be prepared for each session. Students are to prepare the paper independently (Think), discuss it with other people at the beginning of the following session (Pair) and afterwards present it to the plenary (Share).

(Peer) Feedback	Through continuous and reciprocal feedback, students reflect on their learning process and performance, as constructive feedback can improve student learning performance (Das 2023). Students give feedback to the other groups on their work, feedback to the teacher on the course concept, and anonymous peer feedback to their group members on their teamwork, commitment and performance. For the peer feedback, they receive instructions to constructively formulate criticism. Students also receive both oral and structured written feedback from the instructor on their work, i.e., the perspectives of all actors involved in the learning and teaching process are considered.
Reflective Writing	To foster (self-)reflection and critical thinking among students, reflective diaries are used. These were inspired by and adapted from Wallin et al. (2016); and Wallin and Adawi (2018). By answering weekly guiding questions, students reflect on their learning process and experience which also enables the instructor to understand them better. Moreover, the students can submit voluntary critical reflection papers that relate to self-selected topics from a session. This is also an opportunity to receive bonus points for the final grade. Students get feedback by the instructor for both reflection activities.
Self-Assessment	To not only reflect on their competencies and attitudes, but also to reflect on their learning process, students complete a survey before and after the course. The results are presented to the students and discussed with them.

These methods are presented transparently to the students, and it is explained to them why they are relevant and used in the course.

2.2 Learning Outcomes and Content

The course is constructively aligned with its content and assessment (Biggs and Tang 2011). In terms of intended learning outcomes, after completing the course students should be able to:

- **Assess** various competencies with regard to their relevance for social and sustainable technology design
- **Reflect** on the relevance of socially responsible and sustainable technology design for solving global challenges
- **Reflect** on the relevance of responsible and sustainable technology design in the context of their studies and for their later professional life
- **Evaluate** self-generated research results with regard to a research question based on a qualitative content analysis
- Independently **develop** ideas and problem-solving skills regarding an integration into a university teaching context

With regard to professional competencies, the course aims especially at fostering analytical, problem-identification and -solving, creative and critical thinking, teamwork and collaboration, communication, (self-)reflection and learning skills.

The individual lecture sessions are divided into the following themes:

- **Introduction**: What global challenges need to be overcome in the context of sustainable development? What role does education for sustainable development play in this? And why is it relevant for engineers?

- **Competencies and Engineering Education**: What does competency-based education mean? What challenges does this pose for engineering education? What discrepancies arise with regard to the acquisition of competencies?
- **Engineering Identity**: What factors define technical sciences/engineering? What role profiles can engineers have? Why do students decide to become engineers? What competencies characterize engineers?
- **Shaping Competency** („Gestaltungskompetenz“): Why are topics such as sustainability, ethics and responsibility relevant for engineers? Which competencies are relevant in the context of sustainable development? To what extent do engineers bear responsibility for lived and built environment?

These themes are presented and discussed in the individual sessions. Each topic is introduced through current research from the field of engineering education. This enables students to familiarize themselves with international discourses on the subject and at the same time to reflect on their own (previous) acquisition of competencies.

2.3 Examination

The examination is divided into three parts, two collaborative parts and one individual part. The collaborative parts are graded, the individual one is not, as it is about students' personal reflection.

Students work in groups of around five people to answer the following research questions: *Which competencies for solving global challenges are addressed in selected engineering degree programs? What are deficits in acquisition of competencies in the individual degree programs and in a university comparison? Which teaching and learning concepts are suitable for addressing these deficits?*

In the first collaborative part, students analyze the qualification/learning outcomes of selected engineering degree programs (M.Sc.) of European universities with regard to competencies for solving global challenges. In particular, the students are asked to work out *deficits*. The preliminary assumption that there *are* deficits in the learning outcomes of the degree programs was made, as the students analyze and evaluate the competencies more critically as a result. Moreover, based on previous research, it was already known that learning outcomes in engineering degree programs are formulated very heterogeneously (Winkens and Leicht-Scholten 2023). In order to delimit the scope appropriately, the task is restricted at various points: For the comparison, the students have to select two universities from the European IDEA League (Chalmers University of Technology, Delft University of Technology, ETH Zurich, Polytechnic University of Milan, RWTH Aachen University), as it represents a strategic alliance between five leading European university of science and technology (see https://idealeague.org/). Furthermore, they must decide which of the respective degree programs are engineering programs. They also have to decide on a competency related to the course content to analyze. This decision has to be scientifically justified and motivated. Based on the examination documents provided by the universities, they then qualitatively analyze the qualification/learning outcomes formulated there for the individual degree programs and compare the results of the respective universities. They must consider the following key questions in their analysis: *How far are the chosen competencies relevant for engineers to solving global challenges? Are they actual competencies or a description of the program* *content? How are the competencies presented/formulated? To what extent are they included in the study programs? What differences arise between the individual study programs? Are there any differences/conspicuous features when comparing the two universities?*

In the second collaborative part, inspired by James Trevelyan (2010a) paper *Engineering Students Need to Learn to Teach*, the students develop a theoretical teaching and learning concept based on the deficits analyzed in the first part. The concept should relate to the duration of one semester, explicitly address engineering students and aim to improve engineering education. The students are free to decide on the specific target group (e.g., bachelor or master, individual disciplines or multidisciplinary), the course size and any content requirements. The application of constructive alignment is central, i.e., they must define learning outcomes, consider how these can be achieved, what content is necessary for this and how these can then be assessed. The task is not about specific time scheduling, but about a sound concept. The groups present their concept creatively and freely through a screencast aimed at convincing the other students in the course of the suitability of the teaching concept.

Students can arrange consultation hours with the instructor at any time. However, each group must arrange at least one consultation hour in the middle of the semester to ensure that their work on the assignment is going in the right direction. This mandatory consultation hour has proven to be effective in the past, as otherwise only those students who are already very motivated will request feedback on a voluntary basis (Winkens and Leicht-Scholten 2022b).

The students submit their work from both parts as part of a screencast lasting a maximum of 30 minutes. The videos of all groups are made available to all students. These are then critically discussed in a joint discussion session. For this purpose, the students were given questions to guide their feedback: *What do you like about the teaching concept and why? What are the strengths of the concept? What are weaknesses? For what reasons would you (not) choose the course yourself? To what extent is the concept suitable for addressing the respective competencies? To what extent has constructive alignment been taken into account? Do the teaching concept and target group align? What suggestions for improvement would you give to the other group? What possible extensions would you include in your own concept?* After this session, the students were asked to integrate the feedback in a final report, reflect on it and explain what they would have done differently in retrospect. This report serves as documentation of their group work and their work steps; it also contains a reflection on the group work (what worked well and what less and why?). This more detailed documentation aims to make it easier for the teacher to understand how the students have developed their task.

The assessment is mainly based on the quality of the content of the results (consideration of the key questions, scientific soundness, comprehensible analysis, stringent argumentation/evidence/reasoning). Further assessment criteria are the completeness and comprehensibility of the documentation of the procedure and the discussion and reflection of the results. The assessment criteria were presented and explained to the students at the beginning of the course.

The individual part includes the reflective diaries and the peer feedback, which are submitted individually by the students. For the peer feedback, the students complete a survey on all their group members, with items relating to communication, teamwork and commitment. They also give free feedback to each of them, which must be formulated respectfully and constructively. The students also have to assess themselves. An evaluation of the feedback and a comparison with the self-assessment is made available to the students individually.

3 RESULTS AND DISCUSSION

In the context of a scientific evaluation various methods and indicators are used and combined to measure the success of the course and to assess whether the intended learning outcomes have been achieved. This includes a standardized evaluation provided by the university, the pre-post survey on competency acquisition, the learning diaries, the students' elaborations and a final joint feedback session, in which the seminar concept is discussed with the students. In the following, we summarize and discuss the most important aspects of these feedback methods.

In general, the course was evaluated very positively in both semesters. Students especially highlighted the groupwork and the discussions in the sessions, the requirement to actively engage and the opportunities for (self-)reflection. Concerning the course contents, they especially valued the sessions on engineering identity and responsibility, as they led them to reflect on their role and responsibility as engineers by asking "the simple and banal question: 'Why am I an engineer?'", to cite one student. In some learning diaries, the students' previous insecurity on their sense of engineering identity became apparent, as one female student pointed out:

> The discussions encouraged me to think about what kind of engineer I want to be and where I see my role. I had previously given a lot of thought to the fact that I don't fit the stereotypical image of a female engineer, which made me feel like I hadn't chosen the right field of study for me. I took away from this course that it is ultimately up to me how I interpret engineering for myself and that has given me a lasting good feeling.

Moreover, they expressed surprise that the topic of "competencies in engineering (education)" is so present and relevant globally, while at the same time expressing a lack of understanding that it seems to be represented so little in their education.

At the same time, in the first iteration of the course in winter 2022, some students criticized the "vague topic" of the course:

> Even though it is an extremely important topic, it is not really 'hard facts' that are learnt.

Going along with the following statement:

> Unfortunately, no specialized knowledge was imparted. The focus was on acquiring non-technical competencies. These were taught well. I think my personal self-reflection in particular improved as a result of this seminar. The unit on engineering identity in particular made a lasting impression on me and led me to scrutinize my self-image again and see which skills in the area of 'being an engineer' I may still need to acquire in the future.

The student quoted here is completely right in his statement that no technical knowledge was taught, as this is not the aim of the seminar. However, the statement illustrates that the (perceived) lack of this technical knowledge is perceived as negative, which mirrors the often-reported discourse in engineering education literature about the (misleading) differentiation between “soft versus hard” skills (Berdanier 2022; Trevelyan 2010b) that is also adopted by the students. As a result, the topic on technical versus “other” competencies was proactively addressed in the following semester in 2023 and discussed with the students, starting with Berdanier’s (2022) statement on “A hard stop to the term ‘soft skills’”. In 2023, no comparable criticism was expressed by any student; on the contrary, the relevance for professional practice was emphasized several times, for example by one student:

> The course imparts knowledge that is not just theoretical but can be applied directly in the course and later in professional practice.

In terms of the acquired (or strengthened) competencies, students highlight self-reflection and critical thinking – both in terms of their engineering profession and in terms of their personal development –, teamwork, communication, problem solving and self-organization. The answers to the pre-post survey are similar in both semesters and show that students self-assess the development of their competencies positively, as, for all items, the competencies were ranked higher after than before the course. This applies not only to specialist knowledge about, e.g., sustainability or the concept of competencies, but also to social and personal competencies such as presentation skills, problem-solving, teamwork and conflict resolution.

The individual learning diaries illustrate the aspects of self-reflection in terms of competencies as well as the reflection on the personal role as engineers, as two students conclude:

> The most important thing for me was realizing what role I have as an engineer and to what extent the engineering skills I perceive as standard differ from the skills required to fulfil social responsibility. In professional life in particular, it is important to apply the skills I have learnt in order to prevent conflicts of responsibility. So that I can continue to have such experiences and develop further, I would ask myself more often in future what I make which decisions for in my job and would reflect on my training in a different way. The course helped me in particular with my self-reflection.

> The course has given me a different and more diverse awareness of my responsibility as an engineer. Regular civil engineering courses do not talk about the competencies of engineers and their responsibility towards society. However, it is very important to be aware of the social and ethical duties we have as engineers. In addition, critical self-reflection was encouraged by the topics covered in the course and I questioned myself and some of the decisions I made in my engineering degree program.

Students’ coursework was overwhelmingly positive. The groups each independently defined and analyzed different foci of competencies for solving global challenges, i.e., critical thinking, problem solving, interdisciplinary thinking/working, intercultural competency, teamwork and communication. In most cases, they scientifically substantiated and argued why they chose this focus and why it is relevant for engineers facing global challenges. The self-developed teaching and learning concepts were also very creative and addressed the competency deficits in their respective degree programs. In some cases, there were weaknesses with regard to the consistent implementation of constructive alignment, in other cases expectations were fulfilled as the students precisely formulate learning outcomes and constructively aligned their concept. As explained in Section 2.3, students' elaborations were reviewed and discussed in a joint session. It was noticeable how critically and profoundly the students dealt with each other. As a result, the majority of the strengths and weaknesses of the concepts that the instructor had identified were also addressed by the students. This demonstrates an in-depth examination and understanding of the topic.

However, in all feedback activities it became apparent that the groups had several challenges to deal with. Especially time management in the context of students' groupwork was frequently mentioned, where the obligatory consultation hour was considered to be helpful to structure work around the given time constraints. Moreover, students pointed out challenges in dealing with scientific literature and difficulties in the qualitative analysis of learning outcomes, where they sometimes tended to analyze quantitatively, as this seemed more intuitive to them. The formulation of constructive feedback to group members was cited as a further challenge. At the same time, however, they also saw this as very valuable, with the knowledge of receiving feedback from their peers being a relevant motivating factor for engaging in group work. Overall, it was found that the feedback was mostly constructive and appreciative.

4 CONCLUSION

This practice paper presented a holistic teaching and learning approach for dealing with and reflecting on competencies in engineering education. By combining different topics related to engineering for sustainable development and different teaching and learning methods in the context of active learning, students reflect on both their professional development as future engineering practitioners to become “real engineers” and on their personal development. The task of developing a theoretical teaching and learning concept has helped students not only to engage more intensively with competencies, but also to reflect on how they can teach them to others. We are aware that the purely theoretical conceptualization and presentation of an actual teaching experience is not sufficient, but this was not feasible for the students due to limited resources and workload. However, there are plans to integrate virtual reality into the concept so that students can then carry out their concepts in a virtual space. Furthermore, this paper focused on the presentation of the course concept and not on a well-founded qualitative or quantitative evaluation of the existing data. In-depth interviews with students may be a useful next step to assess their learning experience in more depth.

Students' elaborations and feedback have shown that they acquired and strengthened especially self-reflection, critical thinking, problem solving, teamwork and communication. Moreover, they highlighted the relevance of the topic of engineering identity for themselves, as the course has helped them to shape and to define it in the first place, but also to question and reflect on their engineering identity. Overall, the course concept has shown to be effective and successful, and underlines that “teaching to learn” is an effective educational approach to strengthen engineering students' acquisition and recognition of professional competencies.

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REFERENCES

Beagon, U., K. Kövesi, B. Tabas, B. Nørgaard, R. Lehtinen, B. Bowe, C. Gillet, and C.M. Spliid. 2022. "Preparing engineering students for the challenges of the SDGs: what competences are required?" *European Journal of Engineering Education* 48 (1): 1-23. https://doi.org/10.1080/03043797.2022.2033955.

Beagon, U., and B. Bowe. 2023. "Understanding professional skills in engineering education: A phenomenographic study of faculty conceptions." *Journal of Engineering Education* 112 (4): 1109-1144. https://doi.org/10.1002/jee.20556.

Berdanier, C.G.P. 2022. "A hard stop to the term “soft skills”." *Journal of Engineering Education* 111 (1): 14-18. https://doi.org/10.1002/jee.2044214.

Biggs, J., and C. Tang. 2011. *Teaching for quality learning at university*. 4th ed. Maidenhead, UK: Open University Press.

Brunhaver, S.R., R.F. Korte, S.R. Barley, and S.D. Sheppard. 2018. "Bridging the Gaps between Engineering Education and Practice." In *U.S. Engineering in a Global Economy*, edited by R. B. Freeman and H. Salzman, 129–163. University of Chicago Press.

Das, D.K. 2023. "Exploring the impact of feedback on student performance in undergraduate civil engineering." *European Journal of Engineering Education* 48 (6): 1148-1164. https://doi.org/10.1080/03043797.2023.2238188.

Felder, R.M., and R. Brent. 2009. "Active learning: An introduction." *ASQ Higher Education Brief* 2 (4).

Jesiek, B.K., N. Trellinger, and S. Nittala. 2017. "Closing the Practice Gap: Studying Boundary Spanning in Engineering Practice to Inform Educational Practice." *2017 IEEE Frontiers in Education Conference (FIE), Indianapolis, IN*. https://doi.org/10.1109/FIE.2017.8190503.

Kolmos, A. 2021. "Engineering education for the future." In *Engineering for Sustainable Development. Delivering on the Sustainable Development Goals.*, 121–126. UNESCO.

Korte, R., S. Brunhaver, and S. Sheppard. 2015. "(Mis)Interpretations of Organizational Socialization: The Expectations and Experiences of Newcomers and Managers." *Human Resource Development Quarterly* 26 (2): 185-208. https://doi.org/10.1002/hrdq.21206.

Trevelyan, J. 2009. "Engineering Education Requires a Better Model of Engineering Practice." *Research in Engineering Education Symposium 2009, Palm Cove, QLD*.

Trevelyan, J. 2010a. "Engineering Students Need to Learn to Teach." *40th ASEE/IEEE Frontiers in Education Conference, Arlington, VA, USA*. https://doi.org/10.1109/FIE.2010.5673616.

Trevelyan, J. 2010b. "Reconstructing engineering from practice." *Engineering Studies* 2 (3): 175-195. https://doi.org/10.1080/19378629.2010.520135.

UNESCO. 2021. *Engineering for Sustainble Development*. Paris, France: UNESCO.
Wallin, P., T. Adawi, and J. Gold. 2016. "Reflective diaries – a tool for promoting and probing student learning." *12th International CDIO Conference, Turku, Finland: Turku University of Applied Sciences*.
Wallin, P., and T. Adawi. 2018. "The reflective diary as a method for the formative assessment of self-regulated learning." *European Journal of Engineering Education* 43 (4): 507-521. https://doi.org/10.1080/03043797.2017.1290585.
Winkens, A., and C. Leicht-Scholten. 2022a. "Teaching Essential Competencies for Social and Sustainable Engineering Design – Case Study of a Research-Oriented Master's Seminar." *International Journal of Engineering Education* 38 (3): 600–610.
Winkens, A., and C. Leicht-Scholten. 2022b. "Local Resilience Strategies for COVID19 – A PBL Engineering Case Study." *18th International CDIO Conference, Reykjavik, Iceland: Reykjavik University*.
Winkens, A., and C. Leicht-Scholten. 2023. "Competencies for designing resilient systems in engineering education – a content analysis of selected study programs of five European technical universities." *European Journal of Engineering Education* 48 (4): 682-706. https://doi.org/10.1080/03043797.2023.2179913.

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AI-Driven Digital Competencies in Engineering Education: A Notebook-based Teaching Approach

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ABSTRACT

In this manuscript, we explore the integration of generative AI into notebook-based teaching in engineering bachelor education. We describe a prototypical educational framework where Jupyter Python notebooks form the core of all teaching and learning methodology. This eliminates traditional lectures and enables interactive, hands-on learning. The manuscript details how the course interweaves programming concepts with engineering problems, using real-life applications to foster a deep understanding of digital tools and AI-supported programming among students. We highlight the integration of Large Language Models (LLMs) like chatGPT into the workflow, as a progressive approach to stimulate students to be part of the rapidly evolving technology. The implementation of AI is discussed along 5 typical dimensions of practical programming. We emphasize the role of interactive notebooks in creating a dynamic and engaging learning environment that comprises a playground for generative AI. By incorporating AI-assisted programming, the course aims to streamline the learning process, in particular outside of class in home assignments, to enhance problem-solving skills, and to prepare students for the future challenges of life-long learning in engineering. Through this innovative educational model, students not only learn programming and engineering principles

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but also how to effectively integrate AI tools into their workflow, equipping them with the skills necessary for success in their further digital education.

1 INTRODUCTION

Digital competences are increasingly becoming a key factor for a successful engineering education. They enable students to be innovative and productive at the same time to succeed in an increasingly globalized and complex working environment. The classical frontal teaching scenario in lectures is unfortunately less suitable to build up digital competences, as they require a high degree of individual involvement and practical experience. At the same time, competences in digital learning need to be taught in a very early stage of studies, so students can benefit throughout their studies early on. A course about digital competences in engineering raises the following questions: Can today's universities offer each student during every Bachelor class with large student sizes an educative computer lab to individually explore numerical concepts, experience the effects of parameter choices on physical problems or engineering applications, and thus learn and experience principles of programming and digital tools while exploring engineering topics? Is it possible to address today's diversity of digital competences, including the application of Large Language Models (LLMs) while providing the cohesion and fundamental perspective Bachelor students need in a course?

In a first-year course on Digital Engineering (120-80 students, 3 ETCS), we meet these challenges by interlinking programming concepts with real-life problems, interactive web-based tools with autodidactic learning, and individual sense of achievement with group progress. The course starts as a programming course, embedding mathematical methods, but in its second part shifts towards forming general civil engineering skills. Python Jupyter notebooks are without exception forming the core of the teaching and learning experience. Consequently, no additional lecture slides or scripts are provided, since everything is generated from the collection of notebooks. This allows students to focus exclusively on working and learning with notebooks during lectures, exercises, and home assignments up to the final exam. Due to the use of Jupyter notebooks, everything is interactive, and students explore concepts in a playful way by versatile hands-on activities that are embedded into their notebooks.

The upraising of AI-based LLMs like openAI's chatGPT and others results in a controversial discussion on their role in university education (Memarian and Doleck 2023, Pradana et al. 2023, Balabdaoui et al. 2023, Garrel et al. 2023). The way we teach and learn digital competences in the future will change drastically, and some scholars even question the need to learn classical ways of programming at all. (Anagnostopoulos 2024). About 50 years ago, we saw the introduction of electronic calculators at universities, which meant freeing teaching from annoying, repetitive, time-consuming calculations. This enabled lecturers to spend more time teaching the essential subject-related skills. 20 years later, programmable calculators also solved eigenvalue problems, inverses of matrices or other error-prone problems that had devoured lecture, exercise, and examination time. As a result, the focus on core competencies could be further increased. LLMs represent an even bigger step. Within one year, the way we solve problems with computers has fundamentally changed due to the widespread use of LLMs. The speed at which new developments are introduced has even further increased to an incredible extent. Today, it is more than foreseeable that LLMs will quickly change the nature of digital skills and how they are taught in a drastic way. As a consequence, skills on productive work with LLMs in engineering applications have to become anchored in the basic studies. Thus, it has to be part of the digital skills of bachelor students (Muhsin 2023, Mollick and Mollick 2023).

In this manuscript we first describe the consistent notebook-based teaching and learning approach for a digital engineering course based on Python. We sketch the topical choice and draft the selected Jupyter notebook-based eco-system used in lectures and for self-study. Subsequently, we explain the AI-integration into the course. In the results section we explain the planned evaluation of the effect on student performance and finally we summarize the key points of the manuscript.

2 IMPLEMENTATION

Our approach is tailored on educating Bachelor students during their first year at the university, preferably after a first course in programming. The aim is not to educate software engineers or programmers, but to provide solution paths to practical engineering problems with Python. Python was chosen as reference language for the bachelor studies, due to its wide distribution, its potential, wide applicability, and open-source philosophy. Any approach chosen has to guarantee:

- A high hands-on part to practice reading - completing – writing – and checking of code,
- teaching cross-topic basic knowledge of relevant digital skills,
- encouragement for self-taught ways of working and finding solutions,
- empowerment of students to benefit from digital resources,
- develop students' digital problem-solving skills at an early stage,
- implementation of AI-assistance in the entire workflow.

These goals can be achieved by our notebook-based teaching approach.

2.1 A consistent notebook-based teaching and learning environment

Our teaching concept is visualized in Fig.1. We created a consistent web-based learning environment entirely based on interactive Jupyter Python notebooks of different nature, like lecture-, exercise-, and assignment notebooks that sequentially build on each other. All utilized programs and packages are open-source and run in a web-based Jupyter-Lab instance. Upon start-up of the instance, all new relevant material is pushed into the respective home directories from a git repository. This allows students to work on the course from anywhere on any platform with a simple browser and without the need for any local data storage and installations. The core content is interwoven with various embedded student activities, guaranteeing a high degree of cognitive activation due to interactivity. Additionally, notebooks comprise various tools for formative assessment and feedback, like embedded links to Moodle quizzes, classroom interaction via Speakup (SpeakUp), and multimedia content, when beneficial. Furthermore, we provide cohesion over multiple topical modules by providing tools to students that enable them to generate their lecture and exercise script based on their individually edited copies of all notebooks at any time and progress. To address different learning styles of students, we provide a script generator. This allows students to individually select topics for their scripts by excluding notebooks or collapsing notebook cells, or to extend it by own notes that are compiled into the pdf lecture notes. To achieve this, PyLaTex (Fennema-Nio 2023) is used in combination with a custom wrapper python script to obtain a consistent document.

During lectures and exercises, students work exclusively on their copy of the notebooks and progress all together with the lecturer, who is teaching from the notebook itself, run in presentation mode. As a consequence, students can focus exclusively on the notebooks as their only source from where lecture notes and lecture slides are generated. Weekly home assignments allow the students to consolidate their knowledge and earn bonus points in the final exam. To be able to cope with the work load from grading home assignments, those notebooks make use of an auto-grading procedure based on NBgrader, a tool that facilitates auto-grading assignments in the Jupyter notebooks (Jupyter et al. 2019, Brichet 2024) (see Fig.1). Our tool embeds Moodle assignments into the auto-grading environment. It automatically corrects all handed in notebooks by running test cases, providing individual feedback.

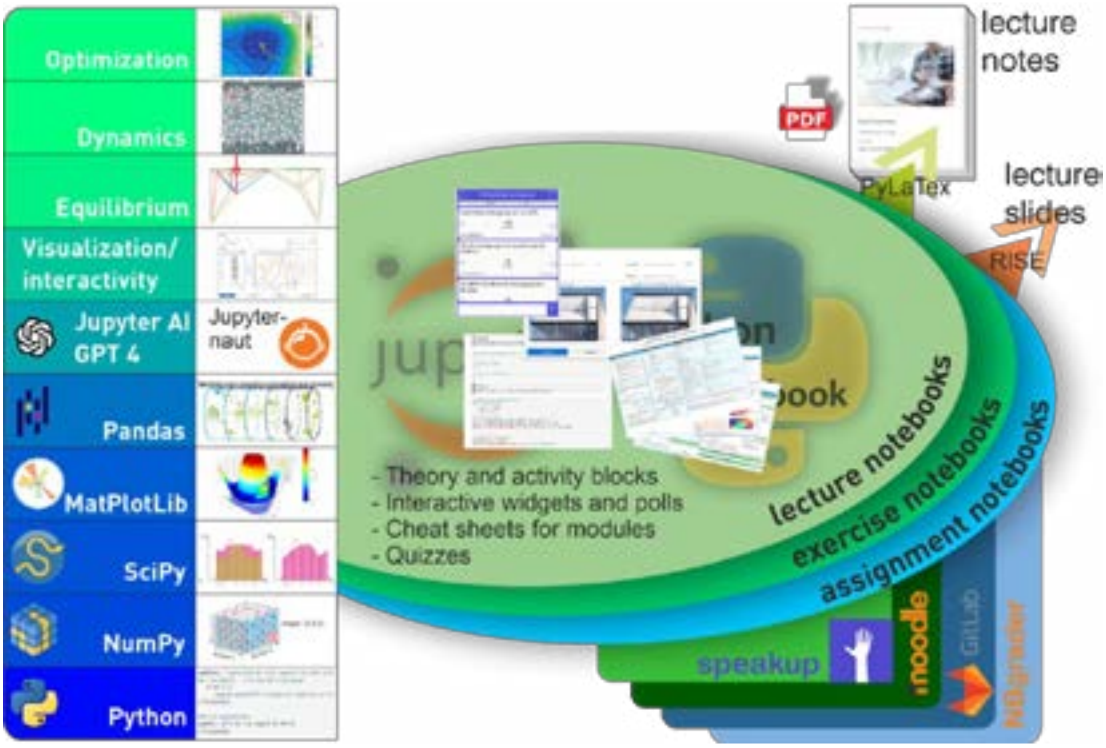

Figure 1.Scheme of modules and Jupyter notebook-based eco-system for lectures.

We build up diverse digital competencies in Python programming systematically, while exploring different aspects of engineering. Typical interactive Jupyter notebooks consist of two to three theory blocks, where key concepts are explained and up to three activity blocks, where the students apply the explained concepts, e.g., by complementing Python code or experiencing the effects of parameter changes in numerical models in a guided “playful” way. Exercises follow an identical pattern, with key concepts being repeated on practical examples from engineering. As an example, we investigate a model structure from various perspectives like time series analysis of structural oscillations, direct stiffness calculations, dynamic oscillations, and optimization. These topics are partly supported by demonstration experiments. During exercise activities, students receive support from the teaching assistants and finally have the possibility to compare their implementations to hidden sample solutions. Additionally, embedded classroom assessment tools like Speakup allow students to share observations and give feedback during the lecture.

As pre-knowledge on Python is very limited, we first address fundaments of the language and then discuss the most popular modules like NumPy, MatPlotLib, SciPy and Pandas. Learning with these modules is supported by a collection of cheat sheets that contain their most important core functions. We focus on fundamental, but relevant topics that students know from their basic courses, like linear algebra, numerical integration and differentiation, or interpolation. The relation to real life problems is particularly easy to establish in Pandas, where data from public sources on environment, traffic, pollution, or earthquakes serve as source. After students are accustomed reading and working with Python code, we discuss the use of LLMs, integrated into the Jupyter environment, as presented in Sec. 2.2. From there the second, engineering-related part starts, with the use of LLMs as AI-teaching assistant in exercises and assignments being mandatory. In our case those topics are visualization, equilibrium solutions, granular and structural dynamics and optimization, potentially serving as a motivator for future studies (see Fig. 1).

2.2 AI-integration into digital engineering education

Learning computational solutions for typical engineering applications relies on homework assignments as a central part of the learning process and success. We experienced extreme differences in the individually required processing times and thus productivity of students, that can result in personal frustration. A possible solution to this problem could lie in the integral application of LLMs. Our activity-intensive lecture series offers ideal conditions for imparting LLMs skills and establishing them as an integral tool for problem-solving. Anchoring these competencies in the first year as part of a large course offers students a new approach to sharpen skills and lecturers the possibility to understand how to integrate AI into their teaching.

The technical implementation is rather straightforward by using JupyterAI (Das 2024), a tool that embeds generative AI capabilities within the Jupyter ecosystem. This empowers students to benefit from AI while staying in their familiar Jupyter notebook environment. As foundational model, chatGPT4 is chosen, due the good quality of the answers and accessibility to API keys.

Five application skills of LLMs are outlined for our course that outsources programming tasks productively (see Fig.2) (Jing et.al. 2024). Those are addressed in the LLMs modules in a lecture and exercise. In detail, the 5 skills or dimensions are:

1 <u>Summarizing the functionality of code blocks or having it explained by the LLMs:</u> Models like chatGPT4 or Google Gemini are surprisingly good at breaking down even complex functions, such as particle simulation using the Störmer-Verlet method, into logical building blocks and explaining them. Here, LLMs offer a perfect opportunity for students to discover and understand code. The aim is to train students to integrate LLMs into their future workflow in order to understand new code blocks in a time-efficient manner. Hereby, they can identify which building blocks are suitable for their solutions and which not. For lecturers this gives the chance to teach also more advanced topics at earlier stages.

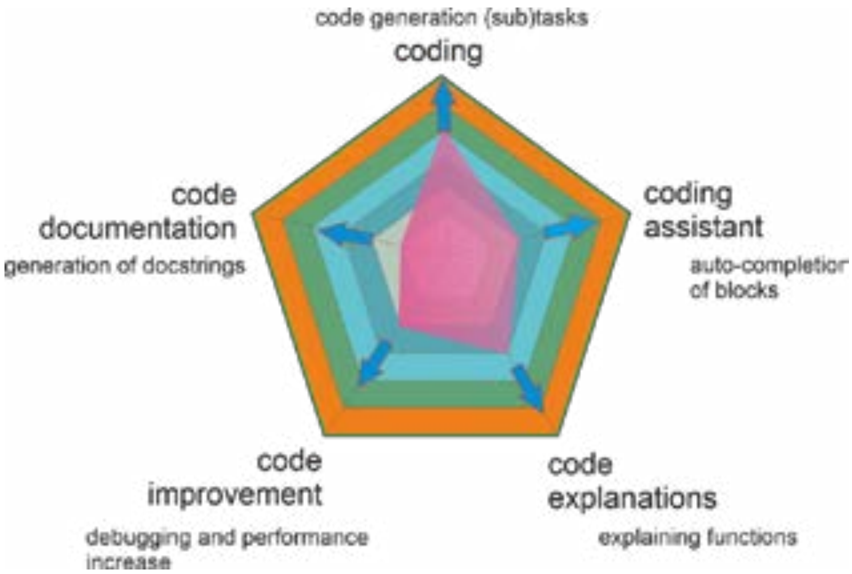

Figure 2. Dimensions of the AI-assistance in programming, developed in the course. Arrows resemble the expected improvement in the respective dimensions due to AI-assistance.

2 Integration of LLMs based programming assistance into the programming workflow for code completion: LLMs can be provide generative AI support via a chat user interface in the Jupyterlab sidebar or via magic commands in the notebook's code cells. We encourage students after the fundamental programming modules to use generative AI to complete code fragments in the assignments. Through AI-powered code suggestions, students will save time while they still gain programming experience. Of course, this does not exempt them from learning programming skills - but with the help of these tools, learning and broadening the horizon about programming approaches should become more efficient.

3 Code improvement: Debugging with LLMs and automated code reviews to identify potential errors: LLMs offers the ability to debug faulty code, suggest "best practices" and achieve higher performance. When assuming that in programming 1/3 of the time is spent on actual programming while 2/3 is lost on debugging, the potential for time savings for students is enormous. Of course, they still need the ability to assess the accuracy of the AI's "correction."

4 Automated generation of documentation for functions with LLM: LLM-based tools allow for the automatic generation of code documentations based on the analysis of code. Writing good documentation requires a lot of working time, which is the reason why it usually gets lost in the flow of work. At the same time, it is essential for the code's long-term use. By using LLM-based tools, we teach students about criteria for good documentation and how they can generate it in the shortest possible time, e.g., by generating docstrings or summaries for functions.

5 Generation of code blocks, graphical visualization, or widgets with LLMs: LLMs can generate code blocks through an appropriate problem description. It is not uncommon that fundamental errors are generated, which is why it is important that students can identify and correct them by targeted prompting. The time savings are still enormous, as they can provide inspiration for a good starting point as it points at possible solutions and functions in libraries that are outside of the previous experience of students. Another strength is that LLMs can

explain the structure of algorithms for solving engineering problems. This means that students receive practical help when working on larger blocks of tasks. In the exercises and homework, students practice how to prompt effectively in a way that useful code can emerge, how to critically judge the generated answers, how to refine the prompts for better answers, and how to use the generated code as a starting point for larger problem-based engineering tasks. Critical reflection on code accuracy and experienced limits of LLMs is another fundamental part of this dimensions, that requires active discussion with the students.

3 RESULTS

The teaching and learning concept are based on a high degree of interactivity in lectures and exercises, in which we exclusively work simultaneously with students on Jupyter notebooks. In those, theory and practical implementation alternate in activity blocks around engineering applications that form a motivating framework. An essential part of learning is through home assignments, which exhibit the largest discrepancies in student performance, and thus potential for individual frustrations. AI-supported workflows can be an important tool of learning support, promoting autodidactic learning and efficient problem-solving. By identifying different dimensions of LLMs support, students learn best-practices to profit from AI assistance by embedding it in their programming work-flow. They experience limits of generative AI, like lack of real understanding and moral, biases or hallucinations, inconsistent and redundant responses, or limited attention spans. By making the use of AI "mandatory" for home assignments while forcing critical reflection on its usage by providing mandatory fields, students have to fill in, they learn to judge the possibilities and drawbacks of AI-assisted programming more realistically.

During the home assignments we surveyed the reception of LLMs. Students highlighted the efficiency and accuracy of LLMs in solving various tasks, especially coding and mathematical problems. Specifically, tasks such as formulating and explaining concepts, writing code, and even handling programming assignments were frequently mentioned as well-suited for LLMs. However, many students commented on the necessity of closely monitoring the LLM outputs for accuracy. In majority, the integration of LLMs were perceived as advantageous in terms of speed and ease of completing tasks. Some students mentioned that LLMs significantly sped up their working process, particularly for theoretical concepts. For instance, one user highlighted that they could learn theory much faster with the help of an LLM. However, others pointed out a downside, suggesting that relying on LLMs for programming might discourage to acquire deep understanding, as users might focus on the provided solutions rather than learning the underlying concepts.

In an end-of semester survey among the students (n=42) students rated their experiences with chaptGPT for the tasks from Sec. 2.2 from 0-4, with 0 meaning very unhelpful, 2 neutral, and 4 very helpful. The use of AI for all tasks was seen as useful, but to different degrees. Explanation of code (3.26) was rated as most useful, followed by code generation (3.02) and code improvement (3.0). For code documentation (2.8) and improvement of programming concepts (2.4) the benefit for AI usage was experienced as less relevant.

Overall, students confirmed a positive reception towards integrating ChatGPT in the DE course (>83% highlight it as important and very important). Students recognize its necessity in todays digital competence education and the value in learning how to use it effectively. 70% of the students stated that they learned effective prompting through the course expressing a shift in their usage of ChatGPT from a simple search tool to a more dynamic, constructive application. The vast majority of students (75%) stated that they could overcome problems while working on their assignment with the help of AI and integrate it into their workflow (85%). Interestingly, almost 50% stated that it reduces the work burden, but that at the same time one would learn and understand less. We observe a split in the attitude, whether the use of ChatGPT increased the self-confidence for the solution of programming tasks. Concerns were raised about over-reliance on ChatGPT for exercises and assignments, to ensure foundational understanding and to maintain the integrity of task completion. Still, 75% of the students considered the 2nd semester to be the ideal time for introducing AI into their digital education.

4 SUMMARY

To summarize, while the importance of AI literacy cannot be overstated for future engineers, the manuscript and surveys highlight the need for a balanced approach where students can independently tackle tasks without over-dependence on AI tools, but still profit from productivity gain for standard works. The most crucial lesson learnt, is that lecturers need to streamline LLM usage to avoid overdependencies on LLMs. The following points can be seen as advice:

- Introduce LLMs only after teaching the fundamentals of programming language and competences.
- For new content we recommend not to rely on LLMs.
- One should stimulate LLM usage to be able to guide and stimulate positive and negative experiences students acquire with LLM usage.
- Set a focus on prompt design and encourage reflections on LLM reactions.
- Try to use an integrated AI of the programming environment.
- Stimulate its use for standard tasks, where errors are easy to grap and debug, like doc-string and plot generation or exception-handling.
- We don’t recommend LLMs for complex programming tasks where assessing the correctness of generated code is not evident.

LLMs proved to be particular successful in error detection and explanation, speeding up the debugging process. Due to this augmentation, more time can be spent on teaching core competences enriching the learning experience.

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REFERENCES

Muhsin, M. “Envisioning the Future of Learning and Teaching Engineering in the Artificial Intelligence Era: Opportunities and Challenges“. *Journal of Engineering Education* 2023/112 (3): 578–82. https://doi.org/10.1002/jee.20539.

Mollick, E. R., and Mollick, L. “Using AI to Implement Effective Teaching Strategies in Classrooms: Five Strategies, Including Prompts“. SSRN Scholarly Paper. Rochester, NY, 2023. https://doi.org/10.2139/ssrn.4391243.

F. Balabdaoui, N. Dittmann-Domenichini, H. Grosse, C. Schlienger, G. Kortemeyer: “A survey on students' use of AI at a technical university”. Preprint ETHZ 2024

Garrel, J., and Mayer, J. “Artificial Intelligence in Studies—Use of ChatGPT and AI-Based Tools among Students in Germany“. Humanities and Social Sciences Communications 2023/10 (1): 1–9. https://doi.org/10.1057/s41599-023-02304-7.

Jing, Y., Wang, H., Chen, X., and Wang, C. 2024. “What Factors Will Affect the Effectiveness of Using ChatGPT to Solve Programming Problems? A Quasi-Experimental Study“. *Humanities and Social Sciences Communications* 11 (1): 1–12. https://doi.org/10.1057/s41599-024-02751-w.

SpeakUp https://www.speakup.info/

Fennema-Nio, J. PyLaTex, GitHub, GitHub repository https://jeltef.github.io/PyLaTeX, 2023

Brichet, N. NBgrader GitHub, GitHub repository, https://github.com/jupyter/nbgrader, 2024

Jupyter et al. NBgrader: A Tool for Creating and Grading Assignments in the Jupyter Notebook. Journal of Open Source Education, 2019/2(11), 32, https://doi.org/10.21105/jose.00032

Das, S. JupyterAI, GitHub, GitHub repository, https://github.com/jupyterlab/jupyter-ai, 2024.

Anagnostopoulos, C.-N. “ChatGPT impacts in programming education: A recent literature overview that debates ChatGPT responses“. https://doi.org/10.48550/ARXIV.2309.12348.

Pradana, MM, Elisa, H., and Syarifuddin, S. “Discussing ChatGPT in education: A literature review and bibliometric analysis“. *Cogent Education* 2023/10 (2): 2243134. https://doi.org/10.1080/2331186X.2023.2243134.

Memarian, B., and Doleck, T. “ChatGPT in education: Methods, potentials, and limitations“. *Computers in Human Behavior: Artificial Humans* 2023/1 (2): 100022. https://doi.org/10.1016/j.chbah.2023.100022.

ENHANCING LEADERSHIP PEDAGOGY WITHIN ENGINEERING EDUCATION – A COURSE EXAMPLE

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ABSTRACT

In recent years, work-life skills such as leadership, self-management, teamwork, and ethics have become increasingly integral to the engineering profession. However, it appears that traditional engineering education often falls short in equipping students with these essential skills. The development of social skills is fundamentally experiential and encompasses the entirety of an individual. In this paper, we introduce elements of impactful leadership pedagogy derived from our research and extensive practical experience in delivering (critical) leadership courses to engineering students. We engage students in a processual and contextual examination of leadership concepts, theories, and phenomena, while placing paramount importance on personal inquiry into their own thinking and agency

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regarding leadership, influence and moral agency. Student feedback indicates that learning experiences have been transformative, for some, even life-changing.

1 INTRODUCTION

Professional skills essential for working life, such as teamwork, communication, leadership, and continuous personal and professional development, have become increasingly vital in the engineering skillset. The shift in the working environment from gradual change to a dynamically evolving VUCA (volatile, uncertain, complex, ambiguous) landscape has intensified the demand for ongoing communication, adaptation to change, and skill enhancement across all professions, including engineering (Millar et al., 2018; Deming, 2018). To meet these evolving demands, organizations have transitioned from rigid hierarchies to dynamic networks, embracing a more autonomous organizational philosophy and practice. This transformation is particularly evident in innovative technology and software companies. The emergence of new organizational structures necessitates advanced competencies in communication, collaboration, and personal and professional influence from all stakeholders.

Moreover, there is a growing expectation for engineering professionals to address and contribute to global challenges such as climate change, biodiversity loss, and societal shifts. Engineering professionals are both contributors to and mitigators of these challenges, as highlighted in the SEFI Conference's call for papers. Consequently, engineers must engage in discussions concerning the ethical implications of technology development and application. However, it appears that traditional engineering education often fails to adequately equip students with these essential skills and knowledge (Hirudayraj et al., 2020).

Developing skills on teamwork, collaboration, leadership, and moral reasoning and agency primarily requires experiential learning and reflection on these experiences. Unlike basic engineering knowledge, social sciences lack a singular theory, fact set, or method that can be taught and applied universally. Social reality is constructed through collective meaning-making, necessitating a willingness to critically examine personal values, thought processes, communication patterns, and actively engage in interactions to enhance one's influence. Thus, acquiring meta-skills for lifelong curiosity and learning about social influence within various professional contexts and relationships is crucial.

Many engineers eventually end up to managerial roles in their careers. It's widely recognized that true learning and adoption of managerial and leadership skills start occuring when individuals get into a position of authority. Some argue that teaching leadership to students is futile as they lack opportunities to apply these skills and knowledge in practice. However, we contend that there are valuable lessons to be learned during academic studies. We have been teaching leadership to engineering students as a team quite a while, and in this paper, we introduce our approach, which has been proven to cultivate deeper and more sustainable personal capabilities for moral agency and leadership within social contexts. Throughout our teaching, we have consistently explored a fundamental question: Should concepts of human interaction, leadership, and moral agency be taught differently to engineering students compared to, for example, business students? So far, our experience suggests that there are no significant differences between students from various disciplines and cultures. The decisive factor appears to be an individual's willingness to adopt a curious mindset, critically assess their own assumptions and ways of relating, expose themselves to new experiences, and reflect on these experiences for learning. Next, we will outline the theoretical foundations of our educational approach and its practical application, as well as discuss the potential for broader implementation

2 THEORETICAL FOUNDATION OF IMPACTFUL LEADERSHIP PEDAGOGY

In the exploration of leadership pedagogy, the initial inquiry often centers on the conceptualization of leadership itself: What exactly are learners expected to master? This question is followed closely by considerations of how leadership-related skills, knowledge, and abilities are acquired, and how educational contexts can effectively nurture and support this learning process.

Leadership enjoys widespread attention within social sciences, yet it eludes a single, universally accepted definition. The traditional leader-centric perspective identifies leadership through individual traits, competencies, characteristics, and behaviors. In contrast, more contemporary viewpoints recognize leadership as a contextual and relational phenomenon, co-constructed, manifested, enacted, and defined uniquely within each organizational setting (Collinson & Tourish, 2015). It is crucial, therefore, to differentiate between enhancing individual leadership skills and fostering collective leadership practices within an organizational context (Day, 2001).

Adopting a contextual and relational perspective, we view leadership as a continuously evolving interaction that involves all participants within a given context. This approach underscores the significance of collective meaning-making (Drath & Palus, 1994) and relational dynamics (Uhl-Bien, 2006) in the co-construction of leadership, along with the role of collective practices as foundational to its emergence (Raelin, 2011). Our stance aligns with the notion that leadership is an "essentially contested concept" (Grint, 2005), reflecting the diversity of phenomena and activities labeled as leadership across both practical and academic domains (Alvesson, 2018).

From this vantage point, leadership becomes relevant not only for current and aspiring leaders but for everyone. Leadership can be seen as an omnipresent, co-creative process, implicating all members of an organization—or any group, for that matter. In today's increasingly non-hierarchical organizations, where leadership capacity is expected from every level, understanding one's agency and influence becomes paramount. Formal leaders, despite their authoritative roles, are integral to, rather than separate from, this collective process. Recognizing this interconnectedness allows individuals to perceive, analyze, and actively participate in these dynamics.

Our approach to designing and delivering leadership courses is informed by our academic research, pedagogical strategy, teaching experience, and continuous refinement through reflection on our experiences and student feedback. This methodology extends from undergraduate courses to executive education programs, grounded in the belief that the core principles of learning and reflecting on fundamental social and human phenomena are consistent across all educational levels and various disciplines. Next, we delve into what we believe is essential leadership knowledge for (engineering) students and the elements that render our teaching impactful, using a Master's level leadership course, *Leading as Practice*, as an illustrative case study.

2.1 The content – what to teach and learn?

We see that in an undergraduate leadership class, understanding the essence of leadership is paramount. We typically begin with an exploration of students' existing perceptions of leadership, often shaped by their past experiences in various spheres such as work, volunteering, military service, and societal influences as well as on popular narratives. Additionally, we delve into students' aspirations for leadership roles, noting initial hesitations among some who feel they don't align with traditional heroic leader stereotypes, alongside those eager to pursue careers in business and industrial leadership. In the end of the course we ask the students to take another look and compare how their view of leadership has evolved through the learning experience.

Throughout the course, we emphasize that leadership is a dynamic, collective, and context-dependent process. We pinpoint that mastery in leadership involves four interconnected aspects: *1) becoming able to see underlying social processes and structures, 2) learning to know oneself: beliefs, values, and ways of seeing oneself, others and the world, 3) making active and deliberate choices on how to conduct oneself in order to have an impact on the world,* and *4) building capacity and practice for continuous personal learning and growth*.

A pivotal aspect of leadership learning is understanding its multifaceted nature, which we enable through familiarizing the students with different perspectives to leadership. We stress the importance of self-awareness, encouraging students to reflect on their worldview, understanding of human behavior, concept of knowledge, and core values. Central to this is recognizing that each person holds unique lenses through which he/she perceives the world, shaping his/her interpretations and actions. One key question to be explored is "*What are the lenses through which I view and interpret the world?".*

The next essential theme is to learn to comprehend one's environment, encompassing interpersonal dynamics, organizational cultures, and broader societal contexts. We see that acknowledging the interconnectedness of individuals and their surroundings facilitates understanding of social processes and informs effective leadership.

At the heart of understanding oneself as a leader lies adopting a systemic approach to one's environment and perception of it. This involves identifying key contextual factors that shape the social landscape where leadership unfolds, reflecting on personal interpretations, and making conscious choices to exert influence and actively engage in leadership endeavors. According to this view, "leadership becomes a process of thinking more critically and reflexively about ourselves, our actions, and the situations we find ourselves in" (Cunliffe, 2009).

We believe that by fostering an environment that encourages exploration, self-realization, and awareness of one's agency within social reality, students can cultivate a sustainable foundation for ethical leadership and influence. Through deliberate reflection and the refinement of perspectives, convictions, and practices, students can develop into morally responsible leaders and influencers.

2.2 The principles – how to teach and learn?

We assume that *first* crucial aspect of learning leadership is the willingness to critically examine one's own habitual ways of thinking, perceiving, interpreting, and making sense of social reality and contexts. This involves questioning ingrained assumptions and being open to new perspectives. *Secondly*, learning entails establishing a connection with one's past experiences while also consciously reflecting on new experiences gained through coursework. This reflective process is vital for synthesizing and integrating new knowledge. *Thirdly*, learners must familiarize themselves with key leadership concepts and theories to enrich their understanding and further develop their own leadership perspectives. This involves not only absorbing information but also actively engaging with and applying theoretical frameworks. *Lastly*, learning is a social endeavor that thrives on shared meaning-making and dialogue. By exchanging ideas, perspectives, and insights with peers, learners can deepen their understanding and refine their thinking collaboratively. In summary, effective learning involves willingness to challenge existing beliefs, reflection on personal experiences, engagement with theoretical knowledge, and active participation in collective learning processes. As educators, we must create environments that foster these aspects to facilitate meaningful and transformative learning experiences.

The anticipated learning approach is strongly rooted in constructivism, emphasizing the active (social) construction of new knowledge and understanding. Additionally, experiential learning (Kolb, 1984) is integral, necessitating reflection (Reynolds, 1999) and (critical) reflexivity (Cunliffe, 2004). Students often note that this learning method deviates from the norm in engineering education. We prioritize engaging students in active, intentional participation throughout the course. Our goal is to cultivate a psychologically safe learning environment where students feel comfortable sharing personal experiences, uncertainties, and evolving ideas. We strive to minimize power dynamics, foster open dialogue, address classroom dynamics, amplify marginalized voices, and reflect on the ethical implications of endorsing particular viewpoints.

In our learning environment, we place significant emphasis on encouraging students to explore their personal thoughts while also venturing into unfamiliar territory. Diversity of ideas is celebrated, but we equally stress the importance of quality thinking—ideas must be thoroughly developed and supported by relevant academic concepts and reasoning. As educators, we actively avoid perpetuating the conventional "orthodox" view of leadership, which may foster hubristic attitudes among students (Sadler-Smith et al., 2017). Instead, we adopt a facilitative role, drawing inspiration from constructivist learning pedagogy and critical pedagogy. In this approach, teachers are viewed as facilitators rather than authoritarian figures, guiding students through the learning process. While we embrace our role as representatives of academic scholarship and leadership knowledge, we acknowledge the importance of avoiding charismatic performances that reinforce the notion of the all-knowing, mythical hero narrative (Sinclair, 2009). Thus, as we shift away from the traditional view, our pedagogy must also evolve accordingly (Iszatt-White et al., 2017). We strive to embody the same principles in our teaching roles as we advocate within our classrooms, promoting a collaborative and inclusive learning environment.

Our students' initial perceptions of leadership often align with values and assumptions criticized in leadership studies (Alvesson, 2019). This underscores the importance of addressing leadership from the perspectives of values and assumptions to engage students effectively. The most influential management and leadership theories focus on beliefs and aspirations rather than theoretical constructs (Bridgman et al., 2016). We've found that challenging the orthodox view of leadership and presenting alternative perspectives not only captivates students but also prompts self-reflection, offering valuable insights into their own beliefs and assumptions.

3 IMPACTFUL LEADERSHIP PEDAGOGY IN PRACTICE

We offer a range of leadership courses, spanning from bachelor level to executive education, where we implement the pedagogical approach outlined earlier. In this paper, we aim to underscore the practical application of effective leadership pedagogy by focusing on one of our core courses in the Master’s level curriculum, titled *Leading as Practice*.

3.1 Course design and delivery

Leading as Practice (*LaP*) is a 5-credit course within the Master’s Program of Industrial Engineering and Management at Aalto University It takes a critical, relational, and reflexive approach to leadership, social reality, and human agency. The overarching goal of the course is to acquaint students with contemporary leadership theories and frameworks, empowering them to identify and analyze various leadership-related social phenomena, practices, and experiences through critical and reflective thinking. Moreover, the course aims to help students further develop their personal critical leadership thinking and practice while realizing their potential in learning leadership-related skills sustainably. *LaP* has been offered in its current format ten times, with minor adjustments made each year.

The student body comprises individuals from various engineering disciplines, predominantly industrial engineering and management. The proportion of international students fluctuates between 10% and 15%. Currently, there are some 40 participants each year, which is deemed optimal for the pedagogical approach employed, facilitating lively class discussions. Previously, the course accommodated over 80 participants; however, changes to the Master’s Program curriculum resulted in a decrease in enrollment.

The course consists of nine lectures, two substantial personal essays, six weekly "mini-essays," and a group assignment spanning a two-and-a-half-month period. The curriculum draws from nine articles covering a range of topics, including multi-paradigm perspectives and contemporary leadership theories, as well as themes such as inclusion and critical thinking. The introductory personal essay in the beginning of the course serves as a cornerstone for the coursework, introducing various paradigmatic perspectives on social reality. It underscores how biased theory construction can inadvertently endorse distorted management thinking and practice, while also challenging the prevailing heroic leadership narrative. This exploration of different paradigms and their influence on knowledge construction is often eye-opening for engineering students, shedding light on perspectives they may not have previously encountered. However, for some, it can also be perplexing, particularly if they have never questioned the dominant functionalist view of reality before.

Following the introduction, the course adopts a consistent weekly structure, with each session dedicated to reviewing an assigned article prior to the lecture. Three-hour lecture sessions prioritize mutual dialogue in small groups and as a whole class, fostering the development of ideas and insights gleaned from essay writing while also prompting new questions. Peer sharing is actively encouraged, enhancing collaborative learning.

Interwoven between group discussions are short presentations by the teachers, summarizing and highlighting key viewpoints from the discussions and texts. Midway through the course, students form five-person groups for a group assignment centered on their personal leadership experiences. This assignment aims to broaden students' perspectives by illustrating how their everyday experiences can be interpreted from diverse viewpoints, challenging any narrow or one-sided perceptions.

As a conclusion, students craft personal reflection essays, summarizing their learning journey. They integrate course materials and personal experiences to develop their personal leadership philosophies and ideas for implementation their learnings further. Additionally, students compare their initial leadership constructs and definitions, written at the course's outset, with their evolved understanding at the course's conclusion. The final workshop consolidates the learning process, as students share personal reflections and insights gained from group assignments. Moreover, students engage in coaching discussions in pairs, exploring their future aspirations in the leadership domain.

3.2 Course experience and feedback

The course has consistently garnered positive feedback over its duration, earning a reputation for being exceptional and distinctive (Morikawa, 2020). For many students, the experience has been transformative, leading them to orient their further studies and interests accordingly. However, few students have expressed contrasting views, perceiving the course as overly philosophical and conceptual, and desiring a more practical approach with concrete case studies and definitive answers. Nevertheless, those who successfully complete the course typically exhibit a high level of commitment and engagement. Each year, an impressive 65-75% of students achieve the highest grade, reflecting their dedication to active learning. Assessment in the course is based on personal and group essays completed throughout the duration of the course, with additional points allocated for class attendance. Emphasis is placed on personal, critical, and reflective writing in essay grading, along with the demonstration of adequate academic argumentation. Feedback from participants indicates that LaP-course holds significant value for many students and is regarded as one of the most impactful university courses.

A quote from the student feedback summarizes well the meaningfulness of the course experience: *"Honestly, the first real university course during my four years of IEM studies. That is, the first one that actually encouraged critical thinking in the way university courses should. Vast majority of the IEM courses train you to efficiently solve managerial problems by abstracting the organization into some sort of "mathematical machine" that an engineer is able to optimize. This was the first one to actually set a bigger picture relating to why do organizations exist in the first place* *and whose interests do they actually serve. The meta level of social scientific theories was especially eye-opening."(a student from the LaP-course 2018)*

4 DISCUSSION

In this paper, we have introduced our approach to teaching leadership in a manner that fosters meaningful impact as a part engineering curriculum. Drawing from our extensive experience, research, and exploration, we have developed approach to facilitate sustainable learning outcomes in our students' leadership thinking and skills. Based on our experience we argue that engineering students do not necessitate a specialized course approach on leadership when the aim is to develop deeper understanding of social dynamics, leadership and oneself. We see that impactful leadership pedagogy is grounded in constructivist and experiential learning, which diverges from traditional university teaching methods.

From the teachers this requires a facilitative and participatory role rather than positioning oneselves as sole authorities on knowledge. From the students learning requires to critically examine their own perceptions of social reality and to constructively scrutinize their own agency. Furthermore, the classroom experience should embody the very leadership principles the course is aiming to instill, and foster a psychologically safe environment for participants to freely share thoughts and questions.

We believe that future engineers must possess a foundational understanding of human dynamics within teams and organizations, coupled with a strong sense of self-awareness and the ability to cultivate professional relationships. Integrating the learning of teamwork and leadership into the engineering curriculum presents a challenge. One approach is to leverage project-based courses, providing students with real-world social experiences as valuable learning opportunities.

REFERENCES

Alvesson, M. (2019). Waiting for Godot: Eight major problems in the odd field of leadership studies. *Leadership*, *15*(1), 27–43. https://doi.org/10.1177/1742715017736707

Bridgman, T., Cummings, S., & McLaughlin, C. (2016). Restating the Case: How Revisiting the Development of the Case Method Can Help Us Think Differently About the Future of the Business School. *Academy of Management Learning & Education*, *15*(4), 724–741. http://dx.doi.org/10.5465/amle.2015.0291

Collinson, D., & Tourish, D. (2015). Teaching Leadership Critically: New Directions for Leadership Pedagogy. *Academy of Management Learning & Education*, *14*(4), 576–594. https://doi.org/10.5465/amle.2014.0079

Cunliffe, A (2004), On becoming a critically reflexive practitioner, *Journal of Management Education*, Vol. 26, No. 4, pp. 407-26

Cunliffe, A (2009), The philosopher leader: On relationalism, ethics and reflexivity—A critical perspective to teaching leadership, *Management Learning*, Vol. 40, No. 1, pp. 87-10

Day, D.V. (2001) Leadership Development: A Review in Context. *Leadership Quarterly*, 11(4), 581-613.

Deming, DJ (2017), The Growing Importance of Social Skills in the Labor Market, *The Quarterly Journal of Economics*, Vol. 132, No. 4, pp. 1593-1640, https://doi.org/10.1093/qje/qjx022

Drath, W. H., & Palus, C. J. (1994). *Making Common Sense: Leadership as Meaning-Making in a Community of Practice* (No. 156). Center for Creative Leadership.

Ford, J., & Harding, N. (2007). Move Over Management: We Are All Leaders Now. *Management Learning*, *38*(5), 475–493. https://doi.org/10.1177/1350507607083203

Gioia, D. A., & Pitre, E. (1990). Multiparadigm Perspectives on Theory Building. *The Academy of Management Review*, *15*(4), 584–602. https://doi.org/10.2307/258683

Grint, K. (2005). Problems, problems, problems: The social construction of 'leadership.' *Human Relations*, *58*(11), 1467–1494. https://doi.org/10.1177/0018726705061314

Hirudayraj, M, Baker, R, Baker, F & Eastman, M (2021), Soft Skills for Entry-level Engineers: What Employers Want, *Education Science*, Vol. 11, p. 641. https://doi.org/10.3390/educsci11100641

Iszatt-White, M., Kempster, S., & Carroll, B. (2017). An educator's perspective on reflexive pedagogy: Identity undoing and issues of power. *Management Learning*, *48*(5), 582–596. https://doi.org/10.1177/1350507617718256

Kolb, D.A.(1984) *Experiential Learining. Experience as The Source of Learning and Development*. Engelwood-Cliffs, NJ, Prentice Hall.

Millar, CCJM, Groth, O, & Mahon, JF (2018), Management Innovation in a VUCA World: Challenges and Recommendations. *California Management Review*, Vol. 61, No. 1, pp. 5–14. https://doi.org/10.1177/0008125618805111

Morikawa, M. (2020). *Becoming adept in maneuvering in leadership* [Master's Thesis]. Aalto University: School of Science.

Raelin, J. (2011). From leadership-as-practice to leaderful practice. *Leadership*, *7*(2), 195–211. https://doi.org/10.1177/1742715010394808

Reynolds, M. (1999). Critical Reflection and Management Education: Rehabilitating Less Hierarchical Approaches. *Journal of Management Education*, *23*(5), 537–553. https://doi.org/10.1177/105256299902300506

Sadler-Smith, E., Akstinaite, V., Robinson, G, & Wray, T. (2017) Hubristic Leader: A review. *Leadership*, Vol 13(5) 525-548. https://doi.org/10.1177/1742715016680666

Sinclair, A. (2009) Seducing Leadership: Stories of Leadership Development. *Gender, Work and Organization*, Vol.16(2)

Uhl-Bien, M. (2006). Relational Leadership Theory: Exploring the social processes of leadership and organizing. *The Leadership Quarterly*, *17*(6), 654–676. https://doi.org/10.1016/j.leaqua.2006.10.007

Navigating the Unknown: Introduction of an Analysis Metric for the Sprint Plan and Sprint Review in Educational Agile Development Projects

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ABSTRACT

In complex project-based courses, students work with a high degree of autonomy, making it difficult to assess individual progress. Thus, feedback and grading are often based on the results, which neglects the applied methods. However, gaining an understanding of students' approaches to complex projects could enhance comprehension of team success or failure. Our hypothesis is that there is a correlation between the consistency of the sprint plan and sprint review and the team's overall performance in the competition. We introduce an approach to analyse the methodological effectiveness of student projects in their development approach.

70 student teams were requested to create a sprint plan at the start and a sprint review at the end of each of the five two-week iterative development sprints. The plan and review were based on four guiding questions for each sprint. A total of ten teams were examined, consisting of five high-performance and five low-performance teams. The teams were analysed quantitatively, and the consistency of sprint planning and sprint review was analysed qualitatively for one team from each group. Successful teams ran more tests and developed more prototypes and thus, delivered

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more profound results. The high-performance team formulated results clearer and more precisely and is more consistent throughout sprint plan and sprint review compared to the low-performance team.

1 INTRODUCTION

Project-based education is well established in engineering education (Türk, Leutenecker, and Meboldt 2014; Condliffe et al. 2017). Students are usually graded solely based on the results of their projects (Krajcik and Kongju 2014). However, this approach does not directly consider the methods learned and applied by the student teams, which is a fundamental learning goal (Ríos et al. 2010). Gathering and analysing such data is challenging, especially in large classes (Condliffe et al. 2017; Ralph 2015). Such data could help in understanding how individual teams work and could provide insights into why teams are either successful or unsuccessful. It may ultimately enable the development of indicators for early interventions. The aim of this approach is to establish a basis for analysing qualitatively and quantitatively the correlation between methodological application in student project work and system performance, highlighting the significance of the learning process.

A fundamental concept of project-based learning is learning through failure (Zhang et al. 2022; Tawfik, Rong, and Choi 2015; Barron et al. 1998). Agile development has proved to be an ideal method to create such environment (Neumann and Baumann 2021; Omidvarkarjan et al. 2020; Batliner et al. 2022; Beck et al. 2001). It forces students to iteratively build and test prototypes, which, especially in complex projects, provokes failure and thus learning at some point.

We propose a method, which considers quantitative and qualitative data, to investigate how students approach the overall project goal by breaking it down into sub-goals and systematically create data-based results to build up their knowledge.

1.1 The Study Context

The subject of the study is a student project in which teams of students developed a physical product over a period of 10 weeks (Türk, Leutenecker, and Meboldt 2014). Approximately 350 students participated in this course, organised in teams of four to six members. The students were taught the basics of agile hardware product development. A key challenge of product development in mechanical engineering is to translate the requirements and problem statement of a specific use case into a technical system. The system must perform well in its intended use case, while meeting additional requirements.

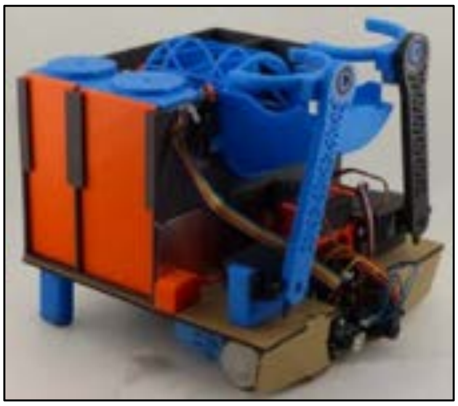

Fig. 1. Result of a high-performance team

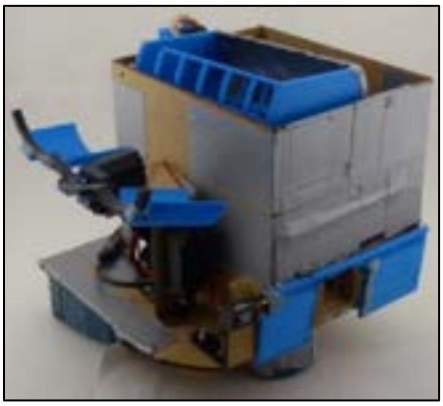

Fig. 2. Result of a low-performance team.

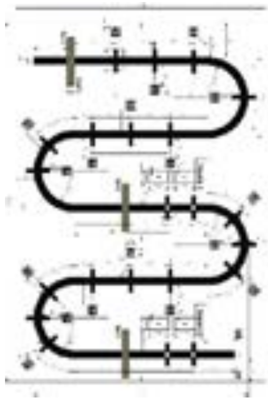

Fig. 3. Driving circuit.

The students were challenged to design an autonomous garbage truck prototype (*Fig. 1* and *Fig. 2*), which could collect mixed waste (black beans and bottle caps), separate and dispose the waste at two landfill sites along a designated route (*Fig. 3)*. The prototype had to comply with size and weight regulations and navigate past checkpoints. The teams received a mechatronic platform and access to a workshop infrastructure, including laser cutters and 3D printers. The objective of each team was to develop a working system and compete in a competition against other teams. The teams that perform best in the defined use case wins the competition.

The educational setting is based on teamwork, where students can apply their theoretical knowledge from different subjects of the first year of the bachelor's programme and acquire skills to master a complex development challenge from the idea to a fully working system. The development process includes mechanical and electrical design, manufacturing, assembly, programming, and testing.

The teams have a high degree of autonomy in their decision-making processes within a framework of minimal constraints. Emphasizing agile hardware development methodologies, the course guides students in adopting agile practices tailored to their project needs, particularly in formulating sprint plans. A sprint is a repetitive timeframe, which consists of the three increments plan, review and retrospective and during which specific work must be completed and made ready for review (Fuior 2019). For this course, each sprint was set to two weeks. Navigating effectively through this process, from an idea to a working prototype, demands a meticulously planned breakdown of the overall system into smaller, testable subsystems. These subsystems can then be individually tested and integrated step by step into the overall system. The progress and learning and the performance of development teams can be assessed by the ability to divide the overarching objectives into measurable, short-term sub-goals and the precision with which the results of prototype testing align with the period defined sub-goals of the development plan. These goals facilitate cohesive team efforts and knowledge synthesis.

The specific self-defined development tasks and intermediate results vary between teams. It is challenging to compare the progress of teams. The students should primarily learn how to break down complex, long-term development goals into smaller, testable sub-objectives and to plan and execute a project with high degree of uncertainty over longer time in a team. This approach systematically builds up the knowledge required to eventually solve the initial problem and build the final system. The evaluation focuses on how well a team develops the results of a sprint and how closely the objectives defined before a sprint match the results of the sprint, including the lessons learned for planning the next sprint.

We assume that the performance and learning of teams can be assessed through the comparison of sprint plan and sprint review. We assume that the quality of this alignment correlates with the overall success of a team.

2 METHODOLOGY

In total, 70 teams participated in the course. The ten-week project was split into five sprints of two weeks each. For this study, quantitative data collected from ten student teams and qualitative data of two teams were analysed. We compared quantitatively the five teams with the highest (‘Top’) and five teams with the lowest (‘Bottom’) score in the competition and exemplary analysed one team of each group (Top and Bottom) qualitatively.

General information regarding team size, age and invested average time per week of the Top and Bottom groups was collected via a questionnaire at the end of the course and are presented in *Table 1*. The teams on average were of the same size and age. The text data from the Top and Bottom groups was analysed qualitatively and quantitatively.

Table 1: General information on the Top and Bottom groups compared to the course. Data was assessed by questionnaires and then averaged.

	Top (n=5)	Bottom (n=5)	Course (n=70)
Team size	4.80	4.80	4.81
Age (in years)	20.13 ± 0.56	21.26 ± 1.19	20.82 ± 0.99
Time (h/week)	9.7 ± 2.65	11.4 ± 4.40	10.44 ± 3.89

2.1 Quantification of learning throughout a sprint

The quantification of textual data focused on the number of clear goals and tests defined per sprint, results per sprint, words per sprint goal and per result and the number of prototypes and tests per results. Clear goals, tests and results were classified manually. The average and standard deviation was calculated to compare the Top and Bottom group with each other.

2.2 Qualitative consistency analysis of sprint plan and review

Each team was asked to complete online plan and review surveys during each sprint. The questions of this survey are shown in *Table 2:* The structure of the sprint plan and sprint review documentation was framed around four leading questions, which correspond. In the planning phase, the student had to formulate a hypothesis based on ‘We believe that...’ (P1). After the sprint, they should provide evidence for this hypothesis in the form of ‘We now know that...’ (R1). Furthermore, the students were asked to formulate a test case in the sprint plan, which included a measurable metric and test validation (P2, P3, P4). The review included further information about the result (R2, R3) and the learning in form of a reflection on the hypothesis (R4). This resulted in forty textual data fields for each team. Based on the gained knowledge, the new sprint plan was designed. This procedure was repeated until project completion.

Table 2: *Sprint plan and sprint review guiding questions. Corresponding questions colorized.*

Sprint Plan			Sprint Review		
Goal	P1	We believe that...	We now know that...	R1	Result
Test Case	P2	To verify this, we will....	This was determined as follows…	R2	
	P3	This is how we will measure it…	The measurement results showed…	R3	
	P4	We are correct in our assumption(s) if…	Our assumption(s) was (were)…	R4	Reflection

The sprint plan and sprint review of one Top and Bottom team each were analysed regarding consistency and content. This demonstrates the proposed qualitative analysis methodology. To reduce complexity, we focused only on the second sprint plan and review. Review questions R2 and R3 were neglected.

A successful agile development project can be characterized by a consistence sequence (C4, *Fig. 4*) of consistence sprints (C1-3, *Fig. 4*). Consistency addresses four steps in a sprint, from hypothesis and goals, test case, results to reflection and, between two sprints, the sprint plan derived from the previous sprint review. The delta between the sprint plan and review represents the amount of gained knowledge about the system, which corresponds to the learning during this period. This was quantified by the number of hypotheses and results, and qualitatively assessed through the evaluation of tests, prototypes, and the logical consistency and clarity of sprint goals, to determine both the quantity and quality of learning. This could predict team performance in the competition.

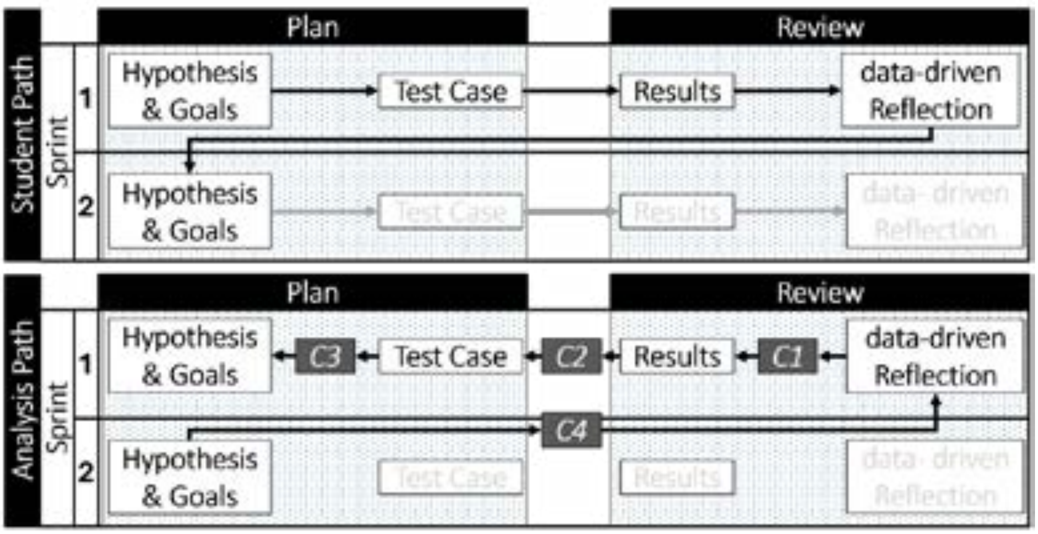

Fig. 4. Schematic of consistency analysis process (grey blocks labelled ‘C1’- ‘C4’) and the student’s documented work during each sprint (white blocks). Exemplary for one cycle. The plan and review from the students were used for data collection.

3 RESULTS

3.1 Quantitative comparison of sprint goals, tests, and results

The results of the quantitative analysis of the textual data are shown in *Table 3.* The Top group defined an average of 0.87 more goals per sprint than the Bottom group. The Top and Bottom group reported about the same number of results per sprint. When formulating the sprint goals, both Top and Bottom group used a similar number of words per sprint goal. However, for the sprint results, the Bottom group used on average 6.90 more words per sprint result than the Top group. The Top group run more tests and developed more prototypes per sprint.

Table 3: Quantitative text analysis of sprint plan & sprint review characteristics of the Top and Bottom groups.

	Top (n=5)	Bottom (n=5)
Goals per Sprint	4.56 ± 2.36	3.69 ± 1.31
Results per Sprint	3.98 ± 1.34	3.97 ± 1.13
Words per Sprint Goal	10.20 ± 2.97	12.5 ± 4.08
Words per Result	11.70 ± 3.15	18.60 ± 10.98
Prototypes per Sprint	5.45 ± 1.83	4.82 ± 1.62
Tests per Sprint	7.99 ± 3.69	4.88 ± 3.82

3.2 Comparative consistency analysis of two teams

Figure 5 presents the second sprint plan and review of two teams, one of the Top and one of the Bottom groups. Due to space limitations, we focused on the questions P1-P4, R1 and R4.

The Top team defined four specific technical sprint goals (P1): building prototypes for the gripper, the waste container, the emptying mechanism and optimizing the existing sorting mechanism. The team used a decisive tone to formulate the goals, facilitating reader comprehension of desired outcomes. In contrast, the Bottom team focused on team workflow organisation and brainstorming. No technical goal was defined. The tone is indecisive.

The Top team defined test cases (P2-3) for the development of the gripper arm, the emptying mechanism, and the sorting mechanisms. They formulated multiple questions to address the measurement of their test, with a focus on the gripper arm and partially on the sorting and emptying mechanisms. The Top team described how to validate their findings regarding the gripper arm. The Bottom team defined no clear test case nor a measurable verification method but agreed on team workflows. The team did not provide a clear definition of what constitutes a desirable or undesirable number of ideas.

The Top team described compact four core results (R1) of their test, addressing the gripper arm (pick-up system) and emptying mechanism. The Bottom team's results review contrasts greatly with their sprint goals in both form and content. The results are described in meticulous detail. The table displays only one-third of the sprint results due to space constraints. The team described the brainstorming results and next steps in a structured manner including prioritization.

The Top team reflected on their assumptions (R4) of the pick-up system, emptying mechanism and sorting system. The Bottom team reflected on their assumptions in one sentence, concluding that their developed ideas during this sprint should work theoretically.

The Top team mentions the gripper arm in each answer (P1-4, R1, R4), and the emptying mechanism (P1-3, R1, R4) and sorting mechanism (P1-3, R4) in most answers. Except for the sprint goal, the Bottom team only mentions either the teamwork or brainstorming in the following answers to P2-4, R1 and R4.

	Plan				Review	
Team	We believe that...	To verify this, we will...	This is how we will measure it...	We are correct in our assumption(s) if...	We now know that...	Our assumption(s) was (were)...
Top	In Sprint 2, we will complete a first version of the gripper arm, build a prototype for the waste container and emptying mechanism, optimise the prototype of the sorting mechanism	Mount the test arm on the driving platform and have the waste bins collected.	Is the gripper arm in the rest position within the size limit? Does the gripper arm grip the bin reliably? Does the reach arm lift the bin without spilling waste? Does the gripper arm empty the waste in the correct place? Does the gripper arm put the bin back in the right place undamaged? Does the emptying mechanism empty the waste reliably? Does the sorting mechanism sort the waste correctly?	The gripper arm works according to the test criteria and the prototypes provide insights for further development.	The servo power is sufficient and cannot be supported by a spring. The pick-up system is not yet fully developed. Decanting the cup is more difficult than expected.	The servo power for lifting the arm could be scarce (50% of the specified power would already be needed to lift the cup if the arm is assumed to be weightless and the system frictionless). The pick-up system is fully developed. Transferring from the cup to the sorting system does not present any major difficulties.
Bottom	We need to make some changes to the way we work in terms of brainstorming. Up to now we have only been able to define concrete ideas for subsystem 3 (filtering) extremely slowly. In future, we will approach this process much more efficiently and possibly work on different ideas in parallel.	From now on, we will each work on our own concepts and present the results to each other at the meeting.	The success of this plan is measured by the number of qualitative ideas	Our ideas are much better in the future.	1. we will develop our 3 ideas from subsystem 3a with priority. Priority 1: Idea 3a-1 (coin filter, see "Done Sprint 2"), combination with Idea 3a-3 if necessary (i.e. introduce vibration) Priority 2: Idea 3a-0 (half cylinder, see "Done Sprint 1") Priority 3: Idea 3a-2 (cylinder with spiral) Of these, Idea 3a-1 is the simplest, as no servo / motor is needed. It also works well in the test. Idea 3a-0 needs motors but also works well. Idea 3a-2 works but seems rather complicated. (*)	All ideas should work in theory.

Fig. 5. Exemplary sprint plan and parts of the sprint review of sprint two for one team each of the Top and Bottom group. Key words are highlighted in grey. (*) The result entry ('We now know that...') of the Bottom team was shortened to fit the cell

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4 DISCUSSION

Our findings support the broader educational theory that iterative processes, as promoted by agile methodologies, enhance learning by allowing students to learn from failures and continuously improve their work (Zhou, Kolmos, and Nielsen 2011). We propose the use of qualitative and quantitative metrics for analyzing team performance, which aligns with the trend towards data-driven decision-making in education (Mahnic 2015).

4.1 Analysis of sprint results and team efficiency

The Top group reported the same number of results per sprint as the Bottom group, despite defining more goals, running more tests, and developing more prototypes. This may indicate that the results were investigated more thoroughly, are more profound and trustworthy (Fernandes, Dinis-Carvalho, and Ferreira-Oliveira 2021).

The lower word count per result may support this, as it suggests that the Top group was able to express their findings more clearly. Clear and explicitly communicated results can improve the value proposition of the group, which is an indicator of successful teams.(Cooper and Sommer 2016; Duehr et al. 2021; Marquardt, Choon Seng, and Goodson 2010) Defining more specific sprint goals may indicate that the team is clearer about what it wants and what needs to be done to achieve the overall project goal (Liu et al. 2019).

The top group invested less time on average in the project, suggesting greater focus and efficiency. This could also indicate advanced usage of agile methods, which may have reduced the development time (Pócsová et al. 2020). This is a counterargument to the often-assumed idea that low performance is due to low team commitment or ambition.

4.2 Comparative evaluation of consistency analysis of sprint plan and review

A clear sprint plan consists of well-defined hypothesis or goals and test cases, which are easy to understand for the entire team (Neumann and Baumann 2021). It must be clear what is being tested and how the hypothesis can be evaluated, which underscores the significance of clear and concise communication in project documentation and reporting (Rush and Connolly 2020). Overemphasis on planning without empirical testing leads to inconclusive outcomes, whereas excessive prototyping without a strategic framework result in resource inefficiency. Therefore, the optimal strategy entails a balanced approach that harmonizes theoretical groundwork with practical experimentation, thereby facilitating a path to project success.

The display of the sprint plan and review of two teams showed two very different approaches to the project, but also to answer the questions. While the Top team focused exclusively on technical issues, the Bottom team also addressed the teamwork. A sprint usually ends with a deliverable, a minimum viable product. With this plan, the Bottom team was doomed to failure.

The Top team demonstrated consistency throughout the sprint plan and review (C1-C3) by setting goals, designing a test case for these goals and showing results addressing the tests. However, the change of wording from 'gripper arm' to 'pick-up system' decreased comprehensibility. On the other hand, the Bottom team was inconsistent. The test case was not logically derived from the goals (C3) and the results did not easily follow the test case (C2). The results were unexpected due to the vague and unspecific description of the goals and test cases. The team was unclear on what to do, resulting in an unclear understanding of the expected outcome. As a result, the team described everything as a result, possibly creating confusion and a lower team value proposition.

Both teams state goals for the sprint. However, the Top team’s language and tone indicate a concrete and clear proceeding, whereas the Bottom team appears insecure in their plan (‘we will’ vs. ‘we need to’ / ‘possibly work on’). The usage of words such as ‘some', 'much more', and 'possibly' require clarification and a metric for quantification. The Bottom team's desired changes for their teamwork and brainstorming are unclear.

Both teams describe their approach to achieving the set goals. The Top team provides clear metrics for measuring and validating their progress. In contrast, the Bottom team‘s metric for measuring and validating their progress are vague and unspecific. Measuring the sprint success solely on the number of generated ideas may appear arbitrary and disorganized. It is unclear, how the team intends to assess whether future ideas are ‘much better’.

Although the Top team provided a concise description of the results, the sprint goals were not clearly identifiable due to inconsistent wording between the plan and review. The Bottom team's extensive use of new information and terminology made it challenging for the reader to understand the content. In contrast to the Bottom team, the Top Team described negative outcomes as well as successful outcomes, which shows critical thinking and looking at the whole picture.

Neither team explicitly reflected on whether their goals or assumptions were met or correct (C1). Instead, they repeated their assumptions. However, the Top team's assumptions can be partially reflected in the results, which partially address their sprint goals, whereas it is difficult to do the same for the Bottom team's results due to the unspecific sprint plan.

Translating the qualitative criteria into a measurable metric would enable statistical analysis of large classes with large data sets (López-Alcarria, Olivares-Vicente, and Poza-Vilches 2019). There is a huge workload connected to manually analyse qualitative text data. It is tedious and prone to bias. Applying such analysis approach to large classes is practically not feasible. However, the latest developments of large language model and the analysis of big text data may facilitate this and must be investigated in future studies.

5 CONCLUSION & OUTLOOK

The quantitative analysis showed that Top teams developed more prototypes and ran more tests per sprint, which led to more profound results. The qualitative analysis showed that the Top team was more consistent in the formulation of the sprint plan and sprint review.

This paper introduced an approach to analyse the project process qualitatively and quantitatively and highlighted the importance of monitoring the continuous progress throughout the entire project. This may eventually allow predictors to evaluate and provide formative feedback to teams during the early stages of development. The qualitative comparison of two teams demonstrated the underlaying challenges of a standardized and automated analysis of the sprint plan and review. Teams may have completely different approaches to the project and may be at different project stages. An appropriate metric is key to overcoming these challenges. Analysing large text data by hand is not only time-consuming and tedious, but also prone to bias. Large language models may enable new possibilities, decreasing manual labour and bias.

REFERENCES

Barron, Brigid J, Daniel L Schwartz, Nancy J Vye, Allison Moore, Anthony Petrosino, and Linda Zech. 1998. “Doing with Understanding: Lessons from Research on Problem-and Project-Based Learning.” *The Journal of the Learning Sciences* 7 (4): 271–311. http://www.jstor.org/stable/1466789.

Batliner, Martin, Stefan Boës, Johannes Heck, and Mirko Meboldt. 2022. “Linking Testing Activities with Success in Agile Development of Physical Products.” In

32nd CIRP Design Conference, 146–54. Elsevier. https://doi.org/10.3929/ethz-b-000566920.

Beck, Kent, Mike Beedle, Arie van Bennekum, Alistair, Cockburn, Ward Cunningham, Martin Fowler, James Grenning, et al. 2001. “Manifesto for Agile Software Development.” 2001.

Condliffe, Barbara, Janet Quint, Mary G Visher, Michael R Bangser, Sonia Drohojowska, Larissa Saco, and Elizabeth Nelson. 2017. “Project-Based Learning - A Literature Review.” https://americancollegiate.academy/wp-content/uploads/2024/02/Project-Based_Learning-LitRev_Final.pdf.

Cooper, Robert G., and Anita F. Sommer. 2016. “The Agile–Stage-Gate Hybrid Model: A Promising New Approach and a New Research Opportunity.” *Journal of Product Innovation Management* 33 (5): 513–26. https://doi.org/10.1111/JPIM.12314.

Duehr, Katharina, Pauline Efremov, Jonas Heimicke, Emilie Maria Teitz, Ferdinand Ort, Marion Weissenberger-Eibl, and Albert Albers. 2021. “The Positive Impact of Agile Retrospectives on the Collaboration of Distributed Development Teams – a Practical Approach on the Example of Bosch Engineering GmbH.” In *Proceedings of the Design Society*, 1:3071–80. Cambridge University Press. https://doi.org/10.1017/PDS.2021.568.

Fernandes, Sandra, José Dinis-Carvalho, and Ana Teresa Ferreira-Oliveira. 2021. “Improving the Performance of Student Teams in Project-Based Learning with Scrum.” https://doi.org/10.3390/educsci11080444.

Fuior, Flaviu. 2019. “Key Elements for the Success of the Most Popular Agile Methods.” *Romanian Journal of Information Technology and Automatic Control* 29 (4): 7–16. https://doi.org/10.33436/v29i4y201901.

Krajcik, Joseph, and Mun Kongju. 2014. “Promises and Challenges of Using Learning Technologies to Promote Student Learning of Science.” In *Research on Science Education*, 1st ed., 337–60.

Liu, Jing-Wei, Chia-Yu Ho, Jamie YT Chang, and Jacob Chia-An Tsai. 2019. “The Journal of Systems and Software The Role of Sprint Planning and Feedback in Game Development Projects: Implications for Game Quality.” *The Journal of Systems and Software* 154:79–91. https://doi.org/10.1016/j.jss.2019.04.057.

López-Alcarria, Abigail, Alberto Olivares-Vicente, and Fátima Poza-Vilches. 2019. “A Systematic Review of the Use of Agile Methodologies in Education to Foster Sustainability Competencies.” *Sustainability (Switzerland)* 11 (10). https://doi.org/10.3390/su11102915.

Mahnic, Viljan. 2015. “From Scrum to Kanban: Introducing Lean Principles to a Software Engineering Capstone Course.” *International Journal of Engineering Education*, January. https://www.researchgate.net/publication/280148437.

Marquardt, Michael, Ng Choon Seng, and Helen Goodson. 2010. “Team Development via Action Learning.” *Advances in Developing Human Resources* 12 (2): 241–59. https://doi.org/10.1177/1523422310367810.

Neumann, Michael, and Lars Baumann. 2021. “Agile Methods in Higher Education: Adapting and Using EduScrum with Real World Projects.” *IEEE Frontiers in Education Conference (FIE)*, 1–8.

Omidvarkarjan, Daniel, Jonas Conrad, Constantin Herbst, Christoph Klahn, and Mirko Meboldt. 2020. “Bender - An Educational Game for Teaching Agile Hardware Development.” In *Procedia Manufacturing*, 45:313–18. Elsevier B.V. https://doi.org/10.1016/j.promfg.2020.04.023.

Pócsová, Jana, Dagmar Bednárová, Gabriela Bogdanovská, and Andrea Mojžišová. 2020. “Implementation of Agile Methodologies in an Engineering Course.” *Education Sciences* 10 (11): 1–19. https://doi.org/10.3390/educsci10110333.

Ralph, Rachel A. 2015. “POST SECONDARY PROJECT-BASED LEARNING IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS.” *Journal of Technology and Science Education* 6 (1): 26–35. https://doi.org/10.3926/jotse.155.

Ríos, Ignacio De Los, Adolfo Cazorla, José M. Díaz-Puente, and José L. Yagüe. 2010. “Project–Based Learning in Engineering Higher Education: Two Decades of Teaching Competences in Real Environments.” *Procedia - Social and Behavioral Sciences* 2 (2): 1368–78. https://doi.org/10.1016/J.SBSPRO.2010.03.202.

Rush, Daniel E, and Amy J Connolly. 2020. “An Agile Framework for Teaching with Scrum in the IT Project Management Classroom.” *Journal of Information Systems Education* 31 (3): 196–207.

Tawfik, Andrew A, Hui Rong, and Ikseon Choi. 2015. “Failing to Learn: Towards a Unified Design Approach for Failure-Based Learning.” *Education Tech Research Dev* 63:975–94. https://doi.org/10.1007/s11423-015-9399-0.

Türk, Daniel, Bastian Leutenecker, and Mirko Meboldt. 2014. “Experience the Relevance of Testing in Engineering Design Education.” In *Proceedings of the 10th International CDIO Conference*. Barcelona. https://www.researchgate.net/publication/318788189.

Zhang, Liangting, Bin Wang, Xiaoxia Feng, Yue Zhang, and Wenzhou Wang. 2022. “Exploring the Influence of Failure Aversion on Learning From Project Failure: A Sensemaking Perspective.” *Frontiers in Psychology* 13 (May):794390. https://doi.org/10.3389/FPSYG.2022.794390.

Zhou, Chunfang, Anette Kolmos, and Jens Dalsgaard Nielsen. 2011. “A Problem and Project-Based Learning (PBL) Approach to Motivate Group Creativity in Engineering Education A Problem and Project-Based Learning (PBL) Approach to Motivate Group Creativity in Engineering Education*.” *International Journal of Engineering Education* 28 (1): 1–14. https://www.researchgate.net/publication/286072409.

Workshop papers

SEFI
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2–5 SEPTEMBER 2024
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THE LEARNING STATION MODEL: CO-CREATION WITH STUDENTS AND STAKEHOLDERS AS A PRACTICE FOR KNOWING, THINKING, FEELING AND DOING

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***Conference Key Areas**: Track 2 and Track 3*

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***Keywords**: Active learning; Co-creation; Stakeholder engagement*

ABSTRACT

Departing from Active Learning processes, this workshop proposal showcases Learning Station (LS) model as an innovative teaching and learning practice, that enables the modular reconfiguration of learning landscape in higher education institutions. As the LS model is generated concerning individuals' ability to construct their own learning experiences in line with their strengths and preferred learning styles, it also transfers the ownership of learning to learners, requiring a shift from mere instruction to mentorship on the teachers' side. LS model further enables the co-creation of knowledge with all the relevant stakeholders of any learning experience in interactive ways. This workshop invites the participants and the SEFI audience to explore more on this model with the hands-on experience and through a Training of the Trainers program.

1 INTRODUCTION

1.1 Motivation and background

Active learning (AL) is an umbrella term for pedagogies and a broad range of instructional activities that focus on student activities and student engagement in the learning process (Prince, 2004, p.223; Roehl et al., 2013, p.45). AL requires learners to engage in doing things and thinking about what they are doing (Prince, 2004, p.226), as opposed to traditional lectures where learners are often passive recipients of knowledge. Knowledge construction instead of knowledge absorption; critical consideration of learning materials instead of replication and regurgitation of knowledge stock; problem-solving with independent thought, and a deeper understanding of phenomena are amongst the characteristics of AL (Roberts, 2017, p.64), all of which significantly require considerable learner engagement. Empirical evidence shows that the traditional instructional methods often fail to address the learning preferences of young people, who often have less tolerance especially, for the lecture style instruction (Roehl et al., 2013, p.45). Due to the increased interest in AL in the last few decades, instructional designers continuously expand the portfolio of AL methods under the broad categories of individual activities, paired activities, informal small groups, and cooperative student projects (Zayapragassarazan and Kumar, 2012, in Roehl et al., 2013, p.45), which may include several strategies such as conceptual mapping, brainstorming, collaborative writing, case-based instruction, cooperative learning, role-playing, simulation, peer teaching, project-based learning, along with others.

However, while many AL approaches, methods, and tools co-exist in various learning environments and contexts along with classical pedagogical approaches, current educational framings and practices do not provide the *flexibility* needed to use them in a complementary way, although using the right pedagogical approach at the right time and in the right environment is a prerequisite for benefiting from the creative potential of young learners in line with their preferred learning styles, strengths and talents that correspond to alternative ways of *knowing*, *thinking*, *feeling* and *doing* through different learning modalities.

The workshop proposed aims to introduce an innovative teaching and learning model – The Learning Station (LS)- which has been embedded and piloted in various international projects by the Istanbul Technical University Centre for Excellence in Education (ITU CEE). The LS model is also at the focal point of package 6 (‘Innovative Teaching and Learning Hubs’) of the EELISA European University project (eelisa.eu) aiming to “foster the use of and facilitate the exchange on innovative pedagogies, and to support the modularization of educational offers through architectures and complementary IT-processes”. The Turkish Ministry of education is amongst the collaborators of the model which aims to re-design the ‘Playground of Learning’ in a modular way to facilitate the co-creation of learning experiences in education institutions in collaboration with the relevant internal and external stakeholders of the topics of interest, while allowing the complementary use of alternative pedagogical approaches by students, teachers and mentors. Introduction of the LS model to the SEFI community is likely to generate fruitful discussions relating to AL, co-creation, and stakeholder engagement for improving the quality of learning experiences within the higher education ecosystem.

1.2 Target audience and learning outcomes

While the typical use of the LS model within the context of AI prioritizes its use by students for designing learning experiences for themselves in a given topic through the guidance and mentorship of teachers, academics who teach in universities and the administrators who are in charge of the design of educational activities in their institutions will be the specific target audience of the proposed workshop. The workshop, which will be organized in the form of a ‘*Training of the Trainers’* (ToT) Program, will allow its participants to:

- understand a novel approach that organizes the learning landscape in a modular way to allow the use of alternative pedagogical approach;
- explore how the diverse stakeholders of learning experiences can be incorporated into the process to improve the quality of teaching and learning; and
- explore alternative strategies to benefit from the creative potential of young learners when co-creating high-quality learning materials.

1.3 Significance

One of the main strengths of the LS model is that it allows the multiple and complementary use of alternative AL approaches, each of which is likely to function better in different learning environments. Instead of placing overemphasis on a particular AL approach (e.g., project-based learning, research-based learning, experiential learning, cased-based learning etc), the proposed workshop will rather focus on how they can be combined in a value-adding way to transform the traditional learning environments to allow “knowing, thinking, feeling and doing” with a holistic framework. Lessons learned from various international projects relating the use of the LS model will also be shared with the participants.

2 METHODOLOGY

The multi-stage format of the Training of Trainers (ToT) Program, which has been tested in various projects, will be adapted to the participants of the SEFI workshop (see Fig.1 and Fig. 2). Following sub-sections explain the workshop design and introduce the relevant materials.

Fig. 1. A screenshot from the ITU CEE process chart for the ToT

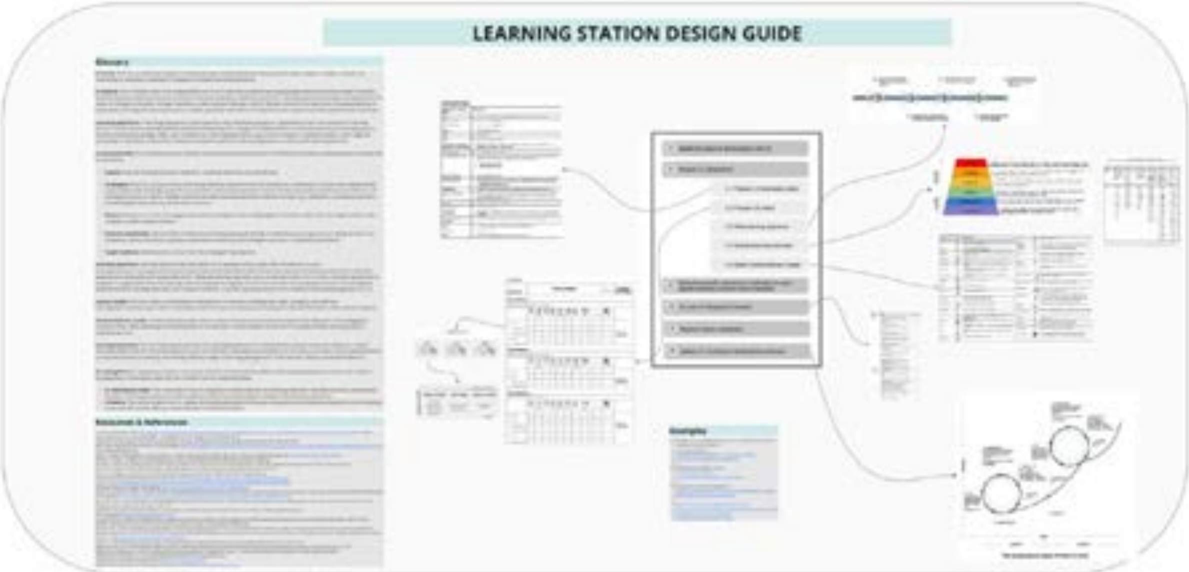

Fig. 2. A screenshot from the ITU CEE content for the ToT

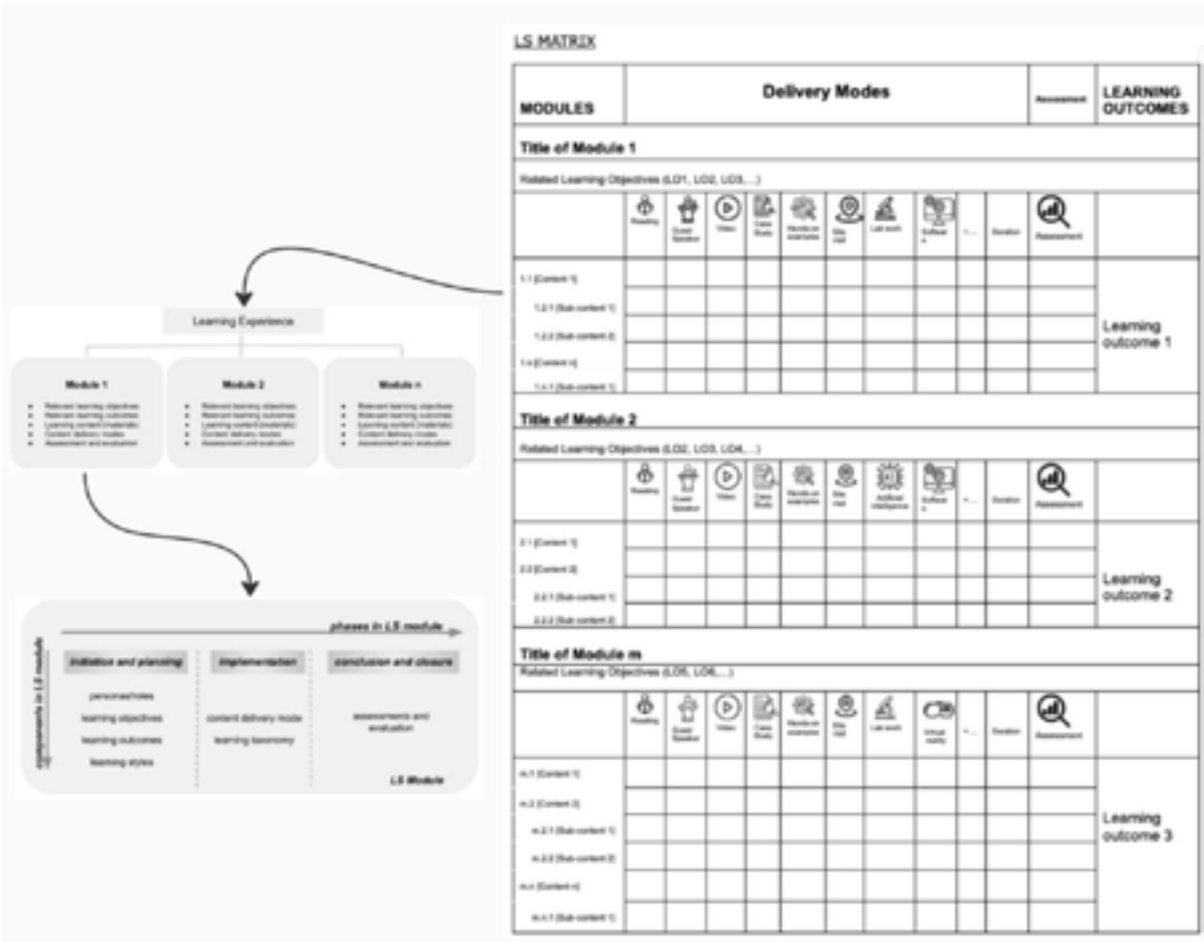

Fig. 3. *A screenshot from the ITU CEE content for the ToT*

2.1 Pre-workshop activities

SEFI community will be invited in advance to an introductory webinar on the Learning Station (LS) model, before the annual conference starts. The webinar will introduce the fundamental building blocks of the LS model and include a Q&A session to address the questions and concerns of the potential participants of the ToT program. The Learning Station Design Guide, the LS Design Toolkit, and the link of a Miro board including all ToT materials will be shared with the participants at the end of the webinar. A second registration form will be sent to the participants of the webinar to clarify the participants of the SEFI workshop and they will be asked either as individually or groups to indicate the topics on which they will be expected to design their LSs. Re-design of existing courses with the LS model or the proposal of new courses or other types of learning experiences will be acceptable. ITU CEE will provide live support from the Miro board to the LS designers until the SEFI workshop and arrange on-demand online sessions, if needed, to give feedback to their LS designs and address challenges.

2.2 Workshop activities

After a short introduction and an icebreaker exercise, the workshop will continue with the presentations of individuals or groups who have designed LSs. A group discussion will follow to allow all participants to share experiences and give feedback to each other for exploring the ways to improve the use of the model for enhancing the quality of teaching and learning in different engineering and related disciplines. An exit survey will be shared with the participants of the workshop at the end of the session to get structured feedback.

2.3 Post-workshop activities

Based on the exit survey, a feedback report will be prepared and shared with the workshop participants after the SEFI conference. Additionally, an online feedback session will be organized to discuss the report and explore potentialities for the future use of the LS model. Meanwhile, ITU CEE will keep the live support (Miro board) open to all participants of the workshop who want to further improve their LS designs.

3 RESULTS

Based on lessons learned from various, international projects, the proposed workshop introduced a flexible and innovative model that aims to re-organize the learning landscape of engineering and the related fields with a modular mindset that allows the use of alternative AL approaches that co-exist in the current learning environments in a complementary way. In total, 13 researchers from various universities participated in the workshop. Following a short introduction of the LS model, the hands-on part included a group exercise which aimed to design a learning experience relating to various topics selected by the participants themselves. Following the completion of the exercise, feedback were given to each group and the workshop was finalized with a Q&A session and group discussion on the LS model. Exploring ways for engaging with the stakeholders of the higher education system to improve the quality of learning and teaching materials and co-creating high quality content with learners were amongst the outcomes from the workshop. Results from the workshop was also instrumental to conceptualizing the 'Co-learning Lab 2024' of the ITU, in addition to revising and publishing the 'Learning Station Design Guide'.

REFERENCES

Prince, Michael. "Does active learning work? A review of the research." *Journal of Engineering Education* 93.3 (2004): 223-231.

Roberts, David "Higher education lectures: From passive to active learning via imagery? Active Learning in Higher Education." 20.1 2017): 63-77.

Roehl, Amy, Shweta Linga Reddy, and Gayla Jett Shannon. "The flipped classroom: An opportunity to engage millennial students through active learning strategies." *Journal of Family and Consumer Sciences* 105.2 (2013): 44.

Zayapragassarazan, Z., and Santosh Kumar. "Active learning methods." *Online Submission* 19.1 (2012): 3-5.

SEFI ANNUAL CONFERENCE 2-5 SEPTEMBER 2024 LAUSANNE

DESIGNING TEACHING AND LEARNING ACTIVITIES IN DIFFERENT LEARNING SPACES: CONSIDERING PACE, PLACE AND PEDAGOGY

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***Conference Key Areas**: 15. Building the capacity and strengthening the educational competences of engineering educators, 11. Engineering skills, professional skills, and transversal skills.*
***Keywords**: student-centred learning spaces, teaching and learning design, scaffolding, collaboration and reflection.*

ABSTRACT

We see a growing interest in learning spaces that facilitate collaborative learning. Research has shown that student-centred approaches and peer interaction improve student learning and therefore should be incorporated in the teaching and learning design. However, for a teacher, this transformation to a student-centred approach requires support and guidance, and there is a need for reflection on various aspects

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of the learning design and the possibilities of the spaces used. This workshop is an opportunity for such reflection.

In this workshop, we will explore different aspects related to designing learning experiences for traditional and student-centred learning spaces. These experiences can range from highly teacher-controlled activities to approaches where students are in 'control' and make decisions about which activities to complete and how to manage them.

Participants of the workshop will engage in various activities to get a better understanding of the challenges that teachers face when developing and orchestrating student-centred activities. They will have the opportunity to develop new ideas and perspectives on teaching and learning designs for various types of learning spaces and get insight into the scaffolding required to manage these activities. Participants will leave the workshop having reflected on their own teaching practice and with a better understanding of how to structure activities in various learning spaces.

1 BACKGROUND AND RATIONALE OF THE SESSION

Many universities have an increased interest in creating learning spaces that facilitate collaborative learning as research shows that student-centred approaches and peer interaction improve student learning (Freeman et al. 2014; Deslauriers et al. 2019). This is also in line with, for example, the CDIO initiative (CDIO 2024). Although spaces that are specifically designed for collaborative learning (UCISA Toolkit 2024) offer teachers many possibilities for student-centred learning experiences, teaching staff still need support and guidance when starting to use active learning spaces. During a previous workshop at the SEFI conference (Korpås et al. 2023) participants highlighted the need for well-described and clear objectives for learning activities. They advised against lecturing in this setting or to limit lecturing to short segments. It was emphasised that peer interaction as well as student-teacher interactions should be encouraged, while individual student work should be kept to a minimum. Participants also mentioned the need for a teacher-driven approach with a set pace and with frequent shifts between group work and plenary activities. However, activities can range from highly teacher-controlled learning activities to approaches where the students themselves are in ‘control’ and decide on which activities they will engage in and how they undertake them.

In a student-centred learning space, students are expected to collaborate, which is reflected in the layout of the space. What is common in almost all physical learning spaces are designated places for the students, and somewhere for the teacher to be based. The positioning of the teacher, furniture and technology will impact to what extent student-centred activities are promoted (Ellis and Goodyear 2016). When the teacher is positioned at the front, there is a tendency for more lecturing, as opposed to a student-centred learning space where the teacher is based to one side, or maybe does not have a designated position at all. In a student-centred learning space, it is easier for the students to have equal access to the teacher, compared to a traditional lecture hall where some students are closer to the teacher than others (Lejon et al. 2022).

In this workshop, we will explore the range of teaching and learning approaches in different types of learning spaces. Participants will exchange thoughts on why they as educators would choose a more teacher- or student-controlled approach and how this is affected by the learning space. They will discuss and reflect on: How to design and orchestrate the learning activities in these spaces? What scaffolding is needed? What challenges and opportunities do these approaches involve?

The workshop is a follow-up of a previous workshop held at the SEFI conference in 2023, which led to a collaboration between the organisers. The organisers regularly teach in student-centred learning spaces and have been using active learning approaches for many years. Additionally, they support colleagues with their transition to active learning approaches and have researched student experiences.

2 LEARNING OUTCOMES

During the workshop, the participants will:

- get a better understanding of the challenges involved when designing teaching and learning activities in different learning spaces.
- reflect on their own teaching practice.
- get insight into the scaffolding required to manage these activities.

3 WORKSHOP DESIGN

The participants will be allocated into small groups and the discussions will be facilitated by the workshop organisers. Images of three different learning spaces will be used as inspiration: a traditional lecture hall (figure 1), and two student-centred learning spaces, one with a clearly defined teacher zone (figure 2), and one without a well-defined spot for the teacher (figure 3).

Fig. 1. Lecture hall with a defined teacher zone

Fig. 2. Student-centred learning space with a defined teacher zone

Fig. 3. Student-centred learning space without a well-defined zone for the teacher

The workshop will consist of a series of activities:

Activity 1 (15 min): If you were to teach in these three spaces, where would you as a teacher be positioned? (The participants mark their typical positions using post-it notes to posters of different spaces, and the organisers facilitate a plenum discussion.)

Activity 2 (20 min): How do you plan the teaching and learning activities in these spaces? How will you approach it? What are the challenges? (The participants discuss in groups facilitated by the organisers and subsequently shared in a plenary discussion.)

Activity 3 (5 min): When you are planning your teaching and learning activities, are the students expected to be working at the same pace or not? (The participants mark their typical preference for each space on a scale.)

Activity 4 (20 min): What are the challenges and opportunities of having students working at the same pace or not? (The participants discuss in groups facilitated by the organisers and subsequently shared in a plenary discussion.)

4 RESULTS OF THE WORKSHOP

During the **first activity**, participants placed yellow sticky notes (Table 1) on posters of the different learning spaces to indicate where they would be positioned during teaching. From the pattern of pasted notes (see images Table 1) and the discussion that followed, it became clear that many participants used the lecture hall to its maximal potential, i.e. they would not only stand at the front of the room but walk up the aisles to interact with students or student groups. However, for the two student-centred learning spaces, participants could see themselves interacting much more easily with students and this at the same eye level, which they felt was more pleasant and less teacher-focused. In general, student-teacher interaction was highly valued.

In the **second activity,** the discussion expanded to how participants would approach teaching and learning in these different spaces and what the associated challenges and opportunities would be. In groups of four, participants wrote down their key thoughts on paper, which were collected at the end of the session. The main points raised by the groups have been summarised in Table 1.

Table 1. Key thoughts of participants on how they would plan teaching and learning activities in different types of learning spaces, and the opportunities and potential challenges associated with this.

		
Lecture hall	**Student-centred learning spaces**	
	defined teacher zone	**without a well-defined teacher zone**
• Delivery-focused • Technology is needed to 'upgrade' from just lecturing, e.g. polling • Peer discussion is possible in pairs	• Can alternate between transfer of information and exercises (group work) • Smaller project work in teams is possible • Teacher becomes a facilitator	• Allows for peer interaction and learning • Individual and group work possible • Booths available for quiet learning or consultation (the 'confession room')
+ Possibility to record the session + Can teach many students at once and keep an eye on everyone	+ Furniture can be moved around offering flexibility, students can work on tangible objects on the tables	+ Zones can be created for different activities and tasks + More flexibility in using the space

	+ Layout makes it easy to move around for everyone	
− Layout makes it difficult to move around for teacher and students	− Less control as a teacher	± Lack of teacher control

To broaden this discussion further, the **third and fourth activities** introduced the concept of ‘pace’. Participants indicated on a scale whether students would generally work at the same pace or at a different pace if they would teach in that particular space. This was followed by a discussion on the challenges and opportunities that this element of ‘pace’ can bring (Table 2), which participants wrote on paper. The participants found this a very interesting topic to discuss, and to reflect on in relation to their own teaching practice. When looking at the pink/orange sticky notes that participants placed on the scales (see images Table 1, ‘same pace’ on the left and ‘different pace’ on the right), student-centred learning spaces were felt as more supportive or conducive to having students working at a different pace, while the lecture hall is seen as being limited to students collectively going through activities at the same speed. In Table 2, we have captured the main thoughts that participants expressed about the aspect of pace.

Table 2. Key thoughts of participants on the opportunities and challenges that students working at the same pace or a different pace bring.

	Same pace	**Different pace**
Opportunities	• Easier to manage as a teacher • Video-capturing is possible • Peer interactions are stimulated • Whole group discussions are possible • Students might feel that they belong to a group • Steady progression, as the whole process is teacher-controlled	• Students can work at their own pace • Students can explore different topics • More time for the teacher to focus on students that need extra help • Faster students can support other students or work on extension tasks • Students are less frustrated
Challenges	• More challenging for students, more frustration • Student-student and student-teacher interactions are out of phase • There is waiting time for fast students (extra exercises needed) • Students who need a bit more time fail to complete the activities	• Difficult to manage, more challenging for the teacher because of individual paces • Students who work slower might feel that they are behind • Reliance on time management and self-regulation skills of students • Scaffolding needed for students • Loose progression

From the discussions during the workshop, it became clear that many participants were already educators who highly valued student-teacher and student-student interactions. Even in a lecture hall, that is not conducive to student-centred learning, they forced the teacher-focused space to work in such a way by introducing activities and using a teaching style that supports interaction. Although the type of space was not a barrier for the participants to use active learning approaches, the student-centred learning spaces opened up a range of teaching and learning possibilities not easily feasible in classical lecture halls. Participants highlighted that student-centred learning spaces promote group work and peer learning, offer easy access to students and teacher and are not only flexible in terms of layout and infrastructure but also in terms of the learning design, for example, groups of students can work on different activities at a different pace. The latter seemed most encouraged in a learning space that lacked a well-defined teacher zone. Nevertheless, teaching and learning activities that run in these student-centred spaces require some thought in terms of planning and management and often a bit of courage to give students a bit more control in their learning process.

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REFERENCES

CDIO. “The CDIO Initiative is an innovative educational framework for producing the next generation of engineers.” (2024) Accessed 3 April. 2024, http://www.cdio.org/about.

Deslauriers, L., L. S. McCarty, K. Miller, K. Callaghan, and G. Kestin. "Measuring Actual Learning versus Feeling of Learning in Response to Being Actively Engaged in the Classroom." *Proceedings of the National Academy of Sciences* 116, no. 39 (2019): 19251-19257. https://doi.org/10.1073/pnas.1821936116.

Ellis, R.A. and P. Goodyear. “Models of learning space: integrating research on space, place and learning in higher education.” *Review of Education* 4, no. 2 (2016): 149-191. https://doi.org/10.1002/rev3.3056

Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences* 111, no. 23 (2014): 8410-8415. https://doi.org/10.1073/pnas.1319030111.

Korpås, G. S., T. H. Andersen, M. S. Kahrs, G. Hansen, and K. A. F. Røren. “Teaching in student-centred active learning spaces: How relational, pedagogical, spatial, and technological aspects intertwine and affect the learning environment.” *Proceedings of the 51st Annual Conference of the European Society for Engineering Education, SEFI* (2023): https://doi.org/10.21427/H9Y4-CZ56

Leijon, M., I. Nordmo, Å. Tieva, and R. Troelsen. “Formal Learning Spaces in Higher Education – a Systematic Review.” *Teaching in Higher Education* (2022): 1–22. https://doi:10.1080/13562517.2022.2066469.

UCISA Toolkit, The UK Higher Education Learning Space Toolkit: a SCHOMS, AUDE and UCISA collaboration. Retrieved June 3, 2024, from https://www.ucisa.ac.uk/Resources/The-UK-Higher-Education-Learning-Space-Toolkit

What more can I/we do? Exploring the potential of humor and activism for accelerating educational transformation

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***Conference Key Areas**:* Teaching the knowledge, skills and attitudes of sustainable engineering; Engineering ethics education
***Keywords**:* Educational transformation, societal transformation, sustainability, humor, activism

ABSTRACT

This workshop was designed to be an open space to share and discuss possibilities to act for fundamental, perhaps radical, change in engineering education – towards an education that not only fosters technological excellence, but also contributes to fundamentally transforming society towards more sustainable ways of living. Our aim was to engage the participants in collaborative learning and co-creation activities to develop new knowledge, agency, and networks for educational change. To stimulate discussions, we first introduced two approaches for driving transformation: humor and activism. Then we introduced the "yes and"-technique which has previously been successfully applied for organizational development in higher education. Six groups with five to six participants applied this technique during the workshop. The 'yes and'-technique engaged the groups significantly and participants reported that they were surprised at how difficult it was to avoid the words "no", "not", and "but. We co-developed a list of action points that we can use to contribute to transforming

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engineering education where several action points were inspired by activism and/or humour.

1 INTRODUCTION

Most engineers, engineering educators, and engineering education researchers have chosen their professional path out of a desire to contribute to a positive development of society. Indeed, science and technology have contributed to tremendous improvements of human lives, but this development has also led to negative effects that have been argued to threaten our very existence on this planet. We are living in what is now frequently referred to as the Anthropocene, with humans affecting the planetary system to the extent that it becomes increasingly unstable. For example, our continued emission of greenhouse gasses impacts global climate systems and already today contributes to devastating forest fires, floods, and storms. According to Stoddard et al. (2021), exaggerated techno-optimism – or techno-solutionism – presents a fundamental barrier to climate mitigation. Still, science and engineering education tend to reproduce techno-optimism, rather than critically analyzing what technology we develop, why, and for whom (Ottemo et al. 2020). Engineering students are encouraged to focus on narrow, technical problem-solving (Peters 2018). Ethical concerns, for example, are constructed as something 'other' and less important than technical concerns (Lönngren 2021). For engineering education to remain relevant in the Anthropocene, it must move away from such narrow understandings of engineering and broader societal perspectives must be strengthened. Engineering education can and must contribute to fundamentally transforming all aspects of society towards more sustainable ways of living (IPCC 2018), but efforts for sustainability in engineering education are still mostly limited to minor changes, e.g., adding isolated sustainability modules (Kolmos, Hadgraft & Holgaard 2016). These efforts are also often underpinned by dominant neoliberal ideologies that tend to worsen rather than ameliorate sustainability issues (Gutierrez-Bucheli, Kidman & Reid 2022).

2 A WORKSHOP FOR CHANGE

In this workshop, we discussed the role of education researchers and educational developers in fundamentally transforming engineering education. We directed this workshop to participants who are already aware of the sustainability challenges as well as the need for fundamental change and who ask "What more can I do?". For example, some participants may already have tried to critique current engineering education or develop transformative education, but experienced challenges and resistance. Our aim was to provide an open space to share and discuss possibilities to more effectively drive fundamental, perhaps radical, change in engineering education. We asked the participants:

1. How can we support university teachers who wish to develop their education to contribute to societal transformation?
2. How could we promote change through research to challenge dominant norms and practices?
3. How can we collaborate with other actors (e.g., students, industry leaders, activists) to accelerate change in engineering education?

4. How can we support each other in our diverse struggles for change?

While primarily focusing on engineering education, we also allowed the discussions to move towards broader issues relating to education and engineering. For example, education is said to have been instrumentalized as a tool to promote economic growth (i.e. maintain the status quo; Sterling 2017) rather than leverage knowledge, creativity, and community for societal change. Exploring the role of engineering education for change therefore needs to be seen in the larger context of education, informed by research on education for sustainable development, ESD[2].

ESD research has shown that educators' professional development is important for promoting ESD and catalyzing change in higher education (Mulà et al. 2017). However, few European institutions have implemented significant staff development programs to enhance educators' ESD competences and leadership capabilities (ibid.). Other studies have shown that educators who have completed staff development programs may not be able to leverage what they have learnt for actually transforming education (Elmberger et al. 2023), often because they lack a supportive community. In this workshop, we therefore emphasize collaborative learning, co-creation, and community building. As a starting point for the discussions, we introduce two possible approaches to driving transformation: humor and activism.

3 TWO POSSIBLE APPROACHES: HUMOR AND ACTIVISM

We presented two approaches for change. Our first approach was humor. For several reasons, humor is a powerful tool for addressing societal challenges, such as climate disaster and extreme hunger. Humor concerning our society is often critical; it attacks those in power, and it highlights faults and deficiencies in the political system (Billig 2005). Political humor assumes, and is built on, that the audience have feelings for politics – frustration, joy, hope, enthusiasm, anger, resignation, and so on (Doona 2022). Comic mediations of politics are therefore strongly effective for describing political reality since these are working 'from and upon emotional patterns' (Corner et al. 2013, p.32). For example, Randall Munroe, use both humor and science to explain our climate change in his webcomic xkcd (2024):

[2] Also termed environmental and sustainability education (ESE).

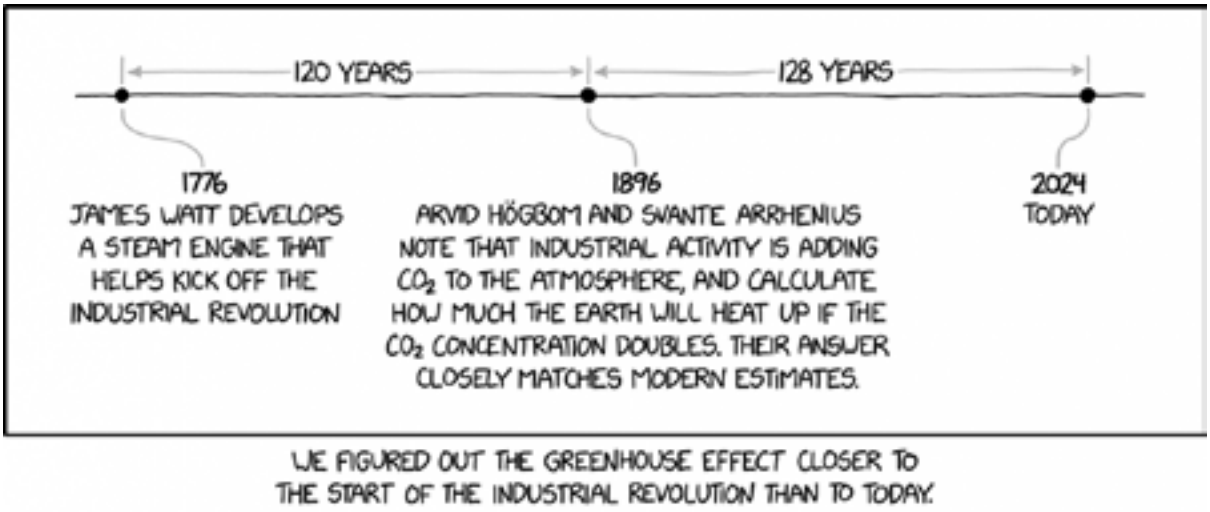

Fig. 1. Randall Munroe portrays when scientist started to talk about climate change

Munroe is using absurd facts to make us laugh, to understand the world around us, but also to feel frustration. Humor may also create a distance to the topic (Cohn 1987); Cohn noted how the participants in a center for defense technology and arms humorously talked about missiles without touching on the realities of nuclear holocaust that lay behind the words. For instance, the MX missile was called ‘the Peacekeeper’ and the bombs dropped over Hiroshima and Nagasaki were called ‘Little Boy’ and ‘Fat Man’. This humoristic language distanced the people working with nuclear weapons from the disastrous impact those weapons can have if they are deployed. The power of humor is connected to patterns of in-/exclusion: Those who understand a joke are brought together, while others are shut out. In other words, humor is both ‘social and anti-social in that it can both forge social bonds and exclude’ (Billig 2005, p. 176). Jokes challenge the taken-for-granted and often deal with taboos and moral boundaries, they provide useful tools for discerning hidden norms (Kobayashi & Berge 2022) and facilitating critical discussions about how we should live our lives. In this workshop, we challenged participants to reflect on the ways in which they consciously or unconsciously use humor when they teach, for example through webcomics or stimulating laughter. What norms are challenged or reproduced through their use of humor? How may the humor participants use contribute to in-/exclusion in the classroom and (dis-)engagement with societal aspects of engineering? And how do/could they use laughter intentionally to diffuse tensions in social interaction, facilitate perspective shifts, and open new possibilities of (inter)action?

Our second approach for change was activism. Following decades of discussions on normativity in ESD (e.g. Kopnina 2015; Tryggvason et al. 2023), we are left wondering whether/how we can reconcile non-prescriptive education with the pressing need for fundamental, radical change for sustainability. Some research has argued for playful and creative approaches to educating students for radically different futures (Barrineau et al. 2022). However, do these approaches remain helpful as the urgency for change increases? Can we still rely on the power of conversations around ‘matters of concern’ (Latour 2004) and openness in educational encounters (Barrineau et al. 2022) or do we need more powerful interventions? Other research focuses on such interventions, suggesting that activism is one of the most effective tools for achieving (radical) change (Sutoris 2022). So far, however, activism seems somewhat taboo in academic contexts and engaging in it may have negative consequences for one's career, health, and safety. Activism may also further increase polarization in academia and the wider society, which we see in the ongoing pro-Palestinian activism on and around university campuses. While we find it important to consider possible risks, we also want to highlight that activism can be done in many different ways. We see that it can be open, playful, co-creative, and peaceful. In this workshop, we discussed the (in)acceptability and (in)effectiveness of potential activist approaches for transforming engineering education. We also reflected on whether/how we could see ourselves engaging in activism or supporting others to do so. Finally, if we do use activism, do we perhaps also limit the possibilities of a peaceful and democratic future in and through education? How can we drive change while paying attention to relationality and emotional engagement with each other and the world?

4 WORKSHOP DESIGN

The workshop was mainly based on a brainstorming tool called the 'yes and'-technique, which has previously been successfully applied for organizational development in higher education (Rossing & Hoffmann-Longtin 2016). In this approach, saying "yes and" means that we accept any ideas and suggestions offered by other participants, rather than blocking or rejecting ideas (ibid.). Thus, we can postpone premature judgement based on taken-for-granted norms and creatively explore alternative ways of being and acting for change. The workshop was structured as follows:

1. We introduced research on the need for profound societal and educational change and humor and activism as two possible approaches. (5-10 min)
2. Participants briefly discussed challenges and opportunities associated with the two approaches and, more broadly, 'What more can I do?'. (10 min)
3. We introduced the 'yes and'- technique (5 min).
4. In small groups, participants used the 'yes and'- technique to collaboratively explore and co-create unexpected possibilities for change. (20-25 min)
5. Participants shared their most important insights in plenum, and we discussed possible ways forward (10 min).

5 OUTCOMES

The 'yes and'-technique engaged the groups significantly, and the sound volume became very high. Participants reported that they were surprised at how difficult it was to avoid the words "no", "not", and "but." Once they got used to it, however, they found the 'yes and'-technique useful for co-creating ideas together, focusing on opportunities instead of obstacles, and creating trust in their small groups. Interestingly, we saw a clear geographic divide: many participants from North America were very familiar with the 'yes and'-technique and even reported using it with their students in their own teaching. Many participants from Europe, on the other hand, said that it was a new experience for them. One participant from South Africa also shared that they regularly and successfully use this technique to obtain buy-in for institutional change.

While the workshop was too short to develop participants' 'agency for change' in real time, we co-developed a list of action points that we could use to contribute to transforming engineering education (see Figure 2). Several of the action points were inspired by activism and/or humour. For example, one group suggested organizing a stand-up comedy festival or post comedy strips on sustainability to raise awareness and create engagement. Another group suggested that we need senior academics as activist role models – to show that activism is something one can engage in in academia and inspire others to follow. After the workshop, we posted the list of action points at the entrance of the conference building, where all conference participants pass by.

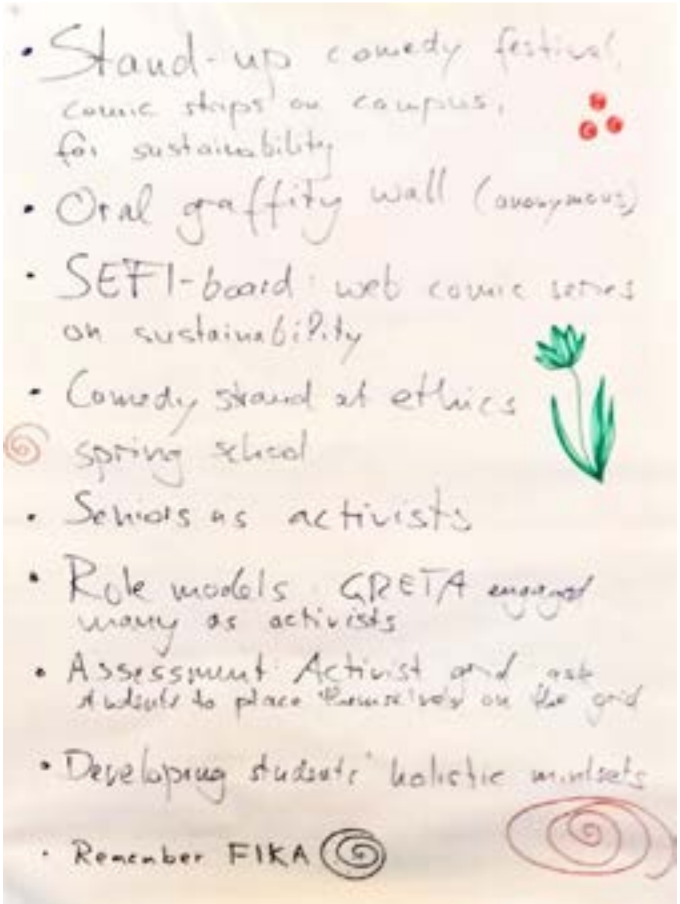

Fig. 2. Co-developed a list of action points

One participant sent us an email a week later, writing that the workshop made him think about pedagogical applications. He envisioned an engineering education practice in which he would ask the students to identify something they would like to change. He also planned to teach students about historical change processes in which technological development, scientific discoveries, social relations, and activism interacted. We feel inspired by this suggestion, and we envision that engineering students, based on lessons learned from historical examples, could use the 'yes and'-technique to identify ways of recreating similar change processes for the future.

REFERENCES

Barrineau, S., L. Mendy, and A.-K. Peters. “Emergentist education and the opportunities of radical futurity”. *Futures*, 144, 103062. (2022) https://doi.org/10.1016/j.futures.2022.103062

Billig, M. *Laughter and Ridicule: Towards a Social Critique of Humor*. London; Thousand Oaks: Sage, 2005.

Cohn, C. S*ex and death in the rational world of defense intellectuals*. Signs, 687–718, 1987.

Corner, J., K. Richardson and K. Parry. “Comedy, the civic subject, and generic mediation”. *Television & New Media*, 14(1), (2013): 31-45.

Corres, A., M. Rieckmann, A. Espasa, and I. Ruiz-Mallén. Educator competences in sustainability education: A systematic review of frameworks. *Sustainability,* 12(23), 9858. (2020)

Doona, J. *Det politiska skrattet: Satir och medborgarskap* [In English: The political laugh: Satire and citizenship]. Studentlitteratur, 2022.

Elmberger A., J Blitz, E. Björck, J. Niemine and K. Bolander Laksov. ”Faculty development participants' experiences of working with change in clinical settings”. *Med Educ*. 57(7) (2023): 679-688. doi:10.1111/medu.14992.

Gutierrez-Bucheli, L., G. Kidman and A. Reid. “Sustainability in engineering education: A review of learning outcomes”. *Journal of Cleaner Production*, 330, 129734. 2020 https://doi.org/10.1016/j.jclepro.2021.129734

Intergovernmental Panel on Climate Change (IPCC). An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. https://www.ipcc.ch/sr15/ 2018.

Kobayashi, S and M. Berge. “Learning norms of science through laughter: a study of humour in life science supervision”. *International Journal of Science Education,* 44(10), (2022): 1680-1699.

Kolmos, A., Hadgraft, R. G. and J. E. Holgaard. “Response strategies for curriculum change in engineering”. *International Journal of Technology and Design Education*, 26(3) (2016), 391–411. https://doi.org/10.1007/s10798-015-9319-y

Kopnina, H. “Neoliberalism, pluralism and environmental education: The call for radical re-orientation”. *Environmental Development*, 15, (2015): 120–130. https://doi.org/10.1016/j.envdev.2015.03.005

Latour, B. “Why has critique run out of steam? From matters of fact to matters of concern”. *Critical Inquiry*, 30(2), (2015): 225–248. https://doi.org/10.1086/421123

Lönngren, J. “Exploring the Discursive Construction of Ethics in an Introductory Engineering Course”. *Journal of Engineering Education*, 110(1) (2021): 44–69 https://doi.org/10.1002/jee.20367

Mulà, I., D. Tilbury, A. Ryan, M. Mader, J. Dlouhá, C. Mader, J. Benayas, J. Dlouhý and D. Alba. “Catalysing Change in Higher Education for Sustainable Development”. *International Journal of Sustainability in Higher Education*, 18(5) (2017): 798–820. https://doi.org/10.1108/IJSHE-03-2017-0043

Munroe, R. (2024) xkcd.com

Ojala, M. “Hope and anticipation in education for a sustainable future”. *Futures*, 94, (2017): 76–84. https://doi.org/10.1016/j.futures.2016.10.004

Ottemo, A., M. Berge and E. Silfver. “Contextualizing technology: Between gender pluralization and class reproduction”. *Science Education*, 104(4) (2020): 693–713. https://doi.org/10.1002/sce.21576

Rossing, J. P. and K. Hoffmann-Longtin. “Improv(ing) the Academy: Applied Improvisation as a Strategy for Educational Development”. *To Improve the Academy*, 35(2) (2016): 303–325. https://doi.org/10.1002/tia2.20044

Peters, A.-K. “Students’ Experience of Participation in a Discipline—A Longitudinal Study of Computer Science and IT Engineering Students”. *ACM Transactions on Computing Education*, 19(1), (2018): 5:1-5:28. https://doi.org/10.1145/3230011

Stoddard, I., K. Anderson, S. Capstick, W. Carton, J. Depledge, K. Facer, C. Gough, F. Hache, C. Hoolohan, M. Hultman, N. Hällström, S. Kartha, S. Klinsky, M. Kuchler, E. Lövbrand, N. Nasiritousi, P. Newell, G. Peters, Y. Sokona, A. Stirling, M. Stilwell, C. Spash, and Mariama Williams. “Three Decades of Climate Mitigation: Why Haven’t We Bent the Global Emissions Curve?” *Annual Review of Environment and Resources*, 46(12) (2021).

Sterling, S. *Assuming the future: Repurposing education in a volatile age* in Jickling, B. and Sterling S. (eds) Post-sustainability and environmental education. Remaking education for the future. Palgrave MacMillan, 2017.

Sutoris, P. “Educating for the Anthropocene: Schooling and Activism in the Face of Slow Violence”. *The MIT Press* (2022) https://doi.org/10.7551/mitpress/14193.001.0001

Tryggvason, Á., J. Öhman, and K. Van Poeck. (2023). “Pluralistic environmental and sustainability education – a scholarly review”. *Environmental Education Researc*h, 29(10), (2023): 1460–1485. https://doi.org/10.1080/13504622.2023.2229076

EXPLORING DEI IN TEACHER PROFESSIONAL DEVELOPMENT IN ENGINEERING EDUCATION IN EUROPE: WHAT, HOW AND WHY?

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***Conference Key Areas**: Diversity, equity and inclusion in our universities and in our teaching; Building the capacity and strengthening the educational competences of engineering educators*
***Keywords:** Diversity, equity and inclusion, professional development, policy implementation*

1. MOTIVATION AND LEARNING OUTCOMES

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A key aspect of social sustainability is diversity, equity and inclusion (DEI) and many European universities have their own DEI policies (Direito et al. 2021). To implement these policies within the classroom setting, teacher professional development (PD) is crucial. However, few universities do this in a systematic way. Within an engineering education context, this topic has received much attention as programs strive for a more diverse and inclusive environment, in an increasingly polarized environment. The SEFI position paper on DEI encourages in-depth and ongoing training for staff in this area that includes practical approaches to bias management. This workshop aims to provide a platform for teachers, teacher trainers, policy advisors and researchers in teacher professional development in engineering education to consider professional development practices in DEI in their own contexts.

The aim of this workshop was to:

-showcase examples of how professional development in DEI is carried out in several European technical universities in response to both institutional and national policies

-reflect on professional development and the DEI needs in different contexts, linking policies, theory and practice

-share good practice from participants' different contexts

2. BACKGROUND AND RATIONALE

Within engineering education, DEI policies can vary considerably where gender features strongly, but also contain aspects such as special needs, socioeconomic background, international diversity and ethnicity (Direito et al. 2021; Van Maele et al. 2023).

While there is some evidence that PD is increasing in general in higher education (Gaebel and Zhang 2018), PD of DEI remains a neglected area. However, in order to implement DEI policies within the classroom setting, teacher PD is crucial. For instance, as regards the international classroom, recent studies have highlighted the need for PD within the international classroom (cf. Coryell and Salcedo 2021; Renfors 2019; Zou et al. 2020). While teachers have sometimes been portrayed as "blockers" in implementing international strategies (Beelen 2018), other research has portrayed their critical role in making internationalisation happen (Van den Hende et al. 2023).

This workshop explores the DEI policies and implementation of them in PD at three universities in Europe: Chalmers University of Technology in Sweden, TU Eindhoven in the Netherlands and KU Leuven in Belgium. The approach in each of these countries differs; for instance, in Sweden the tendency is towards regulation whereas the Dutch depend on collective agreement. These examples will be used as inspiration for discussions of other countries and contexts in empowering teachers in the diverse classroom.

In Sweden, there are recommendations for higher education (HE) pedagogy by the Association of Swedish Higher Education Institutions (SUHF) (https://suhf.se/publikationer/rekommendationer/) where DEI is mentioned as follows: Educators should "reflect on their professional approach to academic teaching and their relationship with the students, and also towards the fundamental values of higher education, such as democracy, internationalisation, gender equality, equal opportunities and sustainability" and "interact with students in an inclusive manner and demonstrate knowledge of rules and regulations regarding students with disabilities and of available student support."

At Chalmers University of Technology, these goals have been put into practice with a compulsory course for all examiners, led by one of the presenters, where DEI is realised through a focus on gender equality, the international classroom and special needs.

In the Netherlands, the Ministry of Education published a National Action Plan on Diversity and Inclusion for Higher Education and Research in 2020, delineating an integral approach to enhance diversity and inclusion (https://open.overheid.nl/documenten/ronl-3d4db279-2786-44c8-a1af-5337604eebfd/pdf). This includes creating awareness and knowledge of DEI at institutions for Higher Education. Most Dutch Universities have a Diversity Officer, whose purpose is to stimulate and advise on matters related to DEI, and they exchange their experiences in a national meeting.

At TU Eindhoven , DEI is one of the strategic priorities of the Executive Board, with the focus, like at Chalmers, mainly on gender equality, the international classroom and students with special needs. In PD, DEI in education is included in the University Teaching Qualification (UTQ), particularly topics related to the international classroom. In addition, (non-compulsory) training on Inclusive Interaction and Education is available as part of the PD offering.

In Flanders, Belgium, all employers from all sectors must provide professionalisation opportunities for their employees. Within HE, DEI is seen as part of both lifelong learning objectives and social policies affecting students and staff. There are no central requirements, but most Flemish institutions have diversity policy officers who coordinate and align work on DEI topics in HR, student services, research and education. Exchange across institutions is organised by the Flemish Interuniversity Council working group Diversity and Social Policy.

At KU Leuven, DEI is a transversal theme in the strategic policy plan and gender equality plan. The onboarding programme for new teaching staff includes a two-hour module on DEI with a focus on the commitments stipulated in the institution's Charter for Inclusion. In addition, (non-compulsory) in-person and online trainings are available to all staff regarding bias in recruitment and selection, diversity responsive education, inclusive communication, and social safety & bystander intervention. The central Diversity Policy Office also supports faculties in creating on-demand DEI trainings.

3. WORKSHOP DESIGN

The workshop was designed with three parts:

(1) setting the scene through examples of professional development within three engineering universities in response to DEI policy

(2) brainstorming possible ways to deliver PD in DEI given different contextual affordances / constraints

(3) sharing best practices

3.1 Part 1 (15 mins): setting the scene

The facilitators provided a snapshot of PD within DEI from their home universities. Amongst the facilitators, one runs PD for DEI, another works with policy making and others work with engineering education and diversity research. We used this combined expertise to give an overview of the process from different perspectives from interpretation of policy to designing course interventions to delivering these interventions.

3.2 Part 2 (25 mins): mapping policy to practice

The participants worked in small groups of 3-4 with people from different backgrounds, for example, different roles at their institutions. They mapped the current situation for PD in DEI, using a step-by-step approach, starting with their own institutions' DEI policies and strategies, moving onto actual or potential PD and reflect on how PD meets these needs, using an adaptation of the 5E model of environmental engagement (Macharis and Kerret 2019). This model uses the key words of Estimate, Engage, Educate, Enable and Encourage to set goals, explore potential paths for achieving the goals and enabling achievement of those goals. We chose the steps of this model as means to describe the link between policy and practice.

This process used some guiding questions reflecting the model:

1. **Estimate**: What are the institutional policies regarding DEI?
2. **Engage**: How are or how could these policies be implemented as regards PD in DEI right now?
3. **Educate**: If there is teacher PD in DEI,
    a. which elements are focused on in the training?
    b. how is the training organized?
    c. who participates in the training?
    d. If not, how could this be organized according to the above questions?
4. **Enable**: How is it made possible for teachers to follow the PD?
5. **Encourage**: What is the incentive for participants to participate?

Each group created its own poster around the topic using a given poster template.

3.3 Part 3 (20 mins): sharing good practice through a poster presentation

Each group displayed their poster and there was an opportunity for a poster mingle and to ask questions. This allowed participants to gain insights on approaches at other institutions.

4. RESULTS

The workshop was attended by participants from 7 different countries (6 within Europe and 1 outside) and 9 different institutions. When presenting the results, it is important to note that these were the impressions of the participants and not necessarily representative of the country as a whole or even the institution. The results are given according to the 5E model, focusing on certain key words.

4.1 Estimate (policies)

Most participants could identify policies concerning DEI at their own institutions, though it was felt that at some institutions, they were more explicit than at others. For example, in the UK, the Equalities Act of 2010 was felt to have made an impact on explicit demands as regards DEI at university level whereas in Denmark, it was felt to be more implicit with a focus on student well-being and inclusivity. Some recognized a focus on gender within engineering education whereas others felt that the policies were more generally formed, talking about DEI capabilities and working against racism and sexism.

4.2 Engage

This section was least developed by participants, possibly because as teachers, it might have been more difficult for them to answer. It is also an area which is generally challenging for institutions in general.

4.2 Educate (PD)

As regards the PD provided for teachers, two clear scales could be identified: 1) compulsory vs optional and 2) online vs on campus delivery. In terms of the first point, there was often compulsory PD to fulfil national criteria, especially for new employees at the institution, and this training often included some element of DEI, though this might be rather perfunctory. In addition, there was the possibility at some institutions to do further training in DEI, sometimes provided online, which was encouraged but not mandatory.

4.3 Enable

Aside from the PD offered (both compulsory and optional), some institutions offered grants for gender equality projects or other DEI projects. Some institutions also offered awards for staff who engaged in DEI. At one institution, a specific DEI community of teachers was in the early stages of development as well as activities such as Diversity Week to create awareness. One issue that emerged was that of accessibility for all involved in teaching, for example in one example, PhD students did not have access to all PD resources, though they were involved in teaching themselves.

4.4 Encourage

It seemed that with more explicit national demands on DEI in higher education (e.g. UK, Sweden), DEI training was needed for promotion within the institution and hours provided (at least in theory) for that training. Otherwise, training was available for staff who were motivated and interested in taking part and encouragement came more from bottom-up initiatives and peer pressure. Several participants stated the need for recognising this training more formally as well.

5. CONCLUSION

To some extent, our expectations were confirmed in this workshop in the sense that while institutions seem to have DEI policies, varied approaches are taken to implementing this in PD for teachers. In countries with national DEI policies, there seemed to be a more systematic way of implementing this in the institutions, with explicit demands for PD in DEI and paths to promotion connected to this, in other words, a more top-down approach. Otherwise, a more bottom-up approach was preferred through offering training, communities of practice, DEI activities and incentives to take part in these activities and combinations of these two approaches.

In terms of interpreting DEI, our discussions revealed differences as well. For example, when discussing diversity, different approaches can be identified, where some institutions place more emphasis on particular aspects such as gender, while other institutions seem to focus more on inclusion aspects through student well-being for example. However, it was discussed that a focus on inclusion alone risks underestimating the complexity of differences within the student group.

Based on the input given during the workshop, we conclude that a combination of more top-down and more bottom-up approaches, with attention for both the more explicit and implicit aspects of diversity is likely most effective. We expect that by combining and aligning these different approaches a more effective translation from policy to practice will be possible, which will enable institutions to reach a broader group. It would be interesting to investigate further how such a combined approach could take shape.

References

Beelen, J. "Internationalisation at home: reinventing the wheel in the STEM disciplines." (2018) *Internationalisierung der Curricula in den MINT-Fächern*

Coryell, J. E., and Salcedo, A. “Values and Attitudes for Teaching International Graduate Student Populations European Faculty Insights for Instructional Professional Development During European Higher Education Internationalization.” (2021). In *The Experiences of International Faculty in Institutions of Higher Education* (pp. 101-116). Routledge, 2021.

Direito, I., Chance, S., Clemmensen, L., Craps, S., Economides, S. B., Isaac, S. R., Jolly, A. M., Truscott, F. R., and Wint, N. “Diversity, equity, and inclusion in engineering education: an exploration of European higher education institutions’ strategic frameworks, resources, and initiatives.” At *SEFI, Technological University Berlin, 2021*. DOI: 10.21427/1D3Q-BD61

Gaebel, M., Zhang, T., Bunescu, L., & Stoeber, H. *Learning and teaching in the European higher education area*. European University Association asbl, 2018.

Macharis, C. and D. Kerret. "The 5E model of environmental engagement: bringing sustainability change to higher education through positive psychology." *Sustainability* 11, no. 1 (2019): 241.

Renfors, S. M. “Internationalization of the curriculum in Finnish higher education: Understanding lecturers’ experiences”. *Journal of Studies in International Education*, 25(1), (2021): 66-82.

Van den Hende, F., Riezebos, J. and Coelen, R. ”Deployment of academic staff and disciplinary contexts in strategies for curriculum internationalization: a dynamic resource-based view of organizational change”, *Studies in Higher Education*, (2023) DOI: 10.1080/03075079.2023.2291516

Van Maele, J., Bergman, B., Direito, I., and Murzi, H. “How Diverse Are Global Perspectives On Diversity, Equity, And Inclusion In Engineering Education?” Paper presented at *SEFI: Dublin Technical University, 2023*.

https://doi.org/10.21427/DP74-4P30

Zou, T. X., Law, L. Y., Chu, B. C., Lin, V., Ko, T., and Lai, N. K. “Developing academics’ capacity for internationalizing the curriculum: A collaborative autoethnography of a cross-institutional project.” *Journal of Studies in International Education*, 26(3), (2022): 334-351.

ENGINEERING EDUCATION RESEARCH: WRITING FOR PUBLICATION

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***Conference Key Areas**: Building the capacity and strengthening the educational competences of engineering educators*
***Keywords**: Engineering Education Research, Journal, Publishing, Authoring*

ABSTRACT

This interactive workshop, facilitated by a team of editors, associate editors and experienced reviewers from a number of leading journals in engineering education, allowed participants the opportunity to network with other researchers and to learn about the journal publication process and how best to navigate it as an author.

It provided an informal opportunity for both early-stage scholars, as well as those with more experience, to share their publication journeys and experiences, both positive and negative, directly with each other and journal editors.

1 INTRODUCTION

The process involved in getting an article published in any academic journal can be difficult to navigate. Within Engineering Education Research (EER), the publication journey can be particularly complex and challenging, in part, as a result of its interdisciplinary nature, meaning that researchers draw upon theories and methods from multiple domains and thus face challenges associated with differences in disciplinary paradigms, terminology, publishing traditions, and norms. The diversity in the research approaches also means that there is a wide range of journals available to those looking to publish their work, each having its own distinct scope. Specific journals may, therefore, focus more on scholarship of teaching and learning (SoTL) as opposed to theory development. They may be aimed at a general education audience, rather than specially at engineering education practitioners and researchers, or their focus may be on quantitative over qualitative studies. Such variation can leave authors wondering exactly what editors and reviewers seek, how to focus their manuscripts, and how to expand conference papers to a level acceptable for journal publication.

Understanding the requirements and appropriateness of each journal can help save time for all involved in the process. It can also help make the experience constructive and meaningful in terms of researcher development and is likely to lead to more impactful publications of higher quality.

Although journals put significant effort into disseminating their scope, it can be challenging to interpret. To help researchers develop a better understanding of the process and landscape, this workshop provided an overview of the academic publishing process to make this process transparent and attainable. This took place through a facilitated discussion that stimulated reflection, allowing everyone the opportunity to share their experiences and help foster a supportive community of authors with a better understanding of the journals' processes.

2 WORKSHOP DESIGN

Understanding the requirements and appropriateness of each journal can help save time for all involved in the process. It can also help make the experience constructive and meaningful in terms of researcher development and is likely to lead to more impactful publications of higher quality.

The workshop mainly attracted authors with little or no experience in publishing in EER Journals. The workshop attracted around 50 participants who worked in groups of 4 or 5, with 10 Editors/Associated Editors distributed across the groups facilitating conversations regarding participants' questions and concerns related to the publishing process.

The Engineering Education Research journals represented included:

- European Journal of Engineering Education (SEFI)
- Journal of Engineering Education (ASEE)
- IEEE Transactions on Engineering (IEEE)
- Australasian Journal of Engineering Education (AAEE)
- Studies in Engineering Education (SEE)

A key part of this process was to introduce participants to the people behind the journals' decision-making in an attempt to bring a human side to what can seem a remote and abstract process.

2.1 Workshop Outline

The workshop agenda was designed to promote engagement and interaction between the participants and the workshop leads.

- 10 Minutes - Welcome and Introductions – Getting to know each other (facilitators and participants).
- 10 Minutes - Think-Pair-Share/Quickfire Discussion – What is your experience of authoring EER journal papers? What would you like to know (or would have liked to know) as a new author? What is the most daunting aspect of authoring?
    - Collating "what you would like to know" and "what is most daunting" to seed discussion in the next activity.
- 20 Minutes - Group Discussion with each group facilitated by an editor (one of the workshop leads) - Strategies for authoring (focused on the outcomes of the initial group discussion regarding daunting aspects of authoring).
    - Break-out groups collaborate on an online shared document to collate and distil workshop discussions and insights.
- 10 Minutes - Synthesis – Discussion of results from each group.
- 10 Minutes – Wrap-Up and Top Tips from the Editorial Teams.

Through these dialogues, participants co-created an enhanced understanding of strategies for success in academic publishing that formed the basis of the final workshop output.

2.2 Workshop Outputs

The final plenary session of the workshop collected a number of key questions and concerns of participants and drew enlightening responses from the editors present. These included:

- How to deal with conflicting feedback between reviewers?: Ideally, if this happens the editor or associate editor should provide guidance, however, if there are concerns the team suggested reaching out the editor for support. Authors were advised to address this specifically in their response to the reviewers and to highlight how they navigated this conflict.
- Can you push back on reviewers' comments?: The general response was yes, but with well-justified answers. The editorial teams reminded authors that the reviewers are advisors in the process. Ultimately the editor is the one with who makes the final decision.
- Concerns over appropriate methodologies: It is important to demonstrate an understanding of the context of the methodologies proposed in your work and, in particular, how they are usually applied in EER. It was suggested to "find your tribe", get in touch with seniors in the field, ask them for feedback on drafts, abstracts, etc. Make sure you tell the story of your work and be clear on the reasoning of the choices. It was noted that mixed and qualitative

methods are increasingly accepted in EER but you must ensure that you ground your research in theory.

- It was asked, ‘How can we show an intervention is actually working if we can’t do a full double-blind trial with the class?’ There is no one answer, but evidence should go beyond student self-report data (student surveys). Care should also be taken in using assessment results—while we aim for comparability of assessment between years, this is not always done with the rigour we would expect of a research tool.
- Choosing a journal: The emergence of ‘predatory’ journals was discussed. It was highlighted that many of the key journals (and those represented at this session) were linked to engineering education societies, such as SEFI, and that this promotes a higher level of confidence in the quality of the publication. For more information on journals within the Engineering Education Research space, authors were encouraged to see the Journals page of the Research in Engineering Education Network (https://reen.co/eer-journals/), which gives a non-exhaustive list of key journals.

Prospective authors were encouraged to engage with reviewing in journals to get a better understanding of the process. For example, many journals will give potential reviewers the chance to sign up for reviewer programme (e.g. JEE - tinyurl.com/ReviewForJEE).

SUMMARY AND ACKNOWLEDGEMENTS

The authors would like to thank all those who participated in the workshop and to the organisers of the 2023 edition of this workshop in Dublin for the inputs and feedback which have strengthened this year’s version.

TEACHING ENGINEERING ETHICS IN THE DISCIPLINES: STRATEGIES TO INTEGRATE ETHICS INTO THE CLASSROOM.

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Conference Key Areas: *Engineering ethics education, Teaching social and human sciences to engineering and science students*
Keywords: *Ethics Education*

ABSTRACT

The importance of ethics education within the engineering curriculum cannot be overstated. As such, it has received considerable emphasis in progressive engineering education curricula worldwide. However, it has been noted that many of the examples used relate to generic issues in engineering, for example, failure to follow codes of ethics, rather than issues that are related specifically to engineering disciplines. We argue that while these generic issues are important, it is vital that discipline specific examples are also available for educators to embed ethics issues and concerns within technical classes.

As part of the development of the Routledge International Handbook of Engineering Ethics Education (Chance et al., forthcoming), the authors represented here have developed a series of chapters to highlight ethics issues and discussions that are

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pertinent to Chemical Engineering, Civil Engineering, Electronic and Electrical Engineering, Mechanical and Aerospace Engineering and Software Engineering.

In this workshop we engaged educators in an exploration of the ways that discipline specific ethical topics may be embedded in the technical subjects within their discipline. The workshop aimed to support those that are looking to make sure of the handbook to enhance their coverage of ethics within their teaching and will help promote the open-access publication within the engineering education community.

1 MOTIVATION & LEARNING OUTCOMES

The teaching of ethics has received increased attention and focus in engineering curricula around the world, driven by both accreditation requirements (D. A. Martin et al., 2021a) and educators' desires to create well-rounded engineering graduates with a sense of global responsibilities. The aim of this workshop is to encourage other educators in engineering to engage with a process of interrogating their technical curriculum to look for opportunities to incorporate ethical content into their teaching.

Technical subjects such as engineering often view themselves as morally neutral (Roeser, 2012) a position often adopted by big tech companies in defence of any unsavoury act that may have involved their technologies or their platforms. As demonstrated by Martin et al. (2021b) this position has been challenged and is changing, albeit slowly. As they also point out, there are significant challenges to implement ethics in the curriculum and coverage is still patchy. It is also often within the context of codes of conduct rather than in addressing ethical design as a fundamental tenet of the engineering design process (Stappenbelt, 2013).

In the field of civil engineering, education has traditionally focused on aspects related to the design, construction, operation and end of use of infrastructure projects from a technological perspective. However, important issues such as professionalism, social responsibility or decolonisation have seldom been introduced in the civil engineering curricula (Josa, Giménez, Nick, forthcoming).

Educators in the field of software engineering have traditionally emphasized the importance of technical proficiency in coding, algorithms, and systems design. However, the rapid integration of computing in society, and the emergence of 'Big Data' has given rise to significant ethical concerns pertaining to algorithmic bias, dark patterns, and privacy invasion. As a result, educators have begun to prioritize ethical considerations within the discipline, laying particular focus on the interlinked lifecycles of software development and data management. Using dialogue approaches and reflection tools aligned with real-world software engineering practice, educators can help students cultivate a deeper understanding of the ethical dimensions and societal impacts of their work (Lunn, Hazewindus, Prasad, and Ramachandran, forthcoming).

In electrical and electronic engineering (E&EE), educators have begun to integrate ethics into technical classes such as Introduction to Circuits and Controls. Opportunities also exist to explore integrating topics such as electromagnetics and health, "right to repair," image technology and privacy, and implications of wireless systems. Further, instructors may consider discussing problematic aspects of E&EE culture such as resistor codes, racist and/or sexist terminology, and the "Lena" image (Lord and Mitchell, forthcoming).

Chemical engineering (ChE) deals with chemicals while other branches of engineering do not. This fact needs to be reflected in ethics teaching for ChE students. Chemical engineers design, manufacture or apply new materials and products, come up with innovative processes to use and transform energy, or work with microorganisms, food, pharmaceuticals, and fuels. These materials, their conversion or transformation products, or their waste products, impact people, society, and the environment. Given the large scale of industrial processes in which ChE expertise is employed, these impacts can potentially be disastrous. Thus, an increased responsibility for overseeing and controlling the impacts of the material output of professional work may be formulated for ChE (Mehlich, Børsen and Kim, forthcoming).

Lastly, the chapter on ethics in aerospace and mechanical engineering argues that ethics education must engage mechanical and aerospace engineering students in deeper conversation to critically analyse the sociotechnical impacts of their fields and develop the critical consciousness (Freire, 1970) necessary to build toward social justice. While there are many microethical topics in the field that address the individual responsibilities of engineers, typically forgotten in engineering are macroethics, the collective social responsibility of the field. For example, macroethical topics relevant to aerospace and mechanical engineering include the military-industrial complex, a lucrative endeavour that benefits governments and defence companies in the Global North at the expense of people and communities in the Global South; automation, which changes labour in ways that widen existing societal power gaps; sustainability efforts, which should consider the existence and purpose of system in addition to the technical functions; and humanitarian engineering, which must empower poor and oppressed people to best determine what sociotechnical solutions will best serve their communities (Johnson, Bowen, Cruz and Rodrigues, forthcoming).

2 IMPORTANCE OF ETHICS IN ENGINEERING EDUCATION

Engineers will design new technologies that have an impact on the world and will therefore have the potential to create new ethical dilemmas. For example, autonomous vehicles (Martinho et al., 2021) and algorithms (Benjamin, 2019; Noble, 2018) are excellent contemporary examples of how real-world and current topics can be used to engage students in the discussion of ethical topics directly related to elements of their technical studies or their design projects.

As students, industry, and accreditation bodies place increased emphasis on global responsibility and the ability for their students to act ethically in the workplace, there is a pressing need for educators to be supported in embedding and integrating the study of ethics and ethical considerations within their disciplinary studies. The workshop attracted educators from a range of disciples with an interest in how they might include discussion of ethical issues at various points within the curriculum in ways that are meaningful for today's students.

3 WORKSHOP OUTLINE:

The workshop will began with short presentations from the 5 disciplinary groups represented:

- Chemical Engineering
- Civil Engineering
- Electronic and Electrical Engineering
- Mechanical and Aerospace Engineering
- Software Engineering

Each gave a short overview of some of the specific ethics challenges that may be explored within the engineering discipline. The workshop then broke into discipline specific working groups to consider the topics that have been discussed and identify areas of their curriculum in which they might be useful and to share any additional topics that they have experienced within their disciplines. These were reported back to the group by each table and collected by the facilitation team.

4 WORKSHOP OUTCOMES:

The two authors of the Electronic and Electrical Engineering (E&EE) facilitated a discussion of those interested in E&EE as well as Mechanical Engineering since the authors of the ME chapter were not able to attend. A variety of topics were discussed including the importance of tying the ethics to the technical content of disciplinary courses so it is seen as “real-world” engineering rather than something extra thereby enhancing student acceptance and reducing resistance. We discussed the challenges of doing this work in large classes and risks of doing this work for the instructor, particularly considering their position in their career. We discussed the importance of and difficulties of working with communities to integrate ethics authentically Attendees were interested in seeing the chapters in the handbook once it is published.

Five workshop participants with affiliations to ChE and Civil Engineering joint one shared table and exchanged experiences with teaching ethics to these segments of engineering. We first agreed to exchange material between the participants by referencing relevant work in this paper. Thus, we shared material on ChE (Schummer and Børsen 2021, 2020, Eckerman and Børsen 2018, Børsen and Nielsen 2027) and civil engineering (Engineering Professors Council n.d., Josa and Real 2023, Engineers without Borders UK 2023, Pérez Foguet n.d.).

The people gathered around the table agreed that a disciplinary approach to engineering ethics education is important and that it must be based on ethical issues in the specific discipline. They also emphasized the importance of having a concept or an approach to structure and compare the different disciplinary-based ethical issues. In the chapter on ethical issues in ChE the issues are structured around different forms of responsibility. In the chapter on civil engineering the structuring factor is the life cycle of civil engineering projects that ethical issues in civil engineering is centered around. Other approaches to structuring ethical issues are possible, for example are the different ethical issues of ChE in the “Ethics of Chemistry” (Schummer and Børsen, 2021) gathered around a classification of the issues as good intentions, possible misuse, adverse effects, long term consequences for culture, society and the environment.

During the workshop, approximately eight participants converged to discuss approaches for incorporating ethics in pedagogy into computing fields. The conversation explored the complexity of ethical considerations for technology, especially in light of challenges in software engineering and the rapid evolution of the tech landscape. Participants agreed that ethics, though not always widely addressed, is crucial as technology continues to advance.

A significant challenge raised was the concept of the end of life in software and devices. This included not just the technical transition when programs or devices are no longer supported, but also the ethical implications of incentivizing consumers to continuously buy newer and newer devices. The practice, though commercially driven, contributes to a "convenience culture" that results in increased carbon footprints and environmental degradation. Moreover, the pressure for backwards compatibility can add to this tension, where older systems may struggle to integrate with newer ones, causing users to upgrade prematurely, which raises questions about the ethical sustainability of current software lifecycles.

One of the emerging points of discussion focused on the role of educators in fostering ethical awareness. Participants pondered the challenge of ensuring students recognize and anticipate ethical dilemmas within the software lifecycle, such as the need for responsible management of open-source software (e.g., handling DLL hells). This directly intersected with the need to address "wicked problems," issues that have no clear solutions but require careful deliberation. When monitoring underlying use changes, such as shifts in how users interact with technologies, educators could adopt an “ethics by design” approach. This method would incorporate ethical philosophies from the very beginning of the design process, ensuring that systems are built to serve users in responsible ways.

The group also discussed comparative assessments, such as the famous MIT Moral Machine experiment, which examined how different cultures respond to ethical dilemmas like the trolley problem. Participants reflected on whether engineers can draw lessons from these comparative studies to design systems that balance ethical concerns with practical utility, while factoring in the cultural context of the user. Overall, the group emphasized that our role as educators is to help future engineers develop the ethical awareness needed to navigate the multifaceted ethical challenges posed by technological advancement. Ethical considerations must not be an afterthought but an integral part of the design process, requiring collaboration, reflection, and a commitment to serve societal needs responsibly.

Teaching resources in ChE:

Botin, L., & Børsen, T. (Eds.) (2021). Technology Assessment in Techno-Anthropological Perspective. (OA ed.) Aalborg Universitetsforlag. Series on Transformational Studies Vol. 10. https://vbn.aau.dk/files/450748064/Technology_Assessment_in_Techno_Anthropological_Perspective_OA.pdf

Schummer, J., & Børsen, T. (Eds.) (2021). Ethics of Chemistry: From Poison Gas to Climate Engineering. World Scientific. https://doi.org/10.1142/12189

Børsen, T. & Schummer, J. (Eds.) (2020). Ethical case studies in chemistry (collection of cases). HYLE - International Journal of Chemistry. [Online]. http://www.hyle.org/journal/issues/special/ethical-cases.html

Eckerman, I., & Børsen, T. (2018). Corporate and Governmental Responsibilities for Preventing Chemical Disasters: Lessons from Bhopal. Hyle - International Journal for Philosophy of Chemistry, 24(1), 29-53. http://www.hyle.org/journal/issues/24-1/eckerman.htm

Børsen, T., & Nielsen, S. N. (2017). Applying an Ethical Judgment Model to the Case of DDT. Hyle - International Journal for Philosophy of Chemistry, 23(1), 5-27. Artikel 23. http://hyle.org/journal/issues/23-1/boersen.htm

Teaching resources in CivilE:

Engineering Professors Council (n.d.). Engineering Ethics Toolkit. [Online] https://epc.ac.uk/resources/toolkit/ethics-toolkit/

Josa, I. & Real, E. (2023). Guide of Civil Engineering to mainstreaming gender in university teaching. Xarxa Vives d'Universitats. ISBN: 978-84-09-57125-3. Available at https://www.vives.org/book/guide-of-civil-engineering-to-mainstreaming-gender-in-university-teaching/

Engineers without Borders UK (2023). Global Responsibility Competency Compass. https://www.ewb-uk.org/global-responsibility-competency-compass/download-the-global-responsibility-competency-compass/

Pérez Foguet, A. (coord.) [et al.]. "Global Dimension in Engineering Education". Barcelona: GDEE, 2014. ISBN 9788469714713. http://hdl.handle.net/2117/26502

REFERENCES

Børsen, T., & Nielsen, S. N. (2017). Applying an Ethical Judgment Model to the Case of DDT. Hyle - International Journal for Philosophy of Chemistry, 23(1), 5-27. Artikel 23. http://hyle.org/journal/issues/23-1/boersen.htm

Børsen, T. & Schummer, J. (Eds.) (2020). Ethical case studies in chemistry (collection of cases). HYLE - International Journal of Chemistry. [Online]. http://www.hyle.org/journal/issues/special/ethical-cases.html

Benjamin, R. Race after technology. Polity, 2019

Chance, S. Børsen, T. Martin, D. Tormey, R Lennerfors, T. and Bombaerts G. (eds.) (forthcoming): "Routledge International Handbook on Engineering Ethics Education". London: Routledge.

Eckerman, I., & Børsen, T. (2018). Corporate and Governmental Responsibilities for Preventing Chemical Disasters: Lessons from Bhopal. Hyle - International Journal for Philosophy of Chemistry, 24(1), 29-53. http://www.hyle.org/journal/issues/24-1/eckerman.htm

Engineers without Borders UK (2023). Global Responsibility Competency Compass. https://www.ewb-uk.org/global-responsibility-competency-compass/download-the-global-responsibility-competency-compass/

Engineering Professors Council (n.d.). Engineering Ethics Toolkit. [Online] https://epc.ac.uk/resources/toolkit/ethics-toolkit/

Freire, P. Pedagogy of the Oppressed. Continuum. 1970

Johnson, A. W., Bowen, C.L., Cruz, C.C., Rodrigues, R.B. “Chapter 15: Ethical issues in mechanical and aerospace engineering”. In S. Chance, T. Børsen, D. Martin, R. Tormey, T. Lennerfors, and G. Bombaerts (eds.), Routledge International Handbook on Engineering Ethics Education, London: Routledge, forthcoming

Josa, I., Giménez, E., Nick, C. “Chapter 14: Ethical considerations in civil engineering”. In S. Chance, T. Børsen, D. Martin, R. Tormey, T. Lennerfors, and G. Bombaerts (eds.), Routledge International Handbook on Engineering Ethics Education, London: Routledge. forthcoming

Josa, I. & Real, E. (2023). Guide of Civil Engineering to mainstreaming gender in university teaching. Xarxa Vives d’Universitats. ISBN: 978-84-09-57125-3. Available at https://www.vives.org/book/guide-of-civil-engineering-to-mainstreaming-gender-in-university-teaching/

Lord S. and Mitchell, J.E “Chapter 16: Ethical issues in electronic and electrical engineering”. In S. Chance, T. Børsen, D. Martin, R. Tormey, T. Lennerfors, and G. Bombaerts (eds.), Routledge International Handbook on Engineering Ethics Education, London: Routledge. forthcoming

Lunn, S., Hazewindus, I., Prasad, P., Ramachandran, V. “Chapter 18: Ethical issues in software engineering”. In S. Chance, T. Børsen, D. Martin, R. Tormey, T. Lennerfors, and G. Bombaerts (eds.), Routledge International Handbook on Engineering Ethics Education, London: Routledge. forthcoming

Martin, D. A., G, Bombaerts, and A. Johri, “Ethics is a disempowered subject in the engineering curriculum”. In H-U. Heiss, H-M. Jarvinen, A. Mayer, & A. Schulz (Eds.), Proceedings - SEFI 49th Annual Conference: Blended Learning in Engineering Education: challenging, enlightening – and lasting? European Society for Engineering Education (SEFI). (2021a). 357-365

Martin, D.A., E, Conlon, and B, Bowe, “A Multi-level Review of Engineering Ethics Education: Towards a Socio-technical Orientation of Engineering Education for Ethics”. Sci Eng Ethics 27, 60. (2021b)

Martinho, A., N. Herber, M. Kroesen, and C. Chorus, “Ethical issues in focus by the autonomous vehicles industry”. Transport Reviews, 41(5), (2021). 556-577, DOI: 10.1080/01441647.2020.1862355

Mehlich, J. Børsen, T. Kim, D. “Ethics in Chemical Engineering” In S. Chance, T. Børsen, D. Martin, R. Tormey, T. Lennerfors, and G. Bombaerts (eds.), Routledge International Handbook on Engineering Ethics Education, London: Routledge, forthcoming

Noble, S. U. “Algorithms of oppression: How search engines reinforce racism.” NYU Press. 2018

Pérez Foguet, A. (coord.) [et al.]. "Global Dimension in Engineering Education". Barcelona: GDEE, 2014. ISBN 9788469714713. http://hdl.handle.net/2117/26502

Roeser, S. “Emotional engineers: Toward morally responsible design”. Science and Engineering Ethics, 18:1, (2012) 103–115.

Schummer, J., & Børsen, T. (Eds.) (2021). Ethics of Chemistry: From Poison Gas to Climate Engineering. World Scientific. https://doi.org/10.1142/12189

Stappenbelt, B. “Ethics in engineering: student perceptions and their professional identity”. Journal of technology and science education, 3(1), (2013) 3-10.

Engineering a Sustainable Future:
Inspiring next STEM generation by Innovation

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Conference Key Areas:
Outreach and openness: industry and civil-society in engineering education
Teaching the knowledge, skills and attitudes of sustainable engineering
Keywords: *STEM education, Innovation, Sustainable Development, High School*

ABSTRACT

The aim of the workshop is to foster a synergetic collaboration between engineers / industry professionals and educators, teachers and students, with goal to address STEM education gaps related to the Sustainable Development Goals (SDGs). Engineers and science experts will be encouraged to reflect on the societal impact of their work and explore ways to transform this impact into inspirational educational content, in form of novel Open Education Resources (OERs) for high, middle and primary schools, which will enhance the accessibility and inclusiveness in sustainable development education. This collaborative co-creation approach has a potential to revitalise engineering education by fostering awareness about sustainability challenges, inspiring future generations, and equipping them with the knowledge to engineer the sustainable future.

1 INTRODUCTION

1.1 Background and Motivation

Lack of the interest of youth, especially girls, to engage in studies and careers in STEM (Science, Technology, Engineering, Mathematics) subjects, and in particular physics and engineering, is a contra-productive trend. Solutions for global challenges, innovations and technologies, which are needed for sustainable development and economic prosperity, heavily rely on expertise in science and research, but also future society leadership with transversal skills and ability to take fact-based decisions. Even if jobs in STEM grow 3 times faster than in other sectors, the lack of qualified workforce (especially engineers) is strongly felt by tech and physics-based industries already today.

To respond to this challenge, it is crucial to take an action and inspire young people (and girls in particular) to become part of the future pool of STEM specialists, already at early age [1]. This issue can be effectively solved only by shaping the science education at high- and even primary school level [2]. Such mission can be tackled only as a collaborative endeavor of multi-stakeholder community, including scientific, education, but also industrial actors.

The large positive impact of research – industry collaboration and physics - based industries on socio-economic progress, innovations and sustainable development (recently reported by EPS, SPS and SAWT [3,4]) is largely unknown, but very powerful to inspire youth and shape the attitude towards physics / science of general public. The avenue of such context-based science education is indeed efficient to increase the interest of students, especially girls, for STEM (as recently proven by studies [5] and projects [6,7,8]).

In the framework of the UNESCO International Year of Basic Sciences for Sustainable Development, the innovative international multistakeholder project Youth@STEM4SF (Youth at STEM for Sustainable Future) [7, 8] has been conceptualized among several European countries and successfully piloted in 2023 in Switzerland with encouraging results, in terms of inspiring high school students, especially girls for STEM careers by presenting science and engineering at work for society and sustainable development, through inspirational tech-industry providing the examples of concrete applications and technologies, interaction with role models of both genders and showcasing vast career opportunities (70% of scientific careers are in business and industry).

Education21 [9] (the Swiss federal authority for education on sustainable development) has chosen the project as a perfect example of pioneer program aligned with new Swiss education plans aiming for transversality and connection with sustainable development.

Within the UN International Decade of Sciences for Sustainable Development (2024-2033), the aim is to extend the scope and increase the impact of the Youth@STEM4SF project to develop the missing high school educational resources integrating sustainable development into science curricula. The first example developed is the Graasp Climate teaching tool offering the interactive modules on physics of climate change to high school teachers [10]. This is enabled thanks to the project ResponSE (Responsible STEM Education) [11] (to be specified at later stage) with goal to co-create such digital resources, using the Graasp [12] learning experience platform to design meaningful inquiry-based learning Open Educational Resources (OERs). The co-creation process will involve high-school students sensitized during the thematic day in the framework of Youth@STEM4SF project, their science teachers, digital education engineers and learning science specialists from EPFL-REACT group [13] / BeLEARN [14], and ideally engineers working on concrete innovative solutions for sustainability.

2 METHODOLOGY

2.1 Workshop Introduction and Objectives

The goal of the workshop is to engage inspiring tech- and engineering companies to actively engage in this challenge and pioneer initiative.

The objectives are to help participants to communicate a clear example of the impact of their STEM work in society through a pitch and to ideate possible Open Educational Resources (OERs) on identified best examples co-developed with secondary students in the framework of the projects mentioned above, that can be shared broadly and used by STEM teachers in Switzerland and abroad.

Helping STEM experts to clearly exemplify their engineering impacts to society in an inspirational way and co-ideating possible OERs to share that message can bridge the gap in educational materials for sciences, engineering, and physics, contextualizing them with the SDGs.

2.2 Participants and Target Audience

The target groups were:

1) Experts and engineers from tech companies, start-ups, spin-offs, but also those working at interfaces of R&D, Knowledge Transfer and Technology Transfer, and who are interested in sharing in a clear way the societal impacts of their work with upper secondary students of Switzerland and are open to potentially create OERs about them.
2) Learning science PhD students and educators seeking innovative ways to incorporate real-world engineering problems and solutions into their curriculum will be invited to attend to contribute in the ideation session in order to include themselves in the possible co-creation of the OERs afterwards.

2.3 Workshop Structure

- *Introduction*

Opening remarks gave the frame to the workshop's purpose and context.

- *Pitch Session*

Main part of the workshop were the 10 minutes pitches of four well selected STEM experts from diverse engineering backgrounds representing the partners from industry and research who inspired high schools' students during the Swiss pilot of Youth@STEM4SF in 2024. They showcased an example how their STEM work contributes to our everyday lives, society and SDGs. The speakers delved into the scientific and engineering principles behind their technologies, highlighting the tangible benefits these innovations offer to society. All these ideas (see Section 3.1) have a potential to be further developed and implemented in form of educational resources, e.g. as part of the ResponSE project [11] scale-up in 2025 and beyond.

- *OERs Ideation and Conclusions*

Based on pitches, the participants were asked to brainstorm about potential OERs, such as games, simulations or apps. The session wrapped up by underscoring the importance of sharing engineering's positive societal impacts through compelling narratives and how OERs and digital education can help to achieving this goal in an accessible manner.

2.4 Significance for Engineering Education

The workshop aims to inspire engineers and educators by showcasing engineering's critical role in sustainable development and its untapped educational potential by:

- Connecting engineering with sustainability, technology, and societal impact.
- Demonstrating how engineers can enhance STEM curricula.
- Advocating for teaching global problem-solving in engineering education.
- Encouraging collaboration to create innovative teaching methods.
- Highlighting the engineering community’s role in inspiring future professionals.

3 RESULTS

3.1 Inspiring engineering stories for sustainable future

3.1.1. Hadron therapy for cancer

Luca Gandolfi (Tera *Foundation on Oncological Hadron Therapy Accelerator*) and Yiota Foka (GSI [15]) presented the educational program connecting STEM, in particular particle physics with medicine, particle therapy for cancer treatment, particular sensitive topic. Under the umbrella of the International Particle Physics Outreach Group (IPPOG) [16] International MasterClass programme [17], a Particle Therapy MasterClass (PTMC) [18, 19] package was developed, where particle physicist reach to high schools students (e.g. in 2021 online version attracted 1500 students in 20 countries). The main idea is to (a) provide a basic understanding of cancer radiation therapy, (b) demonstrate that fundamental properties of particle interactions with matter, which are used for detection in physics experiments, are also the basis for treating cancer tumours; and (c) show that the same accelerator technologies are used in both, research laboratories and therapy centres. During this experience students use the become a team of medical doctors and scientists, using the open-source professional Treatment Planning software matRad, developed for research and training by DKFZ, the German cancer research institute, Heidelberg. With this tool students simulate the radiation of cancer and healthy tissue with different types of particles (photons (X-rays), protons, ions…) learning how important it is to understand the physics of interactions of different elementary particles. Students experience that photons irradiate also healthy tissue before and after the target (tumor), while protons and ions (e.g. carbon) deposit their energy at the target only, and thus spare the healthy tissue.

Short adaptation of the PTMC (which is usually the whole day activity) has been implemented at the Youth@STEM4SF day in Zurich in June 2024. The aim is to develop short user-friendly gamified version of the matRad PTMC, that would be accessible online (e.g. in form of Graasp OERs) without need of installation of software package, and providing an engaging, inquiry-based learning tool implementable to science curricula for the use by the high school teachers.

3.1.2. Engineering innovation for water preservation

One of the challenges we face as a society today, is the clean water scarcity. The innovative solutions are required that only science and technology can provide. The innovative start-up GJOSA [20], created by SWATCH engineers, and integrated to LOREAL, provides Swiss engineering innovation for water preservation. Intelligent solutions engineer at GJOSA, Caroline Jackson, presented how skills learned in STEM are applied at GJOSA technology to create water-efficient showerheads that reduce water consumption without compromising user experience, while minimizing waste.

Designing a water-saving showerhead relies heavily on various scientific concepts learned in engineering classes [21,22]. Fluid dynamics plays a crucial role in understanding how water flows through pipes and nozzles, ensuring efficient flow with minimal water consumption. The continuity equation aids engineers in calculating how reducing the nozzle size increases water speed while using less volume. Thermodynamics also comes into play, as the showerhead is designed to conserve not only water but energy, reducing the need to heat excess water. Finally, problem-solving and design thinking are essential in overcoming challenges in efficiency, performance, and user satisfaction - key skills in any engineering project.

This example shows how by choosing a path in Engineering and Science, one is equipped with the skills to tackle these challenges head-on, and has the power to be a part of the solution, to drive change, and to inspire others. The GJOSA technology was awarded Time Best Inventions 2021 [23].

3.1.3. Engineering a Cleaner future: Catalysing change in tough-to-decarbonize industries

Daphne Technology [24], a Swiss climate deep-tech firm, specialises in solving Greenhouse gas (GHG) challenges in hard-to-decarbonise industries. The company develops technologies and scales innovative products to measure and reduce GHG emissions from industrial sources, using a portfolio approach for global decarbonisation in power generation and energy conversion [25, 26].

Behnaz Varandili, Senior Scientist at Daphne Technology, presented three innovative products developed by the company: SlipPure, an innovative after-treatment system, is tailored to remove methane from exhaust gases in natural gas-fired internal combustion engines in maritime, oil & gas, and land-based industries. It is an environmentally responsible, technologically advanced solution, helping industries meet sustainability targets by cutting their carbon footprint. SulPure is a key player in environmental sustainability, targeting the elimination of sulphur oxide (SOx) pollutants from exhaust or flue gases. Its unique circular economy approach curbs harmful emissions and converts them into valuable resources, notably ammonium sulphate fertiliser for agricultural purposes. Dedicated to mitigating SOx pollution, SulPure serves multiple sectors, including coal-fired power stations and sour gas (H2S) flaring. PureMetrics is a pioneering solution for measuring, reporting, and optimising GHG emissions of industries in real-time and with accuracy.

Daphne Technology is a perfect example how multidisciplinary engineering for innovation offer solutions thanks to knowledge in physics, chemistry, mechanical engineering etc.

3.1.4. How Can Innovative Industry Software Help to Inspire a Passion for Sustainable STEM?

Sven Friedel, managing director of COMSOL Switzerland [27], the physics-based industry with long-term tradition and vast experience in the Software for Multiphysics Simulations, shared with the participants how these simulations work in service for sustainable solutions and even education.

The industrial development and optimization of sustainable technologies, such as electromobility, next generation of batteries, solar cells, electrolyzers, fuel cells, fish-protecting hydropower turbines, live-saving medical devices, food safety, climate change monitoring and mitigation and more have become unthinkable without highly specialized simulation software [28]: algorithms that are able to integrate mechanics, acoustics, heat transfer, electro- and fluid dynamics, mass transport, etc. As a subtask in the R&D process, models and ideas often need to be communicated to non-simulation experts, which is accomplished by embedding highly complex physical, chemical, or biological models into easy-to-use user interfaces, so-called simulation apps that allow playful exploration of science and engineering topics [29]. Royalty-free simulation apps running on Win, Mac, or Linux OS, or accessed via browsers from any device covering diverse interesting topics like superconductivity, acoustics, food safety and many more, are today also widely used in teaching at academies and high schools [30, 31, 32] and occasionally at the primary school level. STEM teachers on all levels can concentrate on aspects of didactics and gamification while relying on industry-proven standards for visualization, numerical concepts and app development, in order to create with ease captivating tools for STEM education.

3.2 Learning Outcomes

Participants have learned about the integration of engineering innovations with sustainable development goals (SDGs) and opportunities how these can be transformed into educational content. Specifically, they increased the awareness and gain insights into:

- The crucial role of engineering in addressing global sustainability challenges (SDGs) through real-world examples.
- The process of translating complex engineering concepts into accessible educational resources / success stories relatable to lay audience.
- Ideation processes for developing digital tools, games, or apps that convey the importance of engineering to young learners.

The objective is to empower engineers to communicate their work's societal impact effectively and inspire public and the next generation through education.

3.2 Result’s Summary

The workshop was a call to action for engineers deeply involved in sustainable development to extend their impact beyond the industry, contributing to educational content that can inspire future generations. By leveraging their innovative work for the SDGs and translating it into inquiry-based learning resources, the workshop aimed to fill the educational void in STEM subjects, contextualizing them within the broader societal and environmental challenges of our time.

- *Take-Home Message:* Participants left with the understanding that engineering has a profound impact on society and that this impact can be amplified through education. They were encouraged to consider how their work can be used to inspire future generations.
- *Open Education Resources*: The ideas presented in pitch session and discussed further will be further analysed in the framework of the ResponSE project, aiming to co-create new OERs in close collaboration with the workshop participants. These and other OERs co-created also with students and teachers through the Belearn Hackathons aim to be offered to ensure its usage through learning experience platform Graasp by science teachers’ community in Switzerland and abroad.

REFERENCES

Bybee, Rodger W. "The case for STEM education: Challenges and opportunities." (2013).

Vennix, Johanna, Perry den Brok, and Ruurd Taconis. "Do outreach activities in secondary STEM education motivate students and improve their attitudes towards STEM?." International Journal of Science Education 40, no. 11 (2018): 1263-1283.

EPS Report on Policy and Economy, https://www.eps.org/page/policy_economy

SPS Focus on Impact of Science of Society, https://www.sps.ch/fr/artikel/sps-focus/sps-focus-2

PhD study, Sarah Zoechling, CERN / Uni Vienna, https://cds.cern.ch/record/2885854?ln=en

UK project Tomorrow's engineers CODE, https://code.tomorrowsengineers.org.uk/

B. Bruant Gulejova, "Enhancing High School Science Education: Integrating Physics, Technology Innovation, and Sustainable Development", Youth@STEM4SF pilot project, PoS EPS-HEP (2023) 645, https://pos.sissa.it/449/645/pdf

B. Bruant Gulejova, "Shaping high school science education with tech industry in action for sustainable development", Youth@STEM4SF, Swiss Physical Society, SPG Mitteilungen Nr. 73, June 2024, https://tinyurl.com/43dxv8nm

Education21, https://www.education21.ch/fr

P. Kobel, "Graasp climate, Active learning simulations for investigating the science of global warming", https://climate.graasp.org/en/

ResponSE project, Responsible STEM education, https://belearn.swiss/en/projekt/response-responsible-stem-education/

Graasp educational resources platform, https://graasp.org/

EPFL REACT group, https://www.epfl.ch/labs/react/

BeLEARN, https://learn.epfl.ch/wwd_learn/belearn/

GSI Helmholtzzentrum für Schwerionenforschung, https://www.gsi.de/

International Particle Physics Outreach Group, IPPOG, https://www.ippog.org

IPPOG International Physics Masterclasses, https://ippog.org/imc-international-masterclasses

P. Foka, Particle therapy masterclass, in proceedings of science, Volume 398, EPS-HEP2021

P. Foka, A. Mamaras, D. Skrjiel, J. Seco, C. Graeff et al. Particle therapy masterclass, in proceedings of vCONF21, EPJ Web Conf. 258, 01002 (2022)

GJOSA technology, https://gjosa.com/technology/

Xiaodong, C., & Vigor, Y. A. N. G, Recent advances in physical understanding and quantitative prediction of impinging-jet dynamics and atomization, *Chinese Journal of Aeronautics*, *32*(1), 45-57 (2019), https://doi.org/10.1016/j.cja.2018.10.010

Ryan, H. M., Anderson, W. E., Pal, S., & Santoro, R. J., Atomization characteristics of impinging liquid jets. *Journal of propulsion and power*, *11*(1), 135-145 (1995).

Gjosa technology awarded the Time Best Inventions 2021, https://time.com/collection/best-inventions-2021/6114369/loreal-water-saver/

Daphne Technology, https://daphnetech.com/

Sulphur Dioxide Reduction from Exhaust Gas via Ammonia Injection and Ammonium Sulphate Production; https://daphnetech.com/downloads/SulPure_WhitePaper_by_Daphne_Technology_December_2022.pdf

Reducing Methane Emissions Onboard Vessels - An overview of regulatory drivers, methane emission sources and levels, reduction technologies and solutions, and techno-economics; https://cms.zerocarbonshipping.com/media/uploads/publications/Reducing-methane-emissions-onboard-vessels.pdf

COMSOL, https://www.comsol.com

COMSOL Inc. (2024) stories, https://www.comsol.com/stories

COMSOL Inc. (2023) https://www.comsol.com/video/building-and-deploying-simulation-apps-with-comsol-software

Riva, N., Grilli, F. and Dutuoit, B. (2021): AURORA: a public applications server to introduce students to superconductivity, Journal of Physics: Conference Series, Volume 2043, 7th edition of the International Workshop on Numerical Modelling of High Temperature Superconductors, https://iopscience.iop.org/article/10.1088/1742-6596/2043/1/012005/meta https://aurora.epfl.ch/app-lib

Moheit, L., Schmid, J. D., Schmid, J. M., Eser, M., and Marburg, S., Acoustics Apps: Interactive simulations for digital teaching and learning of acoustics, J. of. Acoust. Soc. of America, 149(2) (2021), https://doi.org/10.1121/10.0003438, https://apps.vib.ed.tum.de/app-lib

Datta A. K., Ukidwe, M.S., and Way, D.G., Simulation-based enhancement of learning: The case of food safety, Food Science Education, 19 (3), 193-211 (2020). https://doi.org/10.1111/15414329.12199

Promoting Friendship Through Teamwork in Undergraduate Engineering: Exploring Together the Role of the Instructor

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ABSTRACT

Underpinned by our joint consensus about the importance of collaborative project experiences in undergraduate engineering, this study reflects on the often-missing interconnectivity between engineering practice and academic studies by exploring the development of interpersonal skills during undergraduate teamwork. Using the lens of friendships and attachment styles as our underpinning theoretical framework, our aim is for this workshop to act as a collaborative think tank aimed at designing a framework that can be adapted across contextual settings and used by engineering educators who are engaged in supervising student group work projects.

The intended framework is aimed to empower instructors, supervisors and scholars with the necessary support that would enable them to make use of team working spaces as a catalyst for empowering students to form healthy collaborations, networking relations and friendships. This work is relevant to the larger engineering education community for three reasons. Firstly, it addresses questions of student wellbeing and offers a practical tool for educators in this regard. Secondly, it bridges the gap between the skills needed for engineering practice and those fostered during academic studies. Thirdly, it is the first of its kind to challenge instructors to expand their self-perception in terms of their roles in facilitating student friendships in group project supervision.

INTRODUCTION

1.1 Teamwork in Undergraduate Engineering Education

Engineering work relies heavily on socially interacting with co-workers and clients. The complexity of today's socio-technical problems and the reality of distributed knowledge (i.e., no one knows everything), demands engineers who know how to work in diverse teams and engage in collaborative teamwork. To fulfil this need, universities worldwide include teamwork activities in their curricula (ABET 2021; ECSA 2020). Teamwork allows students opportunities to learn to listen, trust, and get along with others (Picard et al. 2022).

For more than a decade, there have been efforts to bridge the gap between academia and industry in engineering education, leading to the integration of 21st century skills into the curriculum (Schefer-Wenzl and Miladinovic 2020). The result is the so-called integrated curriculum (Fung 2017), which intertwines societal, cultural and contextual matters with technical learning objectives. At the heart of these 21st century skills is the ability to work in teams. Most engineering programs incorporate projects that require students to collaborate within groups over an extended period to solve complex problems.

However, undergraduate engineering students sometimes see teamwork as a waste of time, citing challenges in scheduling meetings with their peers outside of class and difficulties collaborating with people who approach tasks differently (Chang 2018; Rajabzadeh et al. 2022). In such instances, team members may resort to strategies such as "divide and conquer" instead of adopting a collaborative and integrated approach. This individualistic mindset privileges personal interests and priorities over the common goal of the team project. By neglecting communication, active engagement and efforts to develop mutual understanding, teams miss out on valuable opportunities for intercultural interactions, empathy-building, cultivating creativity, and skill development (Göl and Nafalski 2007). In the end, this hinders the development of friendship among engineering team members.

1.2 Friendship and Attachment Styles

Pillemer and Rothbard's (2018: 637) definition of workplace friendship fits the context of our study: "a nonromantic, voluntary, and informal relationship between current coworkers that is characterized by communal norms and socioemotional goals."

Friendship development depends on our views of ourselves and others. Bartholomew and Horowitz (1991) describe four quadrants of attachment styles: secure, dismissing, preoccupied, and fearful. Raising awareness of these styles may encourage self-reflection, empathy, and stretching beyond default patterns of behaviour when undergraduate engineering students interact with each other.

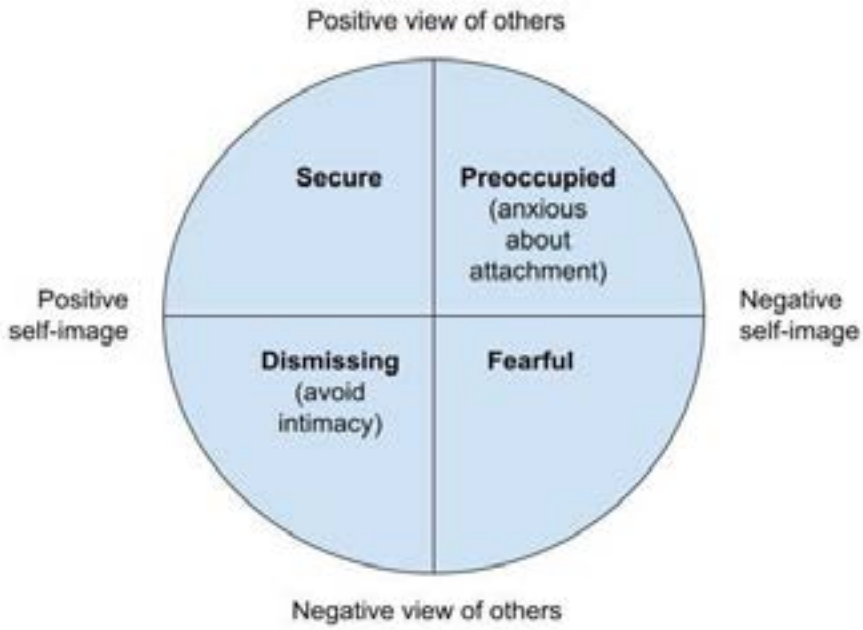

Fig. 1. Attachment styles among young adults (adapted from Bartholomew and Horowitz 1991)

- Secure individuals find it easy to form emotional bonds, value cooperation in friendships, and seek balance in relationships.
- Dismissing individuals prioritize independence, invest minimally in friendships, and downplay their importance. They are "high in self-confidence and low in emotional expressiveness" (Walsh and Houser 2010: 353).
- Preoccupied individuals desire friendships but may feel others are reluctant, often becoming overly self-sacrificing or anxious in relationships. They display high levels of self-disclosure and negative self-image.
- Fearful individuals want closeness but struggle with trust, often fearing potential hurt from others.

Alerting students to these general styles may help them recognise potential obstacles when they try to make friends. It is important to note that some researchers have identified negative outcomes from friendships in groups (Wang et al. 2023; Pillemer and Rothbard 2018). Guidelines from instructors on behaviour expectations when working in teams may help develop trust, cooperation and balance.

1.3 The Impact of Friendships on Undergraduate Engineering Students

To our knowledge, very few scholars have explored the intersectionality between friendship and student group work in the context of undergraduate engineering (Li et al. 2022; White et al. 2022; Schmidt 2020; Shapiro 2011). Since human interactions form a substantial part of a balanced learning experience (Casado, Lopez and Lapuerta 2016), we are interested in exploring this topic further by tapping into insights from engineering educators across different contexts. The next section presents the aim of this workshop in more detail.

2 WORKSHOP AIMS, LAYOUT AND STRUCTURE

2.1 Objectives of the workshop

The workshop was carefully designed to fulfil its objectives and cater to the needs of the workshop audience. With a clear focus on unpacking the complexity and potential of extended interpersonal interactions among students in group settings, the workshop aimed to provide a platform for participants to share their experiences, including success and failure stories, within their unique contexts. Through collaborative efforts, a framework was developed to empower academics, supervisors, and instructors to foster friendships, think-tanks and networks within student groups. This workshop was most relevant to those involved in designing and teaching group work activities for undergraduate engineering students.

2.2 Workshop structure

Engagement and collaboration among participants were actively encouraged to facilitate meaningful discussions and idea exchange. The workshop's duration was carefully calibrated to ensure optimal effectiveness without overwhelming attendees. In the first ten minutes of the workshop, the authors' team started by providing a short description of the key concepts and explaining the structure of the workshop. The workshop participants then engaged in discussion based on the prompts in Table 1 below, which would later make up the components of the framework. The last five minutes were used to summarise the outcomes of the workshop and inform the participants of the logistics of accessing the discussion points from an interactive platform (Padlet). Based on the consolidated outputs of group discussions, the aim was to map different discussion points arising from the activities facilitated by the authors into a navigational framework that would help inform higher education instructors. Ultimately, the outcome of the workshop, along with comprehensive documentation, would equip readers with actionable insights and strategies for designing and teaching group work activities, which would be particularly beneficial for those involved in educating undergraduate engineering students.

Table 1. Key discussion topics

Key topic	Prompt

1. Understanding the Dynamics of Group Interactions	Exploring the complexities of interpersonal relationships within student groups. Identifying factors that contribute to trust, cooperation, and balance within groups.
2. Strategies for Building Trust and Cooperation	Discussing methods to foster trust and cooperation among group members. Exploring techniques for promoting open communication and conflict resolution within groups.
3. Balancing Roles and Responsibilities	Examining strategies for distributing roles and responsibilities equitably within groups. Discussing approaches to ensure accountability and fairness in task allocation.
4. Developing Group Work Guidelines	Brainstorming guidelines for effective group work that promote trust, cooperation, and balance. Collaboratively drafting a framework for group work guidelines tailored to engineering students' needs.
5. Understanding the Impact on Learning and Retention	Reviewing research findings on the influence of group dynamics on learning outcomes and retention rates among undergraduate engineering students. Discussing strategies to enhance student engagement and retention through effective group work practices.
6. Promoting Diversity and Inclusion	Highlighting the importance of diversity within student groups and its impact on learning outcomes. Exploring ways to cultivate an inclusive environment that respects diverse worldviews and beliefs.
7. Gender Dynamics in Group Interactions	Analyzing research findings on how gender influences social outcomes within student groups. Discussing strategies to mitigate gender disparities and promote equitable participation and outcomes for all students.

By incorporating these topics into the workshop discussions, participants would gain valuable insights into effective group work practices tailored to the needs of undergraduate engineering students. Additionally, dedicating time for brainstorming group work guidelines fostered collaboration and empowered participants to develop actionable strategies for promoting trust, cooperation, and balance within their respective academic environments.

Session participants were expected to gain a comprehensive understanding of effective strategies for fostering trust, cooperation, and balance within student groups, particularly among undergraduate engineering students. By delving into key topics such as group dynamics, role balancing, and the influence of same-major friendships on academic and social outcomes, participants were expected to emerge equipped with practical insights and actionable guidelines for designing and facilitating successful group work activities. The session's relevance lay in its direct applicability to the challenges faced by educators and instructors in promoting collaborative learning environments that enhance student engagement, retention, and academic success. The session culminated in the synthesis of key findings and take-home messages, providing participants with a clear roadmap for implementing effective group work practices within their educational settings.

2.3 Workshop Outcomes

Discussion points were captured on a Padlet, available at https://padlet.com/anita_campbell1/sefi-workshop-promoting-friendship-through-teamwork-in-under-bc5quolkivdex9c5

The following synthesis of key findings for successful teamwork to guide practical implementation by instructors was complied with the help of ChatGPT 4.0.

Facilitate Meaningful Connections in Groups

- Prioritize building connections rather than simply task-focused collaboration. Encourage relationships through shared experiences and a sense of mutual respect. Focus on friendship traits such as trust, laughter, and support to strengthen group bonds.
- Address cultural, social, and emotional dynamics, acknowledging that emotional closeness often requires physical proximity and shared values. Instructors should be aware of the role these dynamics play in group cohesion and learning outcomes.

Equip Teams with Tools to Navigate Conflict and Manage Dynamics

- Provide teams with training on managing task completion, conflict resolution, and communication to ensure they work together effectively. Encouraging students to reflect on external factors that may impact the group can help manage tensions.
- Establish clear group guidelines, including roles, responsibilities, and a code of cooperation, to prevent misunderstandings and maintain a productive environment.

Balance the Task Complexity with Team Capability

- Design tasks that challenge students but allow them to collaborate effectively, without leaving anyone behind. Ensure that individual contributions are valued, but team success is emphasized.

- Adjust the expectations of teamwork duration to match the complexity of the tasks, recognizing that the group will need time to go through various stages of development before reaching optimal performance.

Support Trust and Cooperation Through Structured Activities

- Use icebreakers and structured tasks that require cooperation to foster a team spirit. These activities help students move past initial discomfort and begin to rely on each other, leading to more effective teamwork.
- Integrate trust-building strategies and emotional reflection into the curriculum to deepen connections within the group and improve the overall group experience.

Promote Inclusivity and Cultural Awareness in Group Settings

- Recognize and address cultural, social, and gender-related dynamics that may influence group behaviour. Encouraging inclusive practices will help diverse groups of students feel comfortable and contribute meaningfully.
- Utilize tools and strategies like "tangibles" or buddy systems to ease social anxiety, particularly in students who may find it difficult to form connections. Ensure that group processes account for the different emotional and relational needs of students from various backgrounds.

3 RELEVANCE AND FUTURE WORK

Conscious of the realisation of importance of the socio-emotional development of engineering students (Casado, Lopez and Lapuerta 2016), our aim was to unpack different ways in which we, as engineering educators, could foster micro-cultures where trust and friendship are empowered. The impact is relevant on several levels. Firstly, an emphasis is created between the socio-emotional development necessary for real life practice interactions in the engineering field and the academic experience of engineering students. This work will therefore contribute to further strengthening the bridges between academia and practical settings in the engineering field. Secondly, through the development of this framework, educators will have a tool that will enable them to foster the creation of a safe and secure platform, whereby students can learn how to positively approach colleagues and create healthy collaborative work and networking opportunities. This is a crucial empowering tool that educators need to be more aware of, especially in light of the growing globally challenges we face today. Thirdly, from the perspective of student wellbeing, this work promotes the reduction of the culture of competition, which is very damaging to student health and wellbeing (Gadola and Chindamo 2017).

Effective collaboration and the cultivation of a healthy collaborative working environment are essential to the success of engineering practice experiences. We anticipate that the framework created will be adaptable and add value to engineering educators supervising engineering projects around the world. Furthermore, this work holds significant implications for Engineering Education, as it offers tailored solutions to address the unique needs and challenges encountered by engineering students in group settings This, in turn, contributes to the enhancement of learning experiences and outcomes within the field.

REFERENCES

ABET. “Criteria for Accrediting Engineering Programs, 2021–2022”. ABET. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2021-2022/ (accessed April 8, 2024).

Bartholomew, K., and L. M. Horowitz. “Attachment Styles Among Young Adults: A Test of a Four-category Model.” *Journal of Personality and Social Psychology* 61, no. 2 (1991): 226-244. https://doi.org/10.1037/0022-3514.61.2.226

Casado, M. L., D. Lopez, and V. Lapuerta. “Socio-Emotional Competencies in Engineering Education”. *International Journal of Engineering Education* 32, no. 4 (2016): 1660–1678.

Chang, Y., and P. Brickman. “When Group Work Doesn’t Work: Insights from Students”. *CBE—Life Sciences Education* 17, no. 3 (September 2018): ar52. https://doi.org/10.1187/cbe.17-09-0199 .

ECSA (Engineering Council of South Africa), “Ensuring the Expertise to Grow South Africa: Qualification Standard for Bachelor of Science in Engineering (BSc(Eng))/ Bachelors of Engineering (BEng): NQF Level 8," Document No. E-02-PE, Revision No. 6, 2020. https://www.ecsa.co.za/ECSADocuments/Shared%20Documents/E-02-PE%20Qualification%20Standard%20for%20Bachelor%20of%20Science%20in%20Engineering%20(BSc(Eng))%20Bachelors%20of%20Engineering.pdf (accessed April 8, 2024).

Fung, D. *A Connected Curriculum for Higher Education*. Spotlights. UCL Press, 2017. https://doi.org/10.14324/111.9781911576358.

Gadola, M, and D Chindamo. “Experiential Learning in Engineering Education: The Role of Student Design Competitions and a Case Study”. *International Journal of Mechanical Engineering Education* 47, no. 1 (January 2019): 3–22. https://doi.org/10.1177/0306419017749580.

Göl, Ö., and A. Nafalski. “Collaborative Learning in Engineering Education”. *Global Journal of Engineering Education* 11, no. 2 (2007): 173–180. http://wiete.com.au/journals/GJEE/Publish/Vol.11,No.2/GolNafalski.pdf

Li, Y., N. White, K. Evans, and D. Correa Ospina. “The Roles of Friendship Among First-Year Engineering Students and Upper-Level Project Manager Students on Student Retention”. In *2022 ASEE Annual Conference & Exposition Proceedings*, 41599. Minneapolis, MN: ASEE Conferences, 2022. https://peer.asee.org/41599.

Picard, C., C. Hardebolle, R. Tormey, and J. Schiffmann. “Which Professional Skills Do Students Learn in Engineering Team-Based Projects?” *European Journal of Engineering Education* 47, no. 2 (4 March 2022): 314–32. https://doi.org/10.1080/03043797.2021.1920890.

Pillemer, J., and N. P. Rothbard. "Friends without benefits: Understanding the dark sides of workplace friendship." *Academy of Management Review* 43, no. 4 (2018): 635-660. https://www.jstor.org/stable/26528787.

Rajabzadeh, A. R., J. Long, G. Saini, and M. Zeadin. "Engineering student experiences of group work." *Education Sciences* 12, no. 5 (2022): 288. https://doi.org/10.3390/educsci12050288.

Schefer-Wenzl, S.., and I. Miladinovic. “Integrating 21st Century Skills in Higher Education Engineering Curricula.” *International Journal of Advanced Corporate Learning* 13, no. 2, (2020): 77-83. https://doi.org/10.3991/ijac.v13i2.17011.

Schmidt, S. J. “The Importance of Friendships for Academic Success.” *Journal of Food Science Education* 19, no. 1 (January 2020): 2–5. https://doi.org/10.1111/1541-4329.12176.

Wang, S., Y. Liu, Y. Hu, J. Zhang, S. Li, and Y. Chen. "The honey-trap of workplace friendship: Developing and testing a three-way interaction model to understand when and why workplace friendship triggers employee withdrawal behaviour." *International Journal of Psychology* 58, no. 5 (2023): 486-497. https://doi.org/10.1002/ijop.12925

Welch, R. D., and M. E. Houser. "Extending the four-category model of adult attachment: An interpersonal model of friendship attachment." *Journal of Social and Personal Relationships* 27, no. 3 (2010): 351-366. https://doi.org/10.1177/0265407509349632

SECURING FELLOWSHIPS FOR ENGINEERING EDUCATION RESEARCH

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***Conference Key Areas**: Building the capacity and strengthening the educational competences of engineering educators*
***Keywords**: grants; fellowships; funding; internationalization; study abroad*

ABSTRACT

This workshop was geared toward educators seeking to enhance their research capabilities, explore new areas of inquiry, and expand their professional networks through collaborations with colleagues from institutions beyond their national borders. The facilitators introduced the topic and described various pathways to securing fellowships for engineering education research (EER), including prestigious Fulbright, Marie Curie, and EU-funded fellowships. Via practical demonstrations, participants learned how to navigate relevant databases, identify suitable fellowship opportunities, and strategically align their research interests with funding priorities. Participants interacted with previous recipients of grants and fellowships awarded to individuals for research and/or professional development. Overall, the workshop leveraged collective expertise to help participants envision and strategise fellowship opportunities to maximise their chances for future success. Attendees were provided with essential resources, actionable steps for proposal development, and valuable tips to strengthen their funding applications. The ultimate objective of the workshop was to empower participants to secure funding for impactful EER projects, enabling them to advance their research agendas and contribute to the broader landscape of engineering education.

Figure 1: Workshop facilitators (pictured left to right: Aditya Johri, Shannon Chance, Madeline Polmear, Helena Kovacs, Inês Direito, Sandra Cruz, and Rucha Joshi).

1 MOTIVATION AND LEARNING OUTCOMES

The motivation for organising this workshop was to leverage the collective expertise of lead facilitators in securing fellowship funding for international research endeavours and to facilitate entry into the global EER community. The aim is to empower participants to secure funding for research activities and contribute to capacity building within the EER community.

Drawing from pertinent literature (Locke et al. 2013; O'Neal-McElrath et al. 2019; Ward 2006) and personal experience obtaining Fulbright and Marie Skłodowska-Curie fellowships (Chance, 2013; 2020a; 2020b), the lead facilitator guided participants in envisioning pathways to funded research in countries beyond their own. The overall group of facilitators highlighted funding programs highly relevant to the SEFI audience, focusing on fellowship opportunities for Ph.D. candidates, post-doctoral researchers, established researchers, and educators interested in conducting research abroad.

Learning Outcomes:

1. **Understanding Grant and Fellowship Processes:** Participants gained insights into the fundamental processes of obtaining grants and fellowships, including application procedures and competition dynamics.
2. **Exploring Fellowship Programs:** Attendees learned about fellowship programs that facilitate study and research throughout Europe and the US,

regions where EER is well-established, enabling them to extend their research skills and networks.

3. **Navigating Databases and Identifying Funders' Objectives:** Participants discovered where to find databases listing research jobs and fellowships and developed skills in identifying funders' objectives to align their proposals effectively.
4. **Networking and Contacting Prospective Hosts:** Facilitators identified strategies for contacting prospective hosts and leveraging networks to facilitate collaborative research opportunities.
5. **Querying Successful Awardees:** Participants were invited to follow up with the facilitators to query their strategies and experiences and, thereby, enhance the participants' capacity to develop competitive proposals.

Target Audience:

This workshop was designed for individuals interested in pursuing international research opportunities in EER and ambitious enough to seek external funding through competitive applications. Prospective participants had a keen research interest, the desire to develop new skills, a collaborative mindset, and a curiosity about exploring diverse cultures and environments.

2 BACKGROUND AND RATIONALE OF THE SESSION

The facilitators involved in this workshop brought valuable experience as recipients of EER fellowships, including awards from the European Union-based Marie Curie program and the US-based Fulbright program. Motivated by their prior success, they are eager to assist others in securing funding for EER projects.

The term 'fellowship' encompasses various opportunities, often representing postdoctoral positions in the European Union, the United Kingdom, or the United States. In the EU and UK, fellowships may also support individuals seeking doctoral degrees, not solely those holding doctorates.

Fellowships allow academics to pursue focused, independent research or academic projects; the funding can facilitate deep engagement in one's chosen fields. Funders typically aim to (a) generate new knowledge and research insights and (b) cultivate skills among recipients, often supporting international travel for work and study. The financial stability fellowships provide enables recipients to concentrate on their research endeavours.

Securing research funding in a competitive environment entails several key steps, including identifying a suitable funding source, studying the funders' guidelines and priorities carefully, aligning strategically with funders' priorities, developing a clear and compelling research/project proposal, building solid research or supervisorial teams, meticulously crafting the proposal, and leaving time to seek expert feedback to refine the proposal before the submission date.

Given the prestige of research fellowships, applicants must demonstrate outstanding academic achievements. Successful applicants often submit a comprehensive curriculum vitae or significant research output, such as a journal article, as part of their application. They typically also require the development of a research project, including a description of why it's needed (research excellence), what difference it will make in the world (impact), how it will be carried out, and what supports will be provided by the host organization (implementation).

As noted above, applicants are advised to thoroughly understand the application requirements and guidelines, seeking clarification from program coordinators or project officers when needed. Following guidelines meticulously is crucial to avoid disqualification. Additionally, seeking advice from previous fellowship recipients or specialists, such as National Contact Points in European host countries, can provide valuable insights and guidance.

This workshop explored such strategies, aiming to equip participants with the knowledge and skills to construct successful fellowship applications in EER.

3 ENGAGEMENT OF AND INTERACTION

The workshop incorporated active learning, leveraging technology to facilitate interactive sessions. Participants were encouraged to bring WiFi-enabled digital devices to enable online searching throughout the workshop.

Utilising online databases, participants explored job and fellowship opportunities within the European Union and accessed Fulbright platforms in the United States and their current countries of residence. This hands-on approach aimed to empower attendees to conduct real-time searches and identify relevant opportunities aligned with their research interests and career goals.

The open discussion format promoted interaction, allowing participants to share their preferences regarding geographical locations, research topics, and targeted funding programs. The discussion helped foster collaboration, exchange of ideas, and strategic alignment among participants, enriching the learning experience and facilitating networking opportunities. Participants were encouraged to connect with the facilitators regarding the fellowships they had completed. They also introduced the website and databases for their respective programs:

The **EURAXESS** website (https://euraxess.ec.europa.eu/) provides an extensive database of all European-funded research fellowships, jobs, and grant programmes. The facilitators involved in activities listed in the EURAXESS database are:

- **Shannon Chance**, who described her experience with two individual fellowships funded by Marie Skłodowska-Curie Actions (MSCA), which can be found at https://marie-sklodowska-curie-actions.ec.europa.eu/ or via the EURAXESS website.
- **Madeline Polmear**, who discussed university-organized post-doc funded through MSCA.
- **Helena Kovacs**, who discussed participation in MSCA-funded Ph.D. studies.
- **Sandra Cruz**, who described her experience with ERASMUS funding for a European Master's degree, listed at https://erasmus-plus.ec.europa.eu/opportunities/opportunities-for-individuals/students/erasmus-mundus-joint-masters
- **Inês Direito**, who highlighted European Research Council (ERC) opportunities which can be found at https://erc.europa.eu/ or via the EURAXESS website.

Fulbright supports the exchange of students, academics, and professionals between the United States and more than a hundred countries worldwide. The facilitators who have served as Fulbright Scholars are. Prospective applicants can visit https://fulbrightscholars.org/

- **Aditya Johri**, who discussed his participation in both the Fulbright Core Scholars programme and the Fulbright Specialist programme (https://fulbrightspecialist.worldlearning.org/).
- **Shannon Chance**, who also served as a Fulbright Core Scholar.

Many other opportunities exist as well, as experienced by our facilitators:

- **Aditya Johri**, who discussed US National Science Foundation (NSF) support for facilitating international collaborations.
- **Sandra Cruz**, who identified databases for scholarship funding for Ph.D. studies in Europe and the UK, like FindAPhD (https://www.findaphd.com/).
- **Inês Direito**, who described her experience with country-specific funding.
- **Rucha Joshi**, who identified funding opportunities for researchers to travel to and conduct research in India listed at https://aistic.gov.in/ASEAN/ICDST and https://icssr.org/

Through these interactive activities, participants gained insight into fellowship opportunities and developed initial plans to pursue funding for their EER endeavours, leveraging their peers' and facilitators' collective expertise and support.

4 TAKE HOME MESSAGE

Funding opportunities abound for those eager to explore new places and develop research skills. Although crafting a winning proposal requires time and perseverance, it is an achievable endeavour with the right strategy in place. Our facilitation team is committed to supporting participants throughout this journey, offering guidance and expertise to navigate the process successfully. With determination and strategic planning, funding for international research is within reach!

Figure 2: Participants and facilitators of the workshop.

5 Significance for Engineering Education

This workshop aimed to empower participants to secure funding for research, thereby contributing to the vibrancy and growth of our EER community. By equipping individuals with the skills, resources, and networks needed to pursue international research opportunities, SEFI helps foster capacity-building and collaboration across the EER landscape. Ultimately, this workshop's facilitators seek to advance innovative research, drive excellence in engineering education, and strengthen the collective impact that our EER community can have at European and global scales.

REFERENCES

Chance, S. (2013). *A Week in the Life of a Fulbright*. Ireland By Chance. https://shannonchance.net/2013/05/18/a-week-in-the-life-of-a-fulbright/

Chance, S. (2020a). *Example SOC proposal for MSCA IF: Abstract and Eval*. Ireland By Chance. https://shannonchance.net/2020/08/03/msca-abstract/

Chance, S. (2020b). *Final Report of my MSCA Individual Fellowship*. Ireland By Chance. https://shannonchance.net/2020/03/06/final-report-of-my-msca-individual-fellowship/

Locke, Lawrence F., Waneen Wyrick Spirduso, and Stephen J. Silverman. *Proposals that work: A guide for planning dissertations and grant proposals*. Sage Publications, 2013.

O'Neal-McElrath, Tori, Lynn Kanter, and Lynn Jenkins English. *Winning grants step by step: The complete workbook for planning, developing, and writing successful proposals*. John Wiley & Sons, 2019.

Ward, Deborah, ed. *Writing grant proposals that win*. Jones & Bartlett Learning, 2006.

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LEADING THE DEVELOPMENT OF EER BOOKS & SPECIAL ISSUES

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***Conference Key Areas**: Building the capacity and strengthening the educational competences of engineering educators*
***Keywords**: publication; journals; editing; knowledge generation; literature production*

ABSTRACT

This workshop was created for researchers seeking to elevate awareness of specific engineering education research (EER) issues or sub-domains and expand their readership and authorship base within these areas. Drawing from the experience of developing book and journal publications in EER, the facilitators shared insights into the publication process, highlighting the primary considerations involved. The discussion helped participants identify publication formats and understand the usefulness of special-focus journal issues as well as how to conceptualise publication projects, set up editorial teams, select and approach publishers, and prepare proposal documents. The open discussion format allowed participants to query the facilitators.

1 MOTIVATION AND LEARNING OUTCOMES

The workshop was geared toward researchers who want to increase the visibility of engineering education research (EER) and emerging or established sub-topics within this space. The facilitators shared their knowledge and experience (from producing e.g., Chance, Børsen et al., forthcoming; Johri, 2023; Johri & Olds, 2014; Zandervoort et al., 2013, and editing leading journals in the field, including the

European Journal of Engineering Education), the *Australasian Journal of Engineering Education*, and IEEE Education Publications) and insights gleaned from external sources (Guerin 2024; Johri, 2021; Leese 2012; Scholastica 2020).

The workshop design aimed to equip participants with the tools and knowledge necessary to navigate the publication proposal process in EER effectively to advance their research agendas strategically. The session was intended to help participants:

1. **Identify Publication Formats:** The facilitators explored various publication formats available in EER, including wholly authored works and edited collections, and identified publishers accepting such works.
2. **Describe Special-Focus Journal Issues:** Participants learned about special-focus journal issues and their appeal to journal editors in EER.
3. **Conceptualise Projects:** Attendees considered how to conceptualise EER projects, including defining scope, objectives, and target audience.
4. **Set up Editorial Teams:** Participants acquired knowledge on assembling and leading editorial teams for EER publications to help ensure effective project management.

5. **Select and Approach Publishers:** Participants learned strategies for choosing appropriate publishers for their EER projects and how to approach them effectively.
6. **Prepare Proposal Documents:** Participants gained familiarity with proposal documents (including their structure and content), to help them begin the process of preparing one for their own EER project.
7. **Query Editors**: Participants were invited to follow up with the facilitators for advice on their envisioned projects.

2 BACKGROUND AND RATIONALE OF THE SESSION

The workshop targeted individuals keen on helping crystalise focused areas of inquiry within the expansive domain of EER. Areas already bearing some published work offer fertile ground for consolidation and synthesis – and publishing compilations or sets of manuscripts together can facilitate a deeper understanding of pertinent issues. Publications can provide visibility by showcasing collections of curated research within specific sub-topics of EER – including primary and secondary reporting of research. They can become foundational pillars upon which further exploration and advancement can be built.

By consolidating existing knowledge into cohesive collections of journal papers or book chapters, researchers can provide clarity and coherence to the collective body of inquiry. This not only aids in making sense of the diverse strands of research but also serves as an invitation for scholars to delve deeper into topics of mutual interest. Moreover, issuing calls for contributions to collaborative publications fosters a sense of community among scholars, encouraging them to converge around shared research agendas and contribute their expertise to collective efforts. By pooling resources and insights, these collaborative endeavours enrich the scholarly discourse and propel the field of EER forward in innovative and meaningful ways.

The discussions help the community:

- Clarify existing areas of inquiry within EER.
- Advance knowledge within EER.
- Encourage community engagement and shared exploration in EER.
- Advance collaborative efforts in consolidating research efforts.

Collaborative publications catalyse innovation and progress by leveraging the collective expertise and passion of scholars within the EER community, driving the field toward new horizons of understanding and impact.

3 HIGHLIGHTS OF THE SESSION

The format for this session involved the rapid delivery of overview information, in a collaborative environment that encouraged creativity and exploration of diverse perspectives. The discussions focused on:

- **Handbook** expertise with insights from **Aditya Jorhi**, **Tom Børsen**, and **Diana Adela Martin** (editors of Chance, Børsen et al., forthcoming; Johri, 2023; Johri & Olds, 2014; Zandervoort et al., 2013).
- **Special Issues** expertise with insights from **Kristina Edström** (Editor-in-Chief of the *European Journal of Engineering Education*), **John Mitchell** (Head of IEEE Education Publications), **Sally Male** (Editor-in-Chief of the *Australasian Journal of Engineering Education*), and **Inês Direito** (co-guest editor of the emotions special issue for the *European Journal of Engineering Education*).

Through these interactive sessions, participants gained insights and developed initial plans for advancing their research projects within the EER space to leverage their peers' and facilitators' collective expertise and support.

Figure 1: Publications led by the facilitators of this session.

Aditya Jordi explained how putting together a volume, like the three shown in the top row of Figure 1, can be a field-building exercise, as it sparks collaboration and networking and brings those on the periphery toward full participation. He noted that this process can lead to future collaborations among author teams who had not previously worked together. New ideas often emerge during the process, inspiring subsequent papers and projects. Additionally, such publications showcase the field's maturity to stakeholders.

Aditya also described the foundational concepts underpinning Routledge's *International Handbook of Engineering Education Research* (IHEER). He began the editing process by conducting a community-wide survey involving approximately 150 scholars. This survey helped him gather feedback on topics to include and experts who could author chapters. His primary goal was for the volume to cover new content rather than serve as an update of the earlier compilation he had edited, the *Cambridge Handbook of Engineering Education Research* (CHEER). The new volume aimed to focus on educational practice in addition to research and to be more international than its predecessor, reflecting the field's growth (though the final publication remains somewhat US-centric). Aditya employed a conference-inspired review model using EasyChair to manage the process, with leadership support from 18 Associate Editors. He adopted an open-access model, funded by the U.S. National Science Foundation.

The editorial team of *The Routledge International Handbook of Engineering Ethics Education* aimed for the highest global representation possible, a successor of IHEER. During this SEFI workshop, editors Shannon Chance, Tom Børson, and Diana Martin shared some foundational concepts of that forthcoming publication, a two-year project of SEFI's Ethics SIG. The six editors (all members and/or chairs of the Ethics SIG) aimed to produce a comprehensive collection that benchmarks the current state-of-the-art in engineering ethics education. They began with an open call for authors, to which more than a hundred scholars responded. Ultimately, 105 scholars joined the project, collaborating via transnational authoring teams that included many early-career researchers mentored by established researchers. The final result, to be published in late 2024, will contain 36 chapters and 7 overview statements introducing the various sections. The target audience includes teachers, researchers, and academic managers, with the work intended to appeal to newcomers and experts alike. The editors' university covered the open-access fee, ensuring that the digital version will be free to download.

Kristina Edström outlined the process for assembling editorial teams for special issues of journals such as the *European Journal of Engineering Education*. She recommended selecting individuals with diverse expertise, broad knowledge of the topic, and a range of perspectives, including those familiar with the relevant methodologies. She emphasised the importance of recruiting potential authors and reviewers early in the process and finding ways to reduce bias and ensure well-balanced decisions. Kristina advocated including established experts to ensure that the special issue reflects state-of-the-art standards and is considered legitimate and valuable to authors and readers. A robust editorial team is necessary to manage the workload over an extended period, facilitating timely progress and completion, she explained, echoing Aditya, Shannon, Tom, and Diana's comments about using such projects to connect people. Moreover, she highlighted the potential of these projects to link international groups, jump-start junior researchers' careers, and disseminate senior scholars' wisdom.

4 TAKE HOME MESSAGE

Engaging in EER projects to develop books and special issues requires a certain level of expertise and readiness. Individuals (i.e., workshop participants) with experience in leadership, collaboration, and successful publication of journal articles

– like those who attended this SEFI 2024 workshop – are well-positioned to undertake such projects. Beyond technical skills, the most critical aspect is envisioning the topics one aspires to champion or the message one aims to convey. A clear and compelling vision will drive the project forward, inspiring meaningful contributions and fostering community engagement within the realm of EER.

5 Significance for Engineering Education

In recent decades, EER has emerged as a vital force to further engineering education, by advancing knowledge and practice in diverse domains. The global EER community has grown substantially, producing vast, evidence-based research using various methodologies and theoretical frameworks to investigate diverse educational topics. The development of books and journal issues focused on specific topics is on the rise and can help drive the collective generation of new knowledge to advance engineering education and practice.

REFERENCES

Chance, S. (Ed.). (2021). REES/AAEE special focus on ethics: introduction by guest editor, Shannon Chance, *Australasian Journal of Engineering Education*, 26:1, 2-6, DOI: 10.1080/22054952.2021.1936906

Chance, S., Børsen, T., Martin, D., Tormey, R., Lennerfors, T. T., & Bombaerts, G., (Eds.). (forthcoming). *The Routledge International Handbook of Engineering Ethics Education Handbook*. Routledge. DOI: 10.4324/9781003464259

Chance, S., Bottomly, L., Panetta, K., & Williams, B. (Eds.). (2018). Guest Editorial Special Issue on Increasing the Socio-Cultural Diversity of Electrical and Computer Engineering and Related Fields. *IEEE Transactions on Education, (61)*4, 261-264. DOI: 10.1109/TE.2018.2871656

Chance, S., Williams, B., Goldfinch, T., Adams, R. S., & Fleming, L. N. (Eds.). (2019). Guest Editorial Special Issue on Using Enquiry- and Design-Based Learning to Spur Epistemological and Identity Development of Engineering Students. *IEEE Transactions on Education, (62)*3, 157-164. DOI 10.1109/TE.2019.2923043

Guerin, Cally, Claire Aitchison, and Susan Carter. *Creating, Managing, and Editing Multi-authored Publications: A Guide for Scholars*. Taylor & Francis, 2024.

Johri, A. (2021). *The Role of Edited Handbooks in Institutionalizing a Field and Reflections on the Process of Putting them Together*. Higher Seminars 2021-2023 at the Department of Learning in Engineering Sciences. KTH Royal Institute of Technology. https://www.kth.se/social/group/higher-seminars-depa/page/2021-12-03-aditya-johri/

Johri, A. (Ed.). (2023). *International Handbook of Engineering Education Research* (p. 760). Taylor & Francis.

Johri, A., & Olds, B. M. (Eds.). (2014). *Cambridge handbook of engineering education research*. Cambridge University Press.

Leese, Nadine. “Editing Essay Collections & Special Journal Issues” (30 November 2012). https://nadinemuller.org/guides-to-academia/editing-publications/

Scholastica. “5 Tips for Organizing a Successful Special Issue [with advice from a guest editor]” (08 September 2020). https://blog.scholasticahq.com/post/tips-for-a-successful-special-issue/

Zandervoort, H., Børsen, T., Deneke, M., & Bird, S. J. (Eds.). (2013). Editors' Overview Perspectives on Teaching Social Responsibility to Students in Science and Engineering. *Science and Engineering Ethics, 19*, 1413-1438. https://link.springer.com/article/10.1007/s11948-013-9495-7

PUT A FILTER ON IT…the art of reframing practical teaching activities

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***Conference Key Areas**: 2. Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing. 11. Engineering skills, professional skills, and transversal skills*
***Keywords**: Engagement, inspirational, enjoyment, practical, teaching design.*

ABSTRACT

This workshop introduces the concept of "filters" to enhance engagement in engineering education's practical teaching sessions. Highlighting the sparse attention practical teaching has received in academia, it proposes minor adjustments to teaching methods to significantly boost student interest. Through collaborative development and application of these filters, analogous to digital enhancements in photography, educators can apply innovative strategies to various teaching activities. The workshop aims to compile these strategies into a list to inspire and share among educators, by distributing as an open educational resource. This initiative reflects a step towards enriching engineering education by focusing on practical engagement and enjoyment.

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1 INTRODUCTION

Is it possible to enhance the engagement of practical teaching activities without altering their learning outcomes? Can we increase the enjoyment of existing practical teaching sessions with minimal effort and minimal disruption to the engineering curriculum? This workshop will explore how to reframe teaching by applying a 'filter'—making minor adjustments to the session's design to make it more appealing, while preserving the essential aspects of learning.

1.1 Workshop aims

- To collaboratively develop a "menu" of filters that can be applied to practical teaching sessions.
- To share these outcomes with the wider community, offering inspiration for educators seeking to enhance the engagement in their practical teaching.

1.2 Workshop learning outcomes

By participating in this session, you will:

- Reflect on your own memorable and enjoyable educational experiences.
- Identify the elements that made these experiences enjoyable.
- Explore how these elements could be integrated into your own teaching strategies.

2 RATIONALE FOR THE WORKSHOP

Subjects such as employability, ethics, and teamwork receive significant attention from researchers and boast a rich repository of scholarly publications. In contrast, practical teaching, such as laboratories, has garnered comparatively less attention. Most published work in the field focuses on the mechanics of how sessions are delivered, and "there is a lack of literature that shows a general dearth of well-written student learning objectives for laboratories" (Feisel and Rosa 2005). Furthermore, there is an even greater deficit of guidance for educators on how to make practical sessions engaging, enjoyable, or inspirational.

A review of laboratories in our faculty has indicated that the majority are ostensibly 'validation' activities. In these classes, students, already familiar with a theoretical concept, perform an experiment to test the theory, compare the empirical results with those predicted, and demonstrate the model to be correct, within experimental error. However, there are isolated cases of innovation in session design aimed at making the teaching of foundational engineering concepts more engaging, enjoyable, or inspirational. These are typically the result of individual academics implementing a good idea.

The rationale for this session is to attempt to collect a list of methods or tactics that can be used to reframe any practical activity to make it more engaging. This list would then be shared widely to provide inspiration for educators considering how to design new practical teaching sessions or adapt existing ones.

3 SESSION STRUCTURE

3.1 Introduction (5 minutes)

An introduction to the team will be provided, and the rationale described above will be discussed. Participants will then be organized into tables of groups of approximately 4-6 people, and the upcoming table discussion will be outlined. The workshop can be delivered for up to ~50 participants.

3.2 Table discussion: What makes your teaching enjoyable (10 minutes)

Participants will be asked to reflect on sessions they have taught which they believe were enjoyed by students. For inclusivity, those who are not educators are encouraged to contribute by sharing educational activities they have participated in and enjoyed. Participants will be prompted to consider what aspects of the activity made it enjoyable. A digital system will be made available for participants to complete Table 1, with a paper version provided as a backup in the event of technological failure.

Table 1. Enjoyable activities

Teaching Activity	What makes this teaching activity enjoyable?		
…..			

3.3 Presentation: What are filters (10 minutes)

The concept of 'filters' will be introduced as an analogy. Filters can be applied to photographs to enhance them, as illustrated in Figure 1. The image on the left of Figure 1 shows a river, some rocks, a hillside, and some trees. The image on the right depicts the same river, rocks, hillside, and trees, but with a filter applied to make it more appealing.

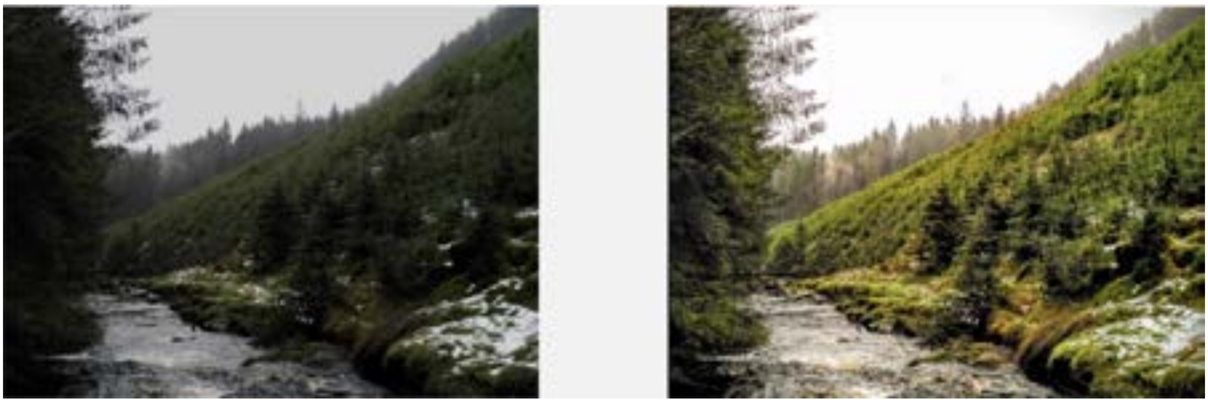


Figure 1. Two photos of the same scene, with the one on the right having a filter applied.

We propose that filters can be applied to teaching sessions. An example of a lab investigating mechanical torsion will be presented. In the original version of the lab, students are presented with specimens of a known material, perform analytical tests to determine the specimen behaviour, and compare the results to theory.

This experiment was reframed by disguising the specimens. Students performed analytical tests, then used the results and theory to deduce the material. The activities the students perform and the learning outcomes are ostensibly the same in both experiments. However, by applying a 'filter' of mystery and detective work, student enjoyment dramatically increased, from a satisfaction rating of 4.1 to 4.83 out of 5.

Mystery and detective work is one example of a filter we have identified. But are there others out there? Can we compile these into a comprehensive list to be shared?

3.4 Table discussion: Abstracting and generalising (10 minutes)

Participants will be asked to consider the enjoyable teaching activities they originally identified and can add more following the presentation. They are then asked to complete the third column of the table by determining if the aspects that made the teaching enjoyable could be abstracted and generated into a 'filter.' A filter should be applicable to types of teaching beyond a specific activity.

Table 2. Abstracting and generalising

Teaching Activity	What makes this teaching activity enjoyable?	Filter: Abstracting and generalising the enjoyable feature	
…..			

3.5 Table feedback (10 minutes)

Tables will have the opportunity to feed back to the whole group the filters that they have managed to identify.

3.6 Table discussion: Drawbacks (10 minutes)

The final task will be to ask tables to consider if there are any drawbacks or operational aspects of the filter that may need to be considered. For example, do any of the filters reduce the inclusivity of activities or compromise data protection?

Table 3. Considerations

Teaching Activity	What makes this teaching activity enjoyable?	Filter: Abstracting and generalising the enjoyable feature	What are the drawbacks or aspects to consider?
…..			

3.7 Wrap up and conclusions (5 minutes)

The session will be wrapped up. This will include a task for participants to reflect on the filter and consider which could be applied to a specific example of their teaching.

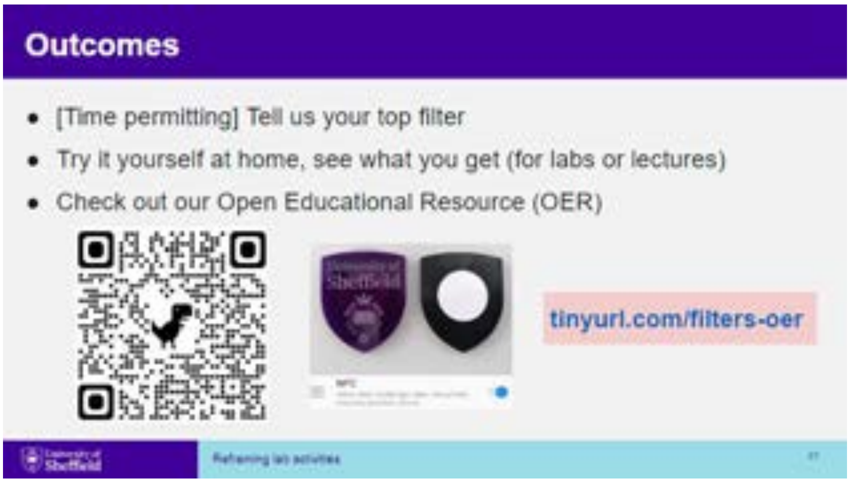
4 OUTPUTS & WORKSHOP REPORT

The workshop ran with some engaged and enthusiastic delegates, who were able to work through the exercises of considering and reflecting on their best teaching activities. This worked within the structure of 3 guided roundtable exercises where delegates discussed practice from their own context, shared and recorded ideas.

The workshop culminated with each group formulating a list of their own *Filters*, which were then discussed at length verbally within the room.

Delegates had 3 main takeaways from the workshop:

- Firstly, they can take and implement the process of the workshop within their own institution by engaging colleagues. This could prove beneficial to share best practices in a rich and focussed manner within departments.
- Second, the discussions provided some very insightful and valuable ideas and best practices which can be implemented at home.
- Finally, a digital resource was provided to all delegates:
  This is an [Open Educational Resource]() (website) containing the culmination of a department wide project within the University of Sheffield, to formulate a list of *Filters*. The resource readily offers ideas and inspiration for educators looking to improve and redesign their teaching sessions.



The authors also gained value from the workshop, in listening to the contributions of the delegates. Their ideas for various *Filters* in their own contexts will help shape further improvements and iterations being made to the Open Educational Resource.

REFERENCES

Feisel, Lyle & Rosa, A.J.. (2005). The Role of the Laboratory in Undergraduate Engineering Education. Journal of Engineering Education. 94. 10.1002/j.2168-9830.2005.tb00833.x.

Kicking off the EER Reading Club -The Handbook of Engineering Research Series

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***Conference Key Areas**: Building the capacity and strengthening the educational competences of engineering educators*
***Keywords**: Engineering Education Research, Reading club*

ABSTRACT

Engineering Education Research is not only a growing but also a fastly maturing research field. The goal of the SEFI Special Interest Group (SIG) of Engineering Education Research is to support the growth and maturing of the engineering education research community in Europe and beyond. With this workshop the SIG launched a new initiative to support the community: a reading club around the recent "International Handbook of Engineering Education Research" (Johri, 2023). The goal of this reading club is to (1) increase the knowledge around engineering education research methodology, (2) to strengthen the engineering education community feeling, and (3) to give a platform to the authors of the handbook's chapters to disseminate their work. The workshop was be the official kick-off of the reading club, which will be continued throughout the coming year in collaboration with other SEFI SIG's using the platform of the SEFI@work sessions. In this first session, Jenni Case

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presented the handbook’s 7th chapter: “The Role and Use of Theory in Engineering Education Research”.

1 MOTIVATION

The field of multi-disciplinary research in engineering education is rapidly evolving. New research teams are being established over Europe, research methodologies from other research fields are adopted, and new insights around engineering education research are emerging regularly. Keeping up with the growth and further supporting this growth can be challenging. The SEFI Special Interest Group (SIG) of Engineering Education Research recognizes this challenge and wants to call upon the power of collective learning and community engagement to overcome it. The motivation behind this workshop and the subsequent reading club is to create a platform where engineering education researchers can come together to learn, discuss, and grow.

2 EXPECTED LEARNING OUTCOMES

The workshop was designed with the following outcomes in mind:

1. **Deepen their Understanding of Engineering Education Research**: Gain a comprehensive understanding of the methodologies used in engineering education research through the exploration of the “International Handbook of Engineering Education Research”.
2. **Community Engagement:** Become an active member of the community of European engineering education researchers, and engage in stimulating discussions and collaborative learning experiences.
3. **Author Insights:** Hear directly from the authors of the handbook’s chapters, directly gain insights into their work, and have the opportunity to ask questions and discuss their research.
   During the conference workshop Jenni Case will present the chapter: “The Role and Use of Theory in Engineering Education Research”.
4. **Continued Learning:** Participate in an ongoing learning experience that extends beyond the workshop, as the workshop will be continued in a reading club during the SEFI@Work sessions.
5. **Networking Opportunities:** Connect with like-minded individuals who share a passion for engineering education research. These connections can lead to future collaborations and enrich the attendees’ professional network.
6. **Co-design the Format of the Reading club:** As part of the workshop, we will collaboratively shape the structure of the upcoming reading club with our participants using co-creation. This participatory approach aims to identify and implement the most effective formats that will actively involve and engage the European engineering education research community.

Additionally, the workshop and subsequent reading club is intended to **strengthen the SEFI SIG’s themselves**. For each of the subsequent reading clubs (SEFI@Work sessions), one of the SEFI SIG’s will be in charge. They can select a chapter that aligns with their interest and shape the sessions connected to it by building on the common format. We believe this will not only strengthen the connection between the SIGs, but also create easy opportunities for the SIGs to reach out to the wider SEFI community during the SEFI@Work sessions.

3 BACKGROUND AND RATIONALE OF THE SESSION

The field of engineering education research is a dynamic and rapidly evolving discipline. It encompasses a wide range of methodologies and approaches, making it a rich but complex area of study. The "International Handbook of Engineering Education Research" (Johri, 2023) is a comprehensive resource that encapsulates this diversity and depth, making it an invaluable tool for those involved in engineering education research. However, the breadth and complexity of the content can be daunting, especially for those new to the field and those wanting to stay on top of all the evolutions in engineering education research. There is a need for a supportive community and structured approach to help navigate this wealth of information.

The workshop serves as the official launch of this reading club, setting the stage for a year of collaborative learning and community building. The co-design approach to determining the format of the reading club ensures that it will be tailored to the needs and preferences of the participants, maximizing engagement and effectiveness.

In addition, by providing a platform for the authors of the handbook's chapters to share their insights, we not only enhance their visibility within the community but also create an avenue for them to effectively disseminate their work. Moreover, this initiative serves as a bridge, narrowing the gap between prominent researchers and the wider community. By facilitating direct interaction with the authors, we democratize access to expert knowledge and insights. This not only enriches the learning experience for all participants but also fosters a more inclusive and collaborative engineering education research community.

In conclusion, the reading club represents a response to the challenges of navigating the complex field of engineering education research. It leverages the power of community and collaboration to enhance learning outcomes and foster a vibrant, inclusive, open, and engaged research community.

4 ENGAGEMENT OF AND INTERACTION WITH SESSION PARTICIPANTS

The workshop was designed to be highly interactive, with multiple opportunities for participants to engage with the content and each other. The following plan was constructed to facilitate this engagement:

1. **Introduction to the Workshop and Reading Club:** The session will begin with an overview of the workshop itself, but also of the subsequent reading club, explaining its purpose, structure, and the benefits of participation. This will set the stage for the activities to follow and help participants understand the context of the workshop.

2. **Chapter presentation by Jenni Case:** Following the introduction, Jenni Case, one of the authors of the seventh chapter of the "International Handbook of Engineering Education Research" (Johri, 2023), will present the

chapter “The Role and Use of Theory in Engineering Education Research”. This presentation will be guided by leading questions, providing a structured approach to exploring the content.

3. **Interactive Discussion**: After the presentation, participants will break into small groups for an interactive discussion. Each group will be given a set of questions to guide their discussion, encouraging deep engagement with the material presented.
4. **Co-Designing Future Sessions**: The final part of the workshop will focus on co-designing the subsequent online reading club sessions. Participants will be invited to share their ideas and suggestions for the format and content of these sessions, ensuring that they are tailored to the needs and interests of the group.

This structure ensures that participants are not just passive recipients of information, but active contributors to the learning process. We anticipated that this level of engagement will enhance the learning outcomes of the workshop and foster a sense of community among participants, and engage the authors for the future reading club sessions as well.

5 TAKE HOME MESSAGES

The intention was that participants will depart from the session feeling a sense of support from the SEFI community, coupled with an enriched understanding of the latest developments in engineering education research. The session was designed to provide an opportunity to interact not only with one of the authors of the Handbook of Engineering Education, but also with other members of the engineering education research community.

Their active involvement in shaping the structure of future reading clubs will foster a sense of ownership and commitment, thereby encouraging continued engagement in upcoming SEFI@Work sessions and the broader SEFI community. This experience is designed to empower participants, making them integral contributors to the evolution of SEFI and the field of engineering education research.

As **organizers** we hoped to gain:

1. **Feedback for Future Sessions:** The workshop provides valuable feedback for the organization of future reading club sessions. The co-design approach ensures that these sessions are tailored to the needs and interests of the participants.
2. **Understanding of Participant Needs:** The interactive nature of the workshop provides insights into the needs and interests of the participants, informing future content and format decisions.
3. **Successful Launch of the Reading Club:** The workshop serves as a successful launch of the reading club, setting the stage for a year of collaborative learning and community building.

In conclusion, both participants and organizers expected to take away valuable insights and experiences from the workshop. The reading club represents a response to the challenges of navigating the complex field of engineering education research. It leverages the power of community and collaboration to enhance learning outcomes and foster a vibrant and engaged research community.

6 CONTRIBUTION TO ENGINEERING EDUCATION

This workshop and reading club were designed to not only enhance the knowledge of the engineering education research community but also to foster a sense of community and collaboration. We believe that through shared learning and discussion, we can advance the field of engineering education research together.

7 RESULTS AND LEARNING FROM THE WORKSHOP

The Reading club was successfully launched with the introduction of the chapter on "The role and use of theory in Engineering Education Research" and a follow-up discussion led by two of the authors of the chapter present; Jenni Case and Aditya Johri. The discussion provided the opportunity for participants to consider the role of theory and its use in their own research as well as their own positioning (are researchers) in relation to relevant theories associated to their work.

The main take-home message from the discussion session on the chapter were:

- Theory is a lens through which we explore/observe/analyse the real-world phenomena that are the focus for a study.
- Theories do not necessary reconcile, it is necessary to be able to justify your choices of theory ("It is a big swamp").
- Theory, empirical data and methodology need to be revisited quite often in a cyclical way, it is not a linear process.
- Learning to use theory is not easy, especially coming from a engineering background. Resources such as the chapter are valuable to get started.

Participants also had the opportunity to provide their views and co-create the upcoming SEFI@Work session for the EER Reading Club to ensure that they are also inclusive to the broad SEFI community.

In the co-creation exercise participants were asked to share their views (preferences and potential pitfalls) on the sessions' format, duration, timing, frequency, topics, participant preparation, time for presentation, time for discussion, networking, interesting format to consider and any other thoughts on conducting the sessions.

Participants proposal for the SEFI@Work sessions are summarized below;

- Format: Interactive sessions where there is some level of structure in the discussion (rather than just open), where authors (a) provide insights of their own experiences and a view on motivations, theories or method(ologies) that they considered originally in their work but rejected (which are aspects that might not be included in the text), (b) ask the authors to so provide an outlook on future research trends and current issues on the topic or generally in EER and, (c) provide clear links to or examples of practice.
- Duration: 1-2 h with minimum of 1h and maximum of 2h.

- Time: Consider time difference that might prevent participants in different time zones to engage with the sessions.
- Frequency: Monthly, perhaps on a regular slot.
- Topics: New and seminal work on key topics, engineering creativity, design ability development.
- Participant preparation: Reading could be done before the meeting and questions could be shared with participants ahead of the session to enable early preparation.
- Structure of session: Preference for first a short re-cap of the chapter/article by authors followed by examples and applications, an exercise for participants to use/apply concepts/points presented and then general discussion, finally closing with a take-home message and/or a short summary. Mixed plenary and group tasks/discussions through breakout rooms.
- Networking: offer also a short time for people to share their own work within the session.

Other suggestions are:

- Having smaller and more frequent activities online.
- Advertising sessions early to provide long-lead time to book.
- Making slots for morning coffee online.
- Setting ‘Skill clinics’ to learn about methods and to get peer-support.
- Setting ‘Match-making’ meetings on topics such as research, funding calls, special courses.
- Setting opportunities to discuss topical issues ad-hoc.
- Having a channel for sharing information, for instance; tips, links and seeking advice about research.

REFERENCES

Johri, A. (Ed.). (2023). International Handbook of Engineering Education Research

ENGINEERING OUTREACH: EXAMPLES, EVALUATION AND EVIDENCING

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Conference Key Areas*: The attractiveness of engineering education; Diversity, equity and inclusion in our universities and in our teaching.*
Keywords*: attractiveness, outreach, pathways, recruitment; schools*

ABSTRACT

Outreach initiatives play a pivotal role in attracting the next generation of engineers. Both academic engineering education institutions and employers engage in various outreach activities to illustrate what engineering entails and to demonstrate the impact of engineering to young children and adolescents. Despite substantial investment of time and resources, there is a lack of comprehensive documentation on the design, content, implementation, and impact of these interventions. This gap hinders the sharing of good practices and raises concerns about the efficiency of these efforts. This workshop aims to showcase diverse outreach activities and gather best practices on outreach activities and evaluation.

1 INTRODUCTION

The shortage of engineers has led to significant investment in outreach activities to encourage children and adolescents to pursue engineering. These interventions vary in aims, forms, target age groups, and contexts (e.g., curricular, or non-curricular), making it challenging to identify successful factors and of good practices. However, better insights into these factors would aid in replicating or designing activities in other contexts and benefit studies on outreach effectiveness, an aspect that is currently underreported in literature.

This paper discusses a workshop at the SEFI Conference 2024 in Lausanne, addressing gaps in understanding engineering outreach. The workshop builds on an ongoing systematic literature review by members of the SEFI Attractiveness SIG, investigating peer-reviewed articles on the effectiveness of in- and out-of-school engineering outreach activities.

2 OUTREACH, A BROAD RANGE OF ACTIVITIES

Preliminary results from ongoing literature research on outreach activities for secondary education (12-18 years old) reflect the wide variety of STEM outreach activities. Different factors influencing the development and organisation of outreach activities are identified.

Firstly, while increasing STEM attractiveness is the primary goal, the activities have varied purposes, such as increasing pupils' motivation and achievement in specific subjects like physics or increasing interest through engineering design challenges. Some activities aim to influence the attitude towards STEM and STEM careers by focusing on the societal impacts like sustainability or climate actions.

Secondly, activities can be offered in school as part of the curriculum (in a specific course, integrating different STEM courses, or in an overall school project), as extracurricular (voluntary lunch or after school activities), or as out-of-school activities.

Thirdly, target groups vary from all pupils to specific groups like girls or broader environments like parents or teachers. Fourthly, many activities involve different stakeholders, such as communal organisations or companies. Fifthly, time and cost investment are significant factors. Lastly, the impact and effectiveness of the outreach activities are often unclear, with few reporting on these aspects

The following three examples illustrate the diversity in purpose and design of such activities:

The Original Brush monster – an example of activity that anyone can do

The Brush Monster Challenge (UK) (1h) aims to provide a creative, practical and fun learning experience for children ages ten to fourteen years old. The activity is a good example of an activity that anyone can do. The resources required are limited: a small motor, a switch, an AA 1.5V battery, and a hand-brush. Each child constructs a simple electric circuit to power the motor, attaching the wiring loom to the brush using cable ties, switching on, and testing that their brush can shuffle across a flat smooth surface. The children can decorate their moving brushes with any available materials, creating the 'brush monster, which is easily customised to various occasions e.g. festive periods, harvest, etc. The activity is fun and engaging where the children get great enjoyment seeing their creations moving around the floor, with a multiplier effect when children bring their creations home. Its impact is not formally assessed.

Dutch Smart City Challenge – an example of collaboration and engagement

The Dutch Smart City Challenge aims to encourage all-age students' interest in STEM through a 14-week long series of out-of-school workshops, aimed at learning and collaborating on building GPS trackers. This activity is an example of collaboration and engagement within the local community and its Smart City initiative, which empowers students to help build their own community leveraging science, engineering and technology. The Smart City Challenge is thus a combination of STEM outreach and citizen engagement. The challenge has met its goal, i.e. to get more students interested in STEM subjects and change their perception of engineering from "boring and difficult" to "fun and meaningful". There is no formal assessment or evaluation for the outcomes and effectiveness of the Challenge initiative.

The engineering world, more than meets the eye – an example of interdisciplinarity and effectiveness

This intervention aims to broaden pupils' image of engineering and make them aware of the societal impact in Belgium. During an interactive workshop (1-2h), last-year secondary education pupils learn about diverse career possibilities and significant societal impact of engineering through activities. For example, pupils explore different engineering roles using the PREFER model (Craps et al., 2021). They discuss societal problems in chosen domains (healthcare, transportation, etc.), identifying necessary professions for tackling future challenges and the role of engineers therein, and emphasizing the collaborative nature and importance of engineering. Using a control-experimental group design, the effectiveness of the intervention was assessed by surveying pupils' image of engineering, sense of belonging in engineering, and engineering identity, including their interest in engineering.

The STEM community would benefit from (1) active sharing of good (and less good) outreach practices and experiences and (2) support in valid measurements and tools to evaluate the effectiveness of outreach activities. Through a systematic literature review, the SEFI SIG Attractiveness aims to contribute to this gap. However, a large number of activities are not published. Hence, the SEFI workshop is an additional step to contribute to the exchange of knowledge and experiences of practices.

3 METHOD

Upon entering, participants (n=27) chose tables for informal group discussions, facilitated by SIG members. The workshop started with sharing the three inspirational examples presented above. Two activity sheets were provided to enhance participation and idea exchange.

Round 1 focused on activity descriptions. Participants individually reflected on an outreach activity from their context (university, organisation or company) using the first activity sheet and presented it in groups, discussing aims, target groups, topics, and formats. Commonalities and unique approaches were explored.

Round 2 focused on activity evaluation. Participants used a second activity sheet to discuss whether the effectiveness of their activities was formally evaluated, including (possible) measurements and outcomes. Inspiring approaches and areas for improvement were identified.

In the final round, SIG facilitators shared each group's main observations and ideas with the audience. The completed activity sheets and facilitator notes were collected for analysis, excluding data from one participant who did not consent to its use. The data can be found in an excel file.

4 RESULTS AND DISCUSSION

4.1 Outreach activity description

- ***Activity purpose***

Outreach activities were categorized into four inductively created **main categories**:

- General interest in engineering (n=8)
- Subject-specific focus (n=8)
- Social challenges and sustainability (n=6)
- Promoting girls and women in technology (n=4)

Most activities aimed to **promote general interest in engineering**. All of the 26 interventions are subordinate to this overall objective, but specifically eight interventions described the aim to raise general awareness of the field of engineering, dispelling misconceptions and showcasing career opportunities. Examples include the *"Scientific Festival,"* which introduces practical engineering application in a fun way to a broad audience.

Eight activities focused on **specific engineering disciplines**, providing fun and creative hands-on experiences in subject-related activities like as robotics (n=4), mechanical engineering (n=2), data science (n=2) and microfabrication (n=1). For example, the *"Dancing Oobleck"* workshop teaches fluid mechanics through interactive demonstrations (how certain fluids, e.g. oobleck, can behave unpredictably under different conditions).

Six activities addressed **ssocial challenges and sustainability**, highlighting engineering's role in solving social and sustainability problems like the Sustainable Development Goals (SDGs) and engineering skills can have a direct impact (Beagon et al. 2023). The *"Engineering our health"* five-day summer programme introduces students to healthcare engineering, raises awareness of the challenges in healthcare and of engineers' contribution in improving public health and people's quality of life.

Four activities aimed to **increase the participation of girls and women in engineering**, using role models and confidence-building exercises. The *"Build a bridge competition"* helps young women gain practical engineering experiences and confidence in a supportive environment.

It should be critically noted that various activities could be assigned to more than one overall category. A limitation of the workshop analyses is that knowledge about the individual activities is limited in some cases, which is why the categorisation could possibly yield different results with more information.

Target groups

As illustrated in Figure 1, most interventions (64%) targeted pupils, with a small proportion (11%) targeting parents, despite their significant influence on the choice to study engineering (Gille et al. 2021) or on the career choice (Cho et al. 2008). Other target groups included teachers, university students, and people from lower socio-economic background.

As shown in Figure 2, primary (6-12 years) and late secondary (15-18 years) school students are well represented, but early secondary school students (12-15 years) were underrepresented (4%). This is notable as this age group is highly receptive to new learning experiences. These learning experiences could strongly influence their decision to study STEM (Buchor et al., 2014).

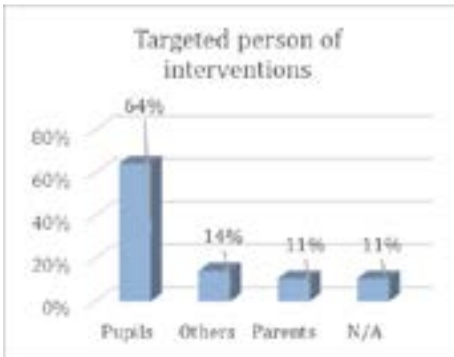

Figure 1: Target groups

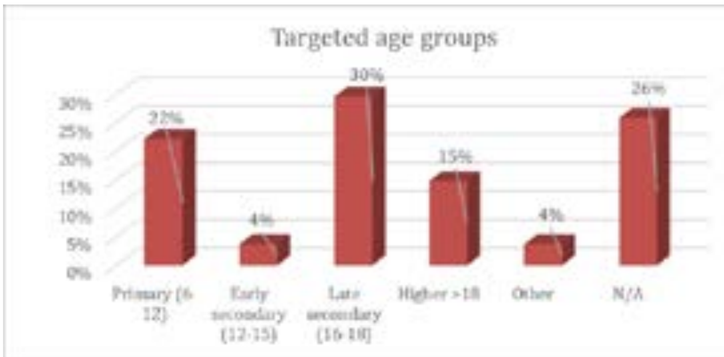

Figure 2: Targeted age groups of interventions N/A was used when the targeted age range spanned several age categories. Other' was used for activities targeting children and parents.

Place and format

Most interventions (56%) took place outside of school (Figure 3), requiring additional effort and resources (e.g., cost of travel or accommodation) but offering opportunities to meet "inspiring allies (role models, career paths)" or peers from other schools. One third (33%) occurred in schools, a familiar learning environment facilitating organisation and feasibility with limited resources.

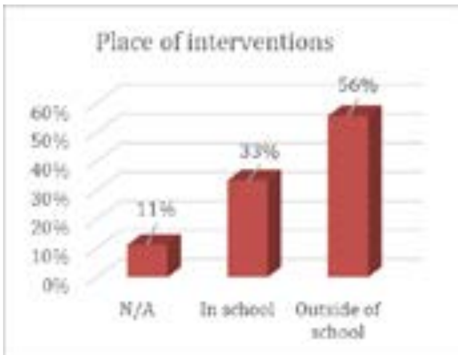

Figure 3: Place of intervention

Intervention formats varied from two-hour sessions to 7-10 days programmes. Most were 1.5 to 2 hours long, with some half-day sessions. Only two interventions were online, highlighting the preference for in-person participation, though online formats could improve inclusion for disadvantaged or remote participants.

4.2 Outreach activity evaluation

Of the 26 activities, 14 were formally evaluated, with results published in journals (n=3) or conference proceedings (n=4). Thirteen reported positive outcomes, while one participant noted positive results for an unevaluated activity. The effectiveness of the remaining activities was undetermined.

Evaluation methods included surveys (in pre-post or post-only), self-evaluation, knowledge tests, skills assessment, qualitative discussions, reflections, and grading. However, details on concrete measures, such as validated questionnaires, were limited.

Discussion highlighted challenges in evaluating outreach effectiveness. While measurable results, liked increased STEM enrolments may take years to manifest, some participants stressed the need for more data collection and improved evaluation methods. The difficulty of obtaining ethics approval for such studies was acknowledged. Additionally, measuring the effectiveness of activities aimed at families and parents versus those for children and teachers is challenging due to varying private settings and circumstances.

5 SUMMARY AND TAKEAWAYS

Significant resources are invested in mostly in-person outreach initiatives. Workshop results confirm the preliminary findings from the systematic literature review: outreach activities vary in purpose, target groups, and formats. While roughly half of the activities were evaluated, the measures used varied widely, and validated measures were not explicitly reported on the activity sheets. The SIG aims to summarise existing literature on engineering outreach effectiveness to inspire the community with appropriate research designs and validated instruments for better effectiveness assessment.

REFERENCES

Beagon, U., Kövesi, K., Tabas, B., Nørgaard, B., Lehtinen, R., Bowe, B., ... & Spliid, C. M. (2023). Preparing engineering students for the challenges of the SDGs: what competences are required?. European Journal of Engineering Education, 48(1), 1-23.

Bieri Buschor, Christine, Simone Berweger, Andrea Keck Frei, and Christa Kappler. "Majoring in STEM—What accounts for women's career decision making? A mixed methods study." The Journal of Educational Research 107, no. 3 (2014): 167-176.

Craps, Sofie, Maarten Pinxten, Heidi Knipprath, and Greet Langie. “Different Roles, Different Demands. A Competency-Based Professional Roles Model for Early Career Engineers, Validated in Industry and Higher Education.” European Journal of Engineering Education 47, no. 1 (2022): 144–63.

Cho, Su-Je, Cynthia Hudley, Soyoung Lee, Leasha Barry, and Melissa Kelly. "Roles of gender, race, and SES in the college choice process among first-generation and nonfirst-generation students." Journal of Diversity in Higher Education 1, no. 2 (2008): 95.

Gille, Maryse, Romain Moulignier, and Klara Kövesi. "Understanding the factors influencing students’ choice of engineering school." European Journal of Engineering Education 47, no. 2 (2022): 245-258.

Sáinz, M., S. Fàbregues, M. José Romano, and B.-S. López. 2020. “Interventions to increase young people’s interest in STEM. A scoping review.” Frontiers in Psychology, 13.

WHO IS THE BEST ENGINEER?: IDENTITY THEORY AS A FRAMEWORK TO REFLECT ON OUR ROLE IN THE CONSTRUCTION OF BELIEFS ABOUT THE VALUE OF SOCIAL RESPONSIBILITY IN ENGINEERING

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Conference Key Areas: *1) Building the capacity and strengthening the educational competences of engineering educators, 2) Teaching social and human sciences to engineering and science students*
Keywords: *identity, research-to-practice, cultural construction, values*

ABSTRACT

The 2024 SEFI conference posed the question, "*How can we ensure the highest quality of technical competence while at the same time ensuring that social and environmental responsibility is core to the identity of engineering graduates?*" Identity formation is a complex process that has been theorized in many ways. In this workshop, I invited participants to consider Holland and colleagues' theory of identity as a useful framework for reflecting on our how our participation in engineering education contributes to beliefs about what makes a "real" or the "best" engineer. This theory posits that within our classrooms, students are participating in a complex cultural practice through which they ultimately learn to identify (and be identified) as more or less of an engineer than others. Our everyday classroom practices ultimately function to co-construct 1) shared beliefs about what makes a "good" engineer, and 2) everyone's relative position in a social hierarchy. Furthermore, identify development is theorized to include both social forces (i.e., rules and guidelines that influence how people behave in a social space) and individual agency (i.e., we are not just carbon copies of culture or norms because our actions shape the culture and norms). Understanding identity development as such empowers us to be intentional with our own participation in identity construction by providing theoretical entry points for conveying the value of social responsibility. The usefulness of this particular identity theory to ideate strategies for integrating social responsibility into students' engineering identities has been corroborated by the

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empirical findings of our U.S.-based engineering education research. During this workshop, we utilized the theory to draw out existing or future concrete practices that each of us, given our unique global and institutional contexts, are motivated to enact in support of social responsibility as core to engineering. Specifically, our interactions culminated with answering the following question: What is one concrete way I can *be intentional* in how I participate in identity co-construction? Participant responses to this prompt are presented directly.

1 INTRODUCTION

1.1 What were session participants expected to learn?

I designed the workshop to achieve the following learning outcomes:

Participants will be able to…

1. Recognize identity as part of a complex social process
2. Reflect on their participation in this social process
3. Generate at least one concrete way to *be intentional* in how they participate

1.2 What made the session relevant and attractive for the audience?

This session was relevant and attractive for the audience because it presented Holland and colleague's theorization of identity (1998) as a framework for reflecting on the ways in which we all play an active role in the complex social process through which students learn to understand them as engineers (or not). More specifically, this theorization of identity acknowledges the complex and interrelated nature of individual agency and the broader social context. The idea is that in any given classroom context, there are rules, guidelines, and social forces that influence (but don't dictate) how people behave, speak and conduct practice within social spaces. We are all subject to the greater power structures around us, and at the same time, we have agency to resist and re-shape these norms. At the end of the day, this identity theory assumes that we are participating, along with the students and others in engineering classrooms, in a complex social process through which we co-construct shared beliefs about what it means to be an engineer and everyone's relative position in a social hierarchy. Therefore, it is through intentional and theory-based action that we can work to integrate social responsibility, or other values, into the very definition of an engineer that students are learning to identify with. Given the theme of the conference, this session was useful for any conference attendee willing to critically reflect on how their own role in engineering education fosters or counters the belief that social responsibility is core to being an engineer.

1.3 How was this work significant for engineering education?

This type of workshop was significant for engineering education because it challenged us to move beyond espousing the value of social responsibility and lean into our agency as part of the cultural production of the very characteristics that are recognized as necessary to be a good engineer. The workshop provided attendees with the opportunity to reflect on the implicit and culturally specific ways in which their own educational praxis is a local site for the co-construction of students' engineering identities. By framing engineering identity as the outcome of a cultural practice, we were prompted to generate theoretically- and empirically-based modifications to our own actions that shift culture from the ground up.

This effort was also significant for engineering education because it is a translation of research to practice. We have significant empirical findings from our research on student beliefs and identities as engineers and as smart that justify the use of this theory to guide the workshop. During the workshop, I justified our use of this framework by briefly sharing highlights of our U.S.-based research findings that corroborate the theory. These findings include: identifying as smart is a fundamental way that students identify as a "good" engineer (A. Kramer et al. 2019; Wallwey et al. 2024); as students transition from a pre-college to a college context, they are actively constructing their identities as "smart enough" for engineering (Kajfez Under Review); students articulate 11 distinct ways that they believe one can behave like a "smart" engineer (Amy Kramer, Kajfez, and Dringenberg 2024); understanding oneself as an engineer is a process of social comparison (Dringenberg, Kramer, and Betz 2022); behaviours related to social responsibility are valued more by students personally than by what they experience in engineering classrooms (with statistical significance) (Amy Kramer, Kajfez, and Dringenberg 2024). In addition, researchers have used Holland and colleagues' framework to study the complex process of engineering identity across contexts of construction engineering in Sweden (Gonsalves et al. 2019) and engineering design in the U.S. (Tonso 2007).

2 METHODOLOGY

2.1 How were session participants activated?

<u>Survey item to assess control beliefs in the room</u>

As participants arrived, they were invited to provide a "pre" response to the following question in a Likert-scale style (1-5 strongly disagree to strongly agree) poll: *I am capable of promoting social responsibility as required to identify as an engineer*.

<u>Overview of workshop</u>

Next, I presented the conference theme (How can we ensure the highest quality of technical competence while at the same time ensuring that social and environmental responsibility is core to the identity of engineering graduates?) and introduced myself by way of my focus on the "core to the identity" bit of this theme for the workshop. I also presented the learning outcomes and corresponding workshop plan to participants.

<u>Introduction of Holland's identity theory and U.S.-based research findings</u>

I provided a brief overview of and justification for the identity theory that I draw on (Holland et al. 1998) when thinking about how we might shift or expand the behaviours that are constructed as necessary to be recognized as a "good" engineer in the context of higher education. As multiple identity scholars were present in the room, we had a lively discussion about multiple facets of this complex theory. I introduced Table 1, which contained three theoretically-grounded entry points for us, as participants in engineering spaces, to influence the co-construction of shared beliefs about what makes a "good" engineer. The second column provides more concrete and detailed components of our classrooms. One participant provided feedback that yet another column to provide further concrete examples would be helpful in future work, with which I agree.

Table 1. Theoretical Entry Points for Practice

We co-construct what is believed to make a "good" engineer in…	**And can therefore be intentional about the values communicated via…**
1. How we design and implement our course	• The learning outcomes we establish for our courses • Which outcomes we prioritize and assess • Our methods of assessment • The discourse within our classrooms • The content of course artifacts
2. The extent to which we understand and name the socio-historical-cultural forces of our context	• The history and culture of our educational context • The cultural landscape of engineering • The behaviours that are rewarded in our classrooms • The expertise that is modelled by our teaching team • The expectation (or not) that engineering education develops students' critical consciousness
3. The extent to which we learn and integrate students' values into our classroom praxis	• How we situate students in our classrooms with respect to knowledge production • The extent to which we work to understand students' values and motivation • The extent to which we are willing to share power with students when it comes to classroom practices

<u>Reflection and discussion to ideate best practices and synthesize insights</u>

Next, participants were invited to first reflect individually and then discuss with others their own ideas (current or future) for how they could be intentional in their participation in co-construction of student identity. We came back together as a group to share out, and the participants exchanged ideas.

<u>Debrief and closing (10 min)</u>

I closed by asking participants to write down at least one action that they are willing to commit to on a sticky note. Additionally, they were invited to respond to the same Likert-style survey question we started with (control beliefs) and provide a free response to the prompt, "Describe one concrete way you'll be intentional in how you participate in identity co-construction."

3 RESULTS

3.1 Pre and Post survey item results

The responses to the pre and post survey item on control beliefs are displayed in Figure 1.

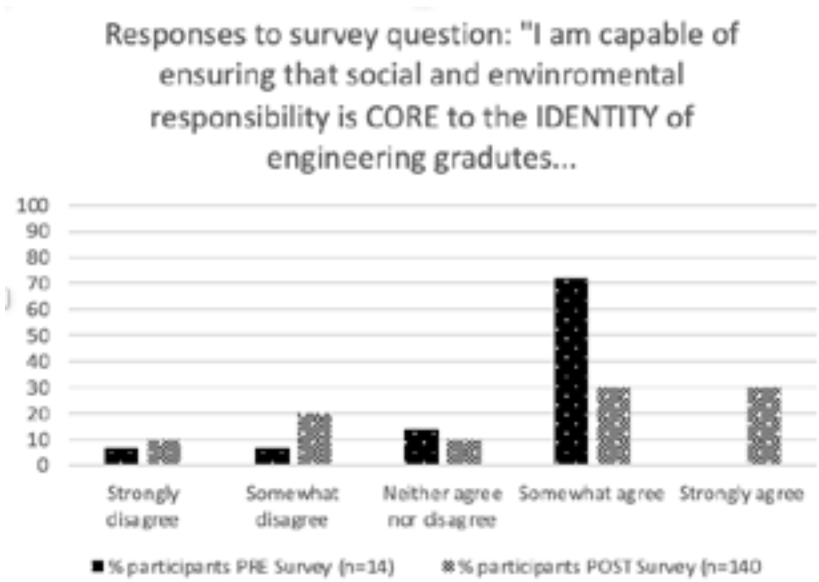

Figure 1. Survey item pre and post responses

A general observation here is that from the beginning to end of the workshop, the bulk of attendees went from "somewhat agree" to split between "somewhat agree and strongly agree," which I found encouraging. No statistics were performed as this was not a formal evaluation plan. As for the open responses, the following bullet point list captures the responses generated by participants, edited only for readability:

- Create awareness of students' own identity → values, perspectives, biases
- Make conversations on identity and perceptions a part of the classroom discourse
- Consider course artifacts as a part of the classroom design and assignments, and as a form of representation (include images that are inclusive)
- When I get students to make up an optimization problem and present the answer for peer-review, I should get them to choose a problem personally important to them and explain to others why it is important to them
- Make students aware of the notion of professional identity which is done/performed through skill demonstration (that they are not just "students")…then they recognize we "become" an engineer when practicing
- Give thought provoking assignments—ask students what kind of engineer do they want to be (instead of what they are expected to be)
- Support student collaboration in problem/practice based educational assignments
- Consider not just student identity, but also teacher identity
- Consider the pressures to conform to "figured world norms"
- Consider how to align student and other values
- Give students the tools to help them become aware of the figured world and how to interpret these artifacts/dialogues
- Didactic contract to be explicit in expectations between student & teacher to build student/teacher/class shared norms & values in class which then shapes identity via building of sense of belonging & self-efficacy
- Tell the students the learning possibility of failing
- Suggest faculty-student tandems for developing sustainability teaching to my university

- Consider classroom discourse and modelling diverse expertise in the teaching team.
- Ask students why the course is important to them and how it aligns with their professional and social values
- Provide more artifacts and discourse in my classes on this topic.

Finally, I sent a draft of this paper with attendees who indicated an interest in seeing the paper and solicited their edits or feedback before submitting the final version for publication. No edits were requested.

4 SUMMARY AND ACKNOWLEDGEMENTS

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REFERENCES

Dringenberg, Emily, Amy Kramer, and Amy R Betz. 2022. "Smartness in engineering: Beliefs of undergraduate engineering students." *Journal of Engineering Education* 111 (3): 575-594. https://doi.org/10.1002/jee.20463.

Gonsalves, Allison J, Eva Silfver, Anna Danielsson, and Maria Berge. 2019. "“It’s not my dream, actually”: students’ identity work across figured worlds of construction engineering in Sweden." *International Journal of STEM Education* 6 (13): 1-17. https://doi.org/0.1186/s40594-019-0165-4.

Holland, Dorothy, William Jr. Lachicotte, Debra Skinner, and Carole Cain. 1998. *Identity and agency in cultural worlds*. Cambridge, MA: Harvard University Press.

Kajfez, R. L., Kramer, A., Braaten, B., Dringenberg, E. Under Review. "Am I smart enough to be an engineer? How undergraduate engineering students articulate they are smart enough for engineering." *Journal of Engineering Education*.

Kramer, A., G. Thanh, E. Dringenberg, R. Kajfez, and C. Wallwey. 2019. "A narrative-style exploration of undergraduate engineering students' beliefs about smartness and identity." Proceedings of the Frontiers in Educational Annual Conference, Cincinnati, OH.

Kramer, Amy, Rachel Louis Kajfez, and Emily Dringenberg. 2024. "Ways of Being Smart in Engineering: Beliefs, Values, and Introductory Engineering Experiences." *International Journal of Engineering Pedagogy* 14 (1): 129-148. https://doi.org/10.3991/ijep.v 14i1.41633.

Tonso, Karen L. 2007. *On the outskirts of engineering: Learning identity, gender, and power via engineering practice*. Sense Publishers.

Wallwey, Cassie, Emily Dringenberg, Bailey Braaten, Yiqing Li, and Rachel Kajfez. 2024. "Engineering Identity and Smartness Identity as They Relate to Women’s Participation in Engineering." *IEEE Transactions on Education* 67 (2): 306-316. https://doi.org/10.1109/TE.2024.3359534.

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ENGINEERING EDUCATION RESEARCH: REVIEWING JOURNAL MANUSCRIPTS FAIRLY, CONSTRUCTIVELY, AND EFFECTIVELY

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***Conference Key Areas**: Fostering Engineering Education Research*
***Keywords**: Engineering Education Research, Journal, Peer review, Reviewer, Editorial process*

ABSTRACT

This workshop focuses on peer review of journal manuscripts in the field of engineering education research. The aim is to jointly consider how to review manuscripts fairly, constructively and effectively. To this workshop we invite both experienced and new reviewers, with a particularly warm welcome extended to doctoral students in engineering education research.

1 BACKGROUND: FAIR, CONSTRUCTIVE, AND EFFECTIVE REVIEWING

1.1 Peer review as a way to safeguard and enhance quality

The function of the peer review process is first to support journal editors in making *fair* decisions by helping them identify which manuscripts deserve to be published. The task is further to *constructively* support the authors in improving their manuscript before publication. The peer review process often goes through some iteration to help authors improve their research ideas and approaches, as well as how they communicate these ideas, methodologies and results to the readers. It is through this process of both selection and enhancement that the quality of publications is safeguarded. By extension, this is how the whole research field can establish and maintain respect. Reviewers therefore play a vital role. It is even fair to say that without peer review there can be no respectable field.

1.2 The work of reviewing

Given that the research field depends on it, reviewing manuscripts is a contribution that all scholars need to make to sustain and further the field. The peer reviewer role is also a part of any academic identity and expresses scholarly collegiality. In addition to such altruistic reasons, it is a rewarding task to review manuscripts, since much can be learned from engaging with the work of others. It is not least helpful to experience the editorial process from the inside. Such insights can be helpful when taking one's own manuscripts from submission to successful publication. However, as reviewing can also be time-consuming, it is a wise investment to improve one's skills to do it *effectively*.

2 ABOUT THE WORKSHOP

2.1 Aims

The workshop aim was to introduce the participants to various credible journals in our field, with their different aims and scope, and review criteria.

During the group exercise, participants were asked to consider the following aspects:

- The roles and perspectives of authors, editors, and reviewers in the peer review process
- How to provide recommendations to support editors in making fair decisions
- How to provide constructive suggestions to authors to support them in improving their manuscripts
- Which aspects of a manuscript that are helpful to focus on in a review, and how to apply the review criteria
- Ethical aspects of peer reviewing – do's and don'ts
- Time management strategies for effectively producing articulate reviews

2.2 Outline

The total duration of the workshop was 60 minutes.

Brief introductions

- Participants and session leaders.
- Journals: aims and scope, review criteria and review process.

Group activity

- Participants were divided into groups of about four, each facilitated by one or more journal editors. The task was to make a virtual poster: "Advice for reviewers". The poster consisted of a slide in an online collaborate writing environment. All participants wrote concurrently during the discussion, without needing to reach full consensus.

Plenary

- Joint discussion about the results – in search for synthesis, collected wisdom and conclusions.

Closing

- At the end, participants were invited to sign up to receive documentation from the session, including the posters that were produced during the workshop. They could also sign up to volunteer as reviewers for the journals.

2.3 Facilitators

The workshop was facilitated by a large team of editors of five leading engineering education journals:

- *European Journal of Engineering Education (published by SEFI)*
- *Journal of Engineering Education (published by ASEE)*
- *Australasian Journal of Engineering Education (published by AAEE)*
- *IEEE Transactions on Education (published by IEEE)*
- *SEFI Journal of Engineering Education Advancement (published by SEFI)*.

3 RESULTS FROM THE WORKSHOP

During the workshop 22 persons worked intensely, in 4 groups, to generate advice for reviewers. The posters that they produced are copied below, slightly edited.

3.1 Group 1

- Put yourself in the shoes of the authors and the readers
- Can you understand the paper even if you're not an expert?
- Don't talk about what you would write; discuss what you would read
- You are not reviewing the author; you are reviewing the paper
- Longer reviews don't necessarily mean better reviews
- 3-4 actionable bullet points are better both for the author and the editor
- Structure your review: what are the main points, and what are minor fixes?
- Give examples (e.g., where is the alignment off?)
- Highlight the positive/strong aspects: This helps us to keep the good aspects when reviewing the paper
- Helps the editor
- Be careful with the use of AI
- Don't put the paper you are reviewing into AI, although GenAI may be used for structuring your review
- Name-dropping is to be avoided
- Don't push citing your work as a reviewer
- Make sure that what you cite is what you say
- Notify editors about possible delays:

- If you know you will be busy in advance already, talk to the editor about your timeline
- If you can't do it, say it as soon as possible
- As a reviewer, you are not correcting – you are making suggestions and advising the author (and the editor)
- You are not the writer
- You are not alone
- Editors and associate editors are also reviewing, especially if the reviewers don't agree
- Reviewing is a way to grow as a part of the community
- You can improve clarity, but novelty is difficult to add
- Even if you reject, provide suggestions as to what can be improved, e.g., "these are necessary," and "these would add value"

3.2 Group 2

- Be constructive in offering ways to improve the work proposed
- Be respectful in a sense of providing peer-to-peer education
- Be concrete on your suggestions
- Provide references when you feel they would be helpful

  Be aware of your own biases; be impartial and non-biased regarding your own research
- It is fine if you make your review only on your line of expertise, you don't need to be an expert on all elements of a paper: give feedback on what you know well enough only (editors will have the role to combine reviewers expertise into one paper revision);
- Be honest about the paper's contribution to the field; let the authors/editors know the relevant already existent publications
- If you notice a review is taking a lot of time, park it for a bit, and try again a few days later

3.3 Group 3

-
- Read the paper, the first time for context and feel, and then reread for detail
- Assess if you can gist the paper from abstract, figures and conclusions
- Give advice that is actionable
- Give realistic Advice, e.g., Don't ask "for more data" (unless the paper is unpublishable without expansion)
- Advise, don't criticise

- Do not proofread
- Be timely
- Is the usefulness of work clearly defined?
- Don't be a gatekeeper
- Be supportive…

3.4 Group 4

- Focus on the key issues - not pages on listing typos
- Be constructive and empathetic. Authors often don't spell out what they've done clearly enough because they're very close to the work. Don't just talk about the things that were done poorly, also highlight what's been done well.
- Write the review in a tone you would want to receive
- Recognize that authors own an interpretivist view of their research
- Use the confidential comments box to be candid (i.e., fit for the journal, citation of literature relevant to the area of study overlooked)
- Consider if the paper has 'potential' and offer suggestions for how to move the paper forward in a productive manner (similar to offering actionable feedback)

4 CONCLUSIONS

The advice for reviewers reflects several common themes. The groups have much to say about what it means for reviews to be *constructive*, in the sense of being directly helpful to the authors to improve the manuscript. In particular, actionable and concrete advice is much valued. Structuring a review by distinguishing between fundamental or serious issues and optional recommendations is also helpful, both to editors and authors. Suggesting relevant references is helpful, but not to promote one's own work. You may highlight very relevant work of your own in the confidential advice to the editors, so the editors can determine its relevance and usefulness to the manuscript and include the suggestion in the editor's comments. Another theme related to *fairness* is the advice to see the manuscript on its own terms. We are reminded to consider the manuscript as the authors' work rather than what the reviewer would have written. Generally, reviewers should understand the role of their own positionality and possible bias. An important theme is *empathy*. A review must be worded in a respectful tone. Highlighting what is good about the manuscripts is recommended, not only for balancing the critique to make the review easier to bear for the authors, but the validation of strengths is important information for both editors and authors. Empathy and respect are also conveyed by helpfulness. A truly supportive review is when the reviewer not only points out weaknesses in the manuscript, but also gives advice on how to overcome problems. As one group pointed out, manuscript reviewing is also *peer-to-peer education*. Approaching the peer-review role with that mindset makes reviewing a valuable contribution to the field.

5 ACKNOWLEDGEMENTS

The editors who facilitated this workshop would like to extend their sincere gratefulness to the reviewers who volunteer their time and effort to engage in the peer review process. Through these anonymous contributions, reviewers are supporting the journals, the authors, and the field of engineering education research.

Re-imagining engineering education through addressing interdisciplinary course design challenges

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***Conference Key Areas**: Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing, Building the capacity and strengthening the educational competences of engineering educators*

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***Keywords**: interdisciplinary education, course design, engineering education, pedagogy*

1 INTRODUCTION

There has been a shift in higher education as universities began to re-evaluate their teaching and learning to ensure that students are well-prepared for the global challenges. Especially in the field of engineering, future graduates are expected to address complex issues such as sustainability and consider the societal impact of their solutions (Hadgraft and Kolmos 2020). These expectations require engineers to collaborate effectively with others from different disciplines and backgrounds (Borrego et al. 2013). However, interdisciplinary collaboration and learning from different disciplines can introduce challenges, as team members often have vastly different perspectives, experiences, methodologies, and even different languages (Feng et al. 2023). This dynamic can be especially challenging for students who are accustomed to discipline-specific collaborations.

Universities have responded to this challenge by creating various opportunities for engineering students to engage in interdisciplinary collaboration projects. Internationally recognized frameworks and accreditations, such as the CDIO (Conceive – Design — Implement — Operate) framework (Crawley 2001) and ABET (Accrediting Board for Engineering and Technology 2021), highlight the critical role of multidisciplinary collaboration for engineers.

Despite these initiatives, developing and implementing courses that integrate multiple disciplinary perspectives remains a challenge for educators. Research indicates a need for pedagogical training in course design to help educators navigate the complexities of interdisciplinary projects and ensuring that students receive appropriate support (Kjellberg et al. 2023; Van den Beemt et al. 2020; O'Connell et al. 2023). Therefore, this workshop aims to assist educators in designing multi-, inter, and transdisciplinary courses that leverage available resources and align course design with intended learning outcomes, effectively preparing students for their future roles in addressing societal challenges. We introduce a toolkit that can be utilized by all engineering educators regardless of their expertise. Novice engineering educators will find the toolkit an accessible starting point for designing multi-/inter-/transdisciplinary courses, while seasoned educators can use it to explore new aspects in their course designs.

2 RATIONALE

Interdisciplinary courses can take various forms, such as incorporating students from diverse backgrounds, introducing interdisciplinary problems or projects, or involving non-academic stakeholders to collaborate with students (Feng et al. 2023). Navigating these characteristics of interdisciplinary teaching and learning is not straightforward. Hurdles have been found among teachers collaborating across different departments and schools (Dym et al. 2005; Feng and Hölttä-Otto 2021). Engineering educators often struggle with how to optimally use resources while balancing the need for disciplinary breadth against depth (Holt et al. 2017).

The aim of this workshop is twofold. First, it introduces a toolkit that provides a platform for engineering educators to re-imagine and co-create course designs for various multi-, inter-, and transdisciplinary teaching scenarios. Second, it offers an opportunity to test the course design toolkit presented in Figure 1, gathering insights for its further development to better meet engineering educators' needs. After the workshop, the participants are equipped to pilot the toolkit in their own course design and to facilitate course design workshops within their respective institutional contexts.

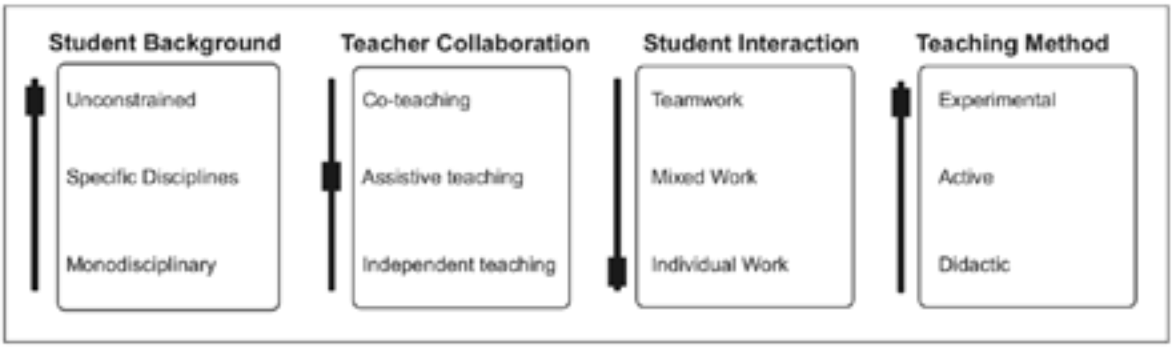

Fig 1. Multi-, inter-, transdisciplinary course design framework. The tool works like a mixing board with a slider; by finetuning the settings, course designers achieve an optimal outcome

In theorizing this workshop, we recognized various relevant terminologies of disciplinary integration, and distinguished between multidisciplinary, interdisciplinary, and transdisciplinary. A multidisciplinary course exposes students to various disciplinary perspectives, offering a broader view. An interdisciplinary course goes a step further by integrating different modes of thinking and methodologies from various disciplines. A transdisciplinary course transcends traditional academic boundaries by involving societal stakeholders in the co-creation of solutions (Lattuca et al. 2017; Klein 2015).

Building on a previously developed course design framework on multi-, inter-, transdisciplinary course design (Feng et al. 2023), the workshop covered four aspects (Figure 1):

- ***Student Background*** refers to the disciplinary backgrounds of the students participating in the course. Students may come from only one discipline, specific sets of disciplines, or any discipline.
- ***Teacher Collaboration*** relates to the mode of working among course teachers. Teacher(s) may teach alone or invite guest lecturers for assistance. Co-teaching represents the highest level of collaboration, including joint course design and teaching efforts throughout the course.
- ***Student Interaction*** pertains to the nature of students' work during the course, ranging from purely individual work, a mix of teamwork and independent tasks, to team-based work throughout the course.
- ***Teaching Method*** refers to method employed by the teacher. Didactic method involves traditional lectures, imparting knowledge to students; active learning method emphasizes experiential learning with, for example, Problem-Based Learning; experimental teaching adopts creative teaching methods, such as writing, drama, debates, role play, etc.

3 METHOD

The workshop was implemented as a course design challenge aimed for engineering educators of all experience levels. It was particularly appealing to those new to or with varying degrees of experience in interdisciplinary teaching who wish to explore the implications of their course designs more deeply. Structured as a 60-minute session, the workshop was comprised of three sections: a 15-minute introduction, a 30-minute group work activity, and a 15-minute conclusion.

First, the workshop provided the participants with an overview of the different aspects of course designs (Figure 1). Then, the participants worked in teams to solve course design challenges. The participant groups were given hand-outs to familiarize themselves with course scenarios and toolkit materials. In the workshop's final part, participants shared their designs and formulated their take-home messages.

The workshop provided several different course design challenges. Three course scenarios were provided, each included three course design challenges. Two to three participants worked together in each group to tackle one challenge. The exemplar course scenarios and challenges are introduced below in Table 1.

When designing their course, participants were asked to consider the four aspects described in the course design framework (Figure 1), which include student background, teacher collaboration, student interaction, and teaching pedagogy. They were also required to justify their course design considering the intended learning outcomes.

Table 1. Engineering course scenarios and design challenges

Course scenarios	**Course design challenges**		
	Multidisciplinary	Interdisciplinary	Transdisciplinary
1. Water governance course	Design a *multidisciplinary* water governance course	Design an *interdisciplinary* water governance course	Design a *transdisciplinary* water governance course
2. Product development course	Design a *multidisciplinary* product development course	Design an *interdisciplinary* product development course	Design a *transdisciplinary* product development course
3. Course on developing sustainable living spaces	Design a *multidisciplinary* course on sustainable living spaces	Design an *interdisciplinary* course on sustainable living spaces	Design a *transdisciplinary* course on sustainable living spaces

4 RESULT SYNTHESIS

There were approximately 25 faculty members who participated in the workshop. The participants collaborated in ten small groups of two or three persons in each. They were asked to tackle a course design challenge with an aim to create a multi-, inter-, or transdisciplinary course. The three given course design scenarios included product development, water governance, and sustainable space design. Once the ten small groups completed their designs, they merged into larger groups to compare and discuss each other's course designs. There were four larger groups, each comprising 4 to 9 participants, who engaged in these comparisons.

The comparisons between the groups revealed that while participants often adopted similar overall approaches to course design, the details and underlying rationales varied significantly. For example, both the multi- and transdisciplinary course design groups tailored their courses for students with specific disciplinary backgrounds, such as architecture, energy, and civil engineering. However, the transdisciplinary group extended their course to include more diverse students, such as sociology students, bringing a broader and more diverse range of perspectives than in the multidisciplinary group. Moreover, while both multi- and transdisciplinary groups incorporated guest lecturers from various disciplines as part of their assistive teaching strategies, the transdisciplinary groups also involved stakeholders, either as guest lecturers or as to provide real-world challenges for students to address. For interdisciplinary groups, their course designs emphasised more on the disciplinary integration regarding co-teaching and students' teamwork throughout the course.

5 SIGNIFICANCE

The workshop provided a valuable opportunity for engineering educators to reflect and collaborate on interdisciplinary course designs. As the current global challenges often demand interdisciplinary approaches, engineering educators are at the forefront of crafting educational experiences that span across disciplines. This workshop, by focusing on the intricacies of designing courses that accommodate diverse student backgrounds and interdisciplinary content, addressed a critical need within the academic community. It encouraged educators, regardless of their experience level with interdisciplinary teaching, to explore and critically evaluate the implications of their course designs. The importance of peer learning was also highlighted in the wrap-up discussion.

Through a structured exploration of course design aspects and tackling exemplary teaching challenges, participants were equipped with the tools and insights necessary to enhance their pedagogical strategies. This not only enriched the learning experience for students but also contributed to the broader goal of fostering a more integrated, holistic approach to engineering education. Through dialogue and sharing of course design ideas, this workshop can help shape the future of engineering education, making it more responsive to the needs of multidisciplinary students and ultimately, a rapidly evolving world.

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REFERENCES

Accrediting Board for Engineering and Technology. “2022-2023 Criteria for Accrediting Engineering Programs.” ABET Engineering Accreditation Commission. (2021).

Borrego, Maura, Jennifer Karlin, Lisa D. McNair, and Kacey Beddoes. “Team Effectiveness Theory from Industrial and Organizational Psychology Applied to Engineering Student Project Teams: A Research Review.” *Journal of Engineering Education* 102 (4). (2023): 472–512.

Burns, Victoria F., and Susan Mintzberg. “Co-Teaching as Teacher Training: Experiential Accounts of Two Doctoral Students.” *College Teaching* 67 (2). (2019): 94–99.

Crawley, Edward F. "The CDIO Syllabus. A Statement of Goals for undergraduate Engineering Education". (2001).

Dym, Clive L., Alice M. Agogino, Ozgur Eris, Daniel D. Frey, and Larry J. Leifer. “Engineering Design Thinking, Teaching, and Learning.” *Journal of Engineering Education* 94 (1). (2015): 103–20.

Feng, Xiaoqi, and Katja Hölttä-Otto. “An Investigation of the Influence of Disciplinary Distance in Interdisciplinary Education Through Faculty’s Experience.” In *Volume 4: 18th International Conference on Design Education*. (2021).

Feng, Xiaoqi, Salu Ylirisku, Elina Kähkönen, Hannele Niemi, and Katja Hölttä-Otto. “Multidisciplinary Education through Faculty Members’ Conceptualisations of and Experiences in Engineering Education.” *European Journal of Engineering Education* 48 (4). (2023): 707–23.

Hadgraft, Roger G, and Anette Kolmos. “Emerging Learning Environments in Engineering Education.” *Australasian Journal of Engineering Education* 25 (1). (2020): 3–16.

Holt, Re, Pj Woods, Asa Ferreira, H Bardarson, S Bonanomi, Wj Boonstra, We Butler, et al.“Avoiding Pitfalls in Interdisciplinary Education.” *Climate Research* 74 (2). (2017):

Kjellberg, Malin, Michael O’Connell, Becky Bergman, Christian Stöhr, and Johanna Larsson. “Teachers’ Reflections On Their Experiences Teaching Interdisciplinary Project-Based Courses.” (2023).

Klein, Julie Thompson. *Interdisciplining Digital Humanities: Boundary Work in an Emerging Field*. (2015). University of Michigan Press.

Lattuca, Lisa R., David Knight, Tricia A. Seifert, Robert D. Reason, and Qin Liu. “Examining the Impact of Interdisciplinary Programs on Student Learning.” *Innovative Higher Education* 42 (4). (2017): 337–53.

O’Connell, Michael T. Michael T., Christian Stöhr, Patric Wallin, and Raffaella Negrett. “Social Regulation of Learning in Interdisciplinary Groupwork.” European Journal of Engineering Education (2023): 1-17

Van den Beemt, Antoine, Miles MacLeod, Jan Van der Veen, Anne Van de Ven, Sophie Baalen, Renate Klaassen, and Mieke Boon. “Interdisciplinary Engineering

Education: A Review of Vision, Teaching, and Support." *Journal of Engineering Education* 109 (3). (2020): 508–55.

Challenges and solutions of teamwork in engineering education

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ABSTRACT

The challenges, issues and concerns regarding the use and assessment of students group work have many commonalities across all engineering disciplines, as well as the methods used to address them. Hence, it is highly significant for the engineering community to discuss and share experiences. This workshop does this two-fold:

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i) Gets a diverse range of staff from a variety of engineering disciplines and institutions to reflect on, share and discuss in this workshop their practice to make the running and assessment of group work more successful;
ii) Gathers teamwork teaching experiences and common challenges across the sector when teaching teamwork and to start identifying methods and approaches for tackling these challenges.

This workshop is relevant to all those in engineering education using group work (instructors, curriculum designers, etc) regardless of their level of experience. Pre-workshop survey (optional): https://forms.office.com/e/6xzKt2GqA6

1 INTRODUCTION, MOTIVATION AND LEARNING OUTCOMES

Teamwork has become an intrinsic element of professional life regardless of the engineering field, allowing diverse and multidisciplinary or specialized teams to address more complex/bigger problems. The World Economic Forum's Future of Jobs Report consistently discusses the need for graduates to have a mix of professional skills, global competency, and technical knowledge (World Economic Forum, 2020). Active learning methods, such as project-based learning (PjBL), are the gold standard for teaching skills in a wide range of contexts (Kolb, 2015). Participating in group projects help students to develop their skills and ability to work in teams in a variety of scenarios, but also develop their technical skills and knowledge further. Consequently, now the use of teamwork activities is highly common in Engineering Higher Education (HE). However, running and assessing group work in any engineering discipline has its own challenges and has raised a range of concerns among students, staff, external examiners and professional bodies that perform external-led degree audits e.g. for accreditation purposes.

Riebe et al (2016) in their systematic review of various case studies, categorised challenges associated with delivering and assessing teamwork in HE context into two themes, i.e., teamwork pedagogy and transaction costs. Challenges associated with teamwork pedagogy include: (I) Instruction strategies, whereby educators and learners lack prior experience, view teamwork as an inefficient use of time and find moving away from tutor-centred teaching challenging (Holt et al, 1997), (II) Curriculum design – the degree to which team skills development is incidental or intentional in the curriculum, (III) Team composition, and (IV) Assessment.

Willamson's (1979) transaction cost theory assumes that engagement is a function of the benefits or costs derived from developing, coordinating, monitoring, participating in, interacting with, and evaluating teamwork pedagogy. Thus, challenges associated with truncation costs include, (I) meeting employer and accreditation body expectations, (II) tutors' readiness to develop resources, strategies and interventions for teaching teamwork, (III) learners' readiness and (IV) availability of institutional resources and focus.

The use of self - and/or peer assessment procedures including the implementation of online team tools to provide feedback on the effectiveness of team members have the potential to reduce the temporal and efficiency related costs (Delaney et al, 2013). This paper focuses on one such tool, the Individual Peer Assessment of Contribution to group work (IPAC), developed at University College London (Garcia-Souto et al, 2020). The application of this tool entails the tutor assessing and awarding a group mark to a group task completed by learners. The learners then assess the level of contributions of each of their peers, including themselves, from which an IPAC factor is generated after moderation by the tutor. This IPAC factor may then be applied formatively or summatively to generate individual marks for the group members. The IPAC assessment methodology has been seen to mitigate a number of the challenges and concerns typically observed by staff and students (Garcia-Souto, 2019, Seatwo A, 2019). UCL has developed an LTI that allows practitioners to implement this assessment methodology easily and time efficiently within their institutional virtual learning environment. The IPAC methodology and system are briefly presented, and attendees invited to try in their own institutions.

The leads of this workshop bring to the table their collective experiences of running 6 different case studies within the Integrated Engineering Programme (IEP) at University College London (UCL) - one of the most comprehensive and largest applications of active learning methodologies within undergraduate engineering curricula in the UK (Mitchell et al, 2019). The selected case studies, all of which use the IPAC methodology, provide a comprehensive representation of the journey the students take from year 1 to year 4, in different class sized (80 to 1000) and with projects of different length and weight towards the final degree classification. A series of challenges/concerns and also mitigations found by the authors (Garcia-Souto et al, 2024) were explored in the workshop.

A long-term potential outcome of this workshop is the identification of further methods that can support any academic in an engineering subject in any HE institution when planning/running group work.

2 BACKGROUND AND RATIONALE OF THE SESSION

The challenges faced by academic staff when implementing and assessing group work truly apply across engineering fields and educational institutions/universities. Yet, staff discussions of good practice and published literature typically (if not always) occur at “local” level and lack breath of disciplines and experiences.

This workshop is an excellent opportunity to discuss and reflect on experiences from a broad range of staff running teamwork activities in engineering education (covering as many case studies, engineering disciplines and institutions as possible) and to help to truly identify good practice across the sector. Analysis will then be done post-workshop to identify common challenges across the sector when teaching teamwork and to start identifying methods and approaches for tackling these challenges. An initial summary will be included in the workshop paper as part of the proceeding with the aim of a more comprehensive paper published later (register interest in the link provided in section 4). This is of relevance to the overall community of engineering educators across institutions, countries, engineering fields that currently run or plan on running group work within their modules or engineering degrees.

3 WORKSHOP STRUCTURE

The structure of the workshop is as follows:

- Introduction – the challenges of running and assessing group work (10 mins):

- Groups discussion - discuss current practice/possible process to address/mitigate challenges of group work (30 mins):
- Groups feedback moderated by workshop leads (10 mins)
- Presentation of the IPAC system/methodology used for the assessment of individual contribution to group work (3 mins)
- Summary of outcomes and closure (3 mins)

4 RESULTS FROM THE WORKSHOP

A total of 20 people from a variety of institutions attended this workshop and agreed to participate in the study (UCL Research Ethics Committee: Project ID number: 6257/003 – part1). They were asked to assess the prevalence and impact of a series of challenges as well as usefulness of various mitigations. Results are presented in tables 1 and 2 respectively. They were also encouraged to comment on additional challenges and mitigations.

Rating criteria: 0-Negligile; 1-Low; 2-Significant; 3-Very

Table 1. Assessment of prevalence and impact of various challenges when running group work.

Challenge	Prevalence			Impact		
	N	avg	SD	N	avg	SD
A. Uneven student contribution/engagement	15	2.2	0.6	14	2.4	0.8
B. Validity of assessment (Is assessment representative of contribution?	14	2.0	0.9	12	1.8	0.9
C. Diversity in the team (Potential conflict from differences in a team's experiences and background)	14	1.9	0.6	14	2.0	0.9
D. Teams with students requiring adjustments (due to disabilities or emergency circumstances)	10	1.1	0.6	11	1.1	0.9
E. Readiness of students to work in a team	14	1.6	1.0	14	1.8	1.0
F. Formation of teams	11	1.2	1.1	11	1.0	0.9
G. Team cohesion	13	2.0	0.7	13	1.9	0.6
H. Staff workload	11	2.4	0.8	12	2.4	0.7
I. Readiness of staff to teach teamwork	10	2.3	0.7	10	2.2	0.9

Table 2. Assessment of how useful were various mitigations when running group work.

Mitigations	Usefulness		
	N	avg	SD
1. Peer assessment of individual contribution (IPAC)	10	2.3	0.6
2. Training students on teamwork skills development	10	2.3	0.5

3. Check points with staff (e.g. IPAC, attendance…)	11	2.2	0.5
4. Team contract	11	0.8	0.8
5. Balance team formation (e.g. diversity, avoiding known conflicts)	10	1.9	1.1
6. Resilience in the projects (e.g. feasible even with a missing team member)	9	1.4	0.5
7. Staff resilience	10	1.8	0.8
8. Exceptional cases addressed/dealt/supported by staff	11	2.4	0.7
9. Staff training	7	2.4	0.5

Workshop participants reported experiencing to some extent all the challenges listed by the authors, although the prevalence and impact of each varied for each participant. Statistically, the challenges with larger prevalence and impact are *A-Uneven student contribution/engagement*, *H-Staff workload*; and *I-Readiness of staff to teach teamwork.* Participants also pointed out additional challenges, with the most common being “language barriers”, “lack of time management skills” or “students dropping out”.

Participants shown to have engaged with a number of the mitigations presented by the authors, but often just a subset. The mitigations that participants used and found most useful were *1-Peer assessment of individual contribution (IPAC); 2-Training students; 8-Staff addressing exceptional cases; and 9-Staff training*. In regards to the “student training”, participants felt compelled to list a series of examples of good mitigations or something that should be incorporated (e.g. self-reflection, teaching time management or conflict resolution), just stressing the importance of training. Some participants also suggested that student training should be done at programme level, with coordination between academics that run group work, which agrees with the approach used by the authors (Garcia-Souto et al, 2024). Another additional mitigation used by some participants was allowing students to choose their own groups, particularly when they know each other from earlier group work in the course.

There was some criticism about how the challenges and mitigations were assessed, since it was considered that some of them were very context dependent and/or had several dimensions, especially when talking about “diversity in the group”. Authors agree with this, and it was a limitation of the workshop time length, but authors hope to address this by collecting more in-depth views via the online form (link in section 5).

5 WORKSHOP OUTCOMES

- Gathered and evaluated teamwork teaching experiences and common challenges across the sector when teaching teamwork and to start identifying methods and approaches for tackling these challenges.
- The IPAC assessment methodology (Individual Peer Assessment of Contribution to group work) has been identified among workshop participants as a commonly used method of addressing/mitigating a number of issues/concerns related to the group work. Staff from all universities are

invited to try the IPAC system, that makes the running of this assessment methodology very easy - just send email to Pilar Garcia-Souto (p.garciasouto@ucl.ac.uk).
- Institutions and teaching teams should be providing staff training to better equip their academics on the running of group work. Training to students should also be expanded or formalized within the course. The actual specifics on staff and student training needed still needs to be defined.
- Authors need to collect a wider and in-depth range of experiences and views from academics. Can you tell us about your experience? Please complete the form here, still open for submissions (https://forms.office.com/e/6xzKt2GqA6) or get in touch.

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REFERENCES

Delaney, D., Fletcher, M., Cameron, C., and Bodle, K. "Online self and peer assessment of teamwork in accounting education." *Accounting Research Journal,* 26, (2013): 222-238. doi:10.1108/arj-04-2012-0029

Garcia-Souto, M. P. "Is It Safe to Use Peer Assessment of Individual Contribution Level When Assessing Group Work?" *EDULEARN Proceedings: EDULEARN19 Conference,* (2019). Palma, Spain: IATED. doi:10.21125/edulearn.2019.1842.

Garcia-Souto, M.P., Azma, Y., Grammenos, R., Kador, T., Striolo, C., Whyndham, M., Vogel, M., et al, "Individual peer assessment of contribution to group work (IPAC): Key points and recommendations." *Proceedings: SEFI 47th Annual Conference: Complexity is the New Normality,* Budapest, Hungary (2019). 1553-1565.

Garcia-Souto, M.P., Siefker, J, Odunsi, A., Truscott, E., Seatwo, A., "Addressing issues related to running and assessment of teamwork in engineering education: Improvements observed when using Individual Peer Assessment of Contribution (IPAC).", *Proceedings: SEFI 2024 Conference: Educating Responsible Engineers,* Lausanne, Switzerland (2024).

Graham, R., "The Global State of the Art in Engineering Education." (2018): Boston, MIT School of Engineering.

Holt, D., Michael, S., and Godfrey, J. "The case against cooperative learning." *Issues in Accounting Education*, 12, (1997): 191-193.

Kolb, D.A. Experiential Learning: Experience as the Source of Learning and Development. 2nd ed. USA: Pearson Education, Inc., 2015.

Mitchell, J. E., A. Nyamapfene, K. Roach and E. Tilley, “Faculty Wide Curriculum Reform: the (unnamed teaching framework)” *European Journal of Engineering Education*, 46:1, (2019): 46-66, DOI: 10.1080/03043797.2019.1593324

Riebe, L., Girardi, A., and Whitsed, C. “A Systematic Literature Review of Teamwork Pedagogy in Higher Education.” *Small Group Research*, 47(6), (2016): 619-664. https://doi.org/10.1177/1046496416665221

Seatwo, A. “Enhancing group work learning with the Individual Peer Assessed Contribution (IPAC)”, *Proceedings: SEFI 47th Annual Conference: Complexity is the New Normality,* Budapest, Hungary (2019). 998-1009. SEFI.

Truscott, F. R., E. Tilley, J. E. Mitchell, and A. Nyamapfene, “Staff Experiences of Leading Large-Scale Multi-Departmental Project-Based Learning for Year 1 Engineering Students.” *Annual Conference of the European Society for Engineering Education, Dublin*, 2023, p1337-1344, Belgium, SEFI, DOI: 10.21427/7Y9A-6C85

Truscott, F. R., E. Tilley, K. Roach and J. E. Mitchell, “Perspectives on putting a large scale first year interdisciplinary project module online” *PBL 2021*, (2021): DOI:10.26226/morressier.60ddad35e537565438d6c49b

Williamson, O.E., “Transaction-cost economics: The governance of contractual relations.” *The Journal of Law & Economics,* 22, (1979): 233-261. doi:10.1086/466942

World Economic Forum, (2023), “Future of Jobs 2023”, Switzerland, World Economic Forum

SUPPORTING THE FULL LIFE CYCLE OF RICH OPEN EDUCATIONAL RESOURCES WITH A LEARNING EXPERIENCE PLATFORM

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ABSTRACT

Digital solutions play a key role for enabling blended learning in higher engineering education, where the acquisition and the appropriation of core competences and transversal skills require interactive resources offering a high-level and quasi-professional learning experience. Hence, it is essential to help educators in the process of designing and implementing value-adding resources, considering both their pedagogical and their technological dimensions. Taking into account the scarcity and the low accessibility of high-quality educational resources, it is also important to promote in academic institutions the culture of co-creating and sharing such resources, which, when openly accessible, are coined as open educational resources. In this workshop, the participants will have the opportunity to jointly discuss the nature of value-adding open educational resources, explore examples of resources with various purposes and granularity levels, and exchange on their implementation in active, collaborative, and/or inquiry learning scenarios, as well as in critical, design, systems, or computational thinking activities. The hands-on activities will be carried out using an open source and open access learning experience platform, which enables to support the full life cycle of basic or rich OERs, from their design or co-design to their sharing, through their actual implementation in the classroom and their impact assessment using learning analytics.

1 INTRODUCTION

1.1 General Framework

Digital solutions play a key role for enabling blended learning in higher engineering education, where the acquisition and the appropriation of core competences and transversal skills require interactive resources offering a high-level and quasi-professional learning experience. Hence, it is essential to help educators in the process of designing and implementing value-adding resources, considering both their pedagogical and their technological dimensions. Taking into account the scarcity and the low accessibility of high-quality educational resources, it is also important to promote in academic institutions the culture of co-creating and sharing such resources (Kimmons and Irvine, 2023), which, when openly accessible and shared with Creative Commons (CC) licenses, are coined as Open Educational Resources (OERs).

1.2 Open Educational Resources

In general, people consider as basic OERs multimedia documents, such as images, pdf version of course material, simulations like the ones found on PhET[2], slide decks, like the ones found on SlideShare[3], virtual reality animations like some found on Sketchfab[4], or video sequences, like some found on YouTube[5]. Such resources should be accessible using a single URL, reusable or modifiable freely, and shared

[2] https://phet.colorado.edu
[3] https://www.slideshare.net
[4] https://sketchfab.com
[5] https://www.youtube.com

using CC licenses[6]. More advanced resources like MOOCs[7] can also be considered as OERs because they are often freely accessible, but they cannot easily be reused or repurposed by educators due to their license schemes. When, in addition, the OERs integrate stateful interactive elements, embedded pedagogical structure, links to external services, learning analytics, as well as communication and collaboration features, they are coined by the co-authors as rich OERs. In such a case, they need to rely on open educational platforms for storing personalized settings together with interaction traces and learning outputs linked to learners.

1.3 Active Learning and x-Thinking

Digital solutions in general, and rich OERs in particular, offer a lot of opportunities to implement active learning scenarios and x-thinking activities to develop core and transversal skills. The x-thinking abbreviation is representing either critical thinking, design thinking, systems thinking, or computational thinking, which are increasingly important educational dimensions of curricula in higher engineering education. When digital solutions are integrated in traditional educational settings to provide additional learning opportunities, the corresponding pedagogical scenarios are considered as blended learning. Blended learning can combine on-campus (in-person) and/or online, synchronous and/or asynchronous, individual and/or collaborative modalities and activities using virtual and/or physical, institutional and/or personal resources (Garrison and Kanuka, 2004; Hrastinski, 2019). The overall instructional ecosystem includes cloud platforms and digital infrastructures, devices, educational content, as well as educational or professional applications.

1.4 Learning Experience Platforms

Traditional Learning Management Systems (LMSs) are focusing on management rather than learning. Learning Experience Platforms (LXPs) are supporting the actual blended learning activities and the personalization of the learning experience. Learners can easily upload content with the integration of any number of applications (Cockrill, 2021). In this workshop, a LXP[8] integrating all the necessary services for supporting the full life cycle of OERs is considered, including the authoring service for the creation or the personalization of OERs, the service for their implementation for teaching and learning, the service to share them privately or publicly, and finally the leaning analytics service providing a dashboard and aggregated data to reflect on their impact and usage.

2 WORKSHOP STRUCTURE

2.1 General Objectives

The motivation of the proposed workshop was to provide the participants with the opportunity to jointly discuss the nature of rich value-adding open educational resources, explore examples of resources with various purposes and granularity levels (Rodríguez-Triana *et al*. 2015, Gillet *et al*. 2017), and exchange on their implementation in active, collaborative, and/or inquiry learning scenarios, as well as in critical, design, systems, or computational thinking activities. The hands-on

[6] https://creativecommons.org
[7] https://www.edx.org
[8] https://graasp.org

activities have been carried out using graasp.org, an open source and open access LXP, which enables to support the full life cycle of OERs, from their design or co-design to their sharing, through their actual implementation in the classroom and their impact assessment using learning analytics (Gillet *et al*. 2022).

2.2 Program

The activities planned for the workshop were the following:

- **30 min**: General introduction, including definition and presentation of rich open educational resources with examples, as well as presentation of previous studies on the OER life cycle in the framework of inquiry learning for STEM education;
- **20 min**: Focus group scaffolded with a questionnaire, aiming at eliciting value-adding rich interactive learning resources and at sharing potential learning scenarios for an effective integration;
- **10 min**: Wrap-up and discussions regarding expectations in terms of open educational resources, support platforms, and associated practices.

2.3 Outcome

It was expected that the participants strengthen their interest and their confidence for creating or co-creating and sharing open educational resources using open learning experience platforms. The workshop organizers also hoped to learn more about the creation or co-creation practices of the participants and their expectations in terms of support features from a techno-pedagogical point of view in higher engineering education. The discussion was structured by a questionnaire on different aspects of the participants' experience and relationship with OERs (see Table 1). The answers were displayed to the participants as a ground for discussion. As only 8 participants (P1 to P8) replied to the questionnaire, the results should be considered as qualitative, but they are aligned with feedback gathered from educators in other contexts.

Table 1. Questionnaire shared with the participants

ID	Questions
Q1	What learning experiences would you offer to your students?
Q2	What type of skill do you want your students to train?
Q3	What would increase your motivation to create learning experiences?
Q4	What would be detrimental to your motivation to create learning experiences?
Q5	What are your needs related to manage your learning material?
Q6	What are your needs related to manage learning journeys in blended learning settings?
Q7	What are your wishes related to a platform managing learning experiences of your students?
Q8	What increases your motivation to share your teaching and learning materials with others?

The first part of the discussion was related to OER in general, the second part was then directed toward the relevance and use of the selected graasp.org OER platform. The discussion started with the first two questions (Q1, Q2) about the potential objectives for OERs that may be of interest for the participants. Regarding the type of learning experience, they would like to offer to their students, all participants but one described variation of active and experiential learning scenarios such as **project-based and hands-on activities** related to real-life scenarios. In relation to that, they evoked their will to support students in developing transversal or higher-order thinking skills. In particular, **critical thinking** was mentioned by several participants. The discussion moved onto the topic of creating, managing, and sharing OERs (Q3 to Q8). When discussing the motivations to create and publish such resources, many participants agreed on the needs and benefits of **collaborating between peers in the authoring** of OERs. Three participants mentioned "being part of a community" (P3) as an additional motivation. When publishing OERs, the participants evoked the need to "get something in return" (P4), such as "learning from peers" (P1), "being paid" (P2), or recognition of the material from one's institution to increase one's reputation.

The importance of the OER platform and the technologies managing the lifecycle of the OERs quickly arose as a primary concern. Specifically, the user experience was considered by the participants as essential for them to engage in the process of creating OERs. The flexibility of the platform was mentioned by several participants as a key aspect to accommodate multiple pedagogical scenarios. In this context, flexibility can be defined as the diversity of features supporting a broad typology of learning experience. For example, the possibility to store multimedia files but also the opportunity to scaffold a learning journey, the chance to add supporting elements for the learners like AI chatbots for summarizing learning contents, or creating tailored individualized formative assessment elements. At the same time, the participants expressed their fear of systems that are complex for both teachers and students, not user-friendly, and undependable. They also considered that an easy and clear mechanism for sharing resources is essential. Along those considerations, it is interesting to note a concern regarding the lack of clarity around ownership, as pointed out by one participant.

Finally, a few participants mentioned the importance of monitoring students' progress. This is motivating the need for strengthening the implementation of **Learning Analytics** in higher education, while ensuring data privacy.

2.4 Concluding remarks

Despite the fact that most of the workshop participants were core engineering faculty members, it is interesting to see that their main concerns were about improving the learning experience and developing transversal skills for students. The challenge to create, and preferably co-create and share OERs is still huge, and no real solutions are provided by academic institutions and within communities.

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REFERENCES

Cockrill, A. "From Learning Management Systems to Learning Experience Platforms: Do they keep what they promise? Reflections on a rapidly changing learning environment." *Cardiff Metropolitan University*, 2021. https://doi.org/10.25401/cardiffmet.14611932.v1

Garrison, D.R., H. Kanuka. "Blended learning: Uncovering its transformative potential in higher education." *The Internet and Higher Education*, Volume 7, Issue 2, 2004, pp. 95-105. https://doi.org/10.1016/j.iheduc.2004.02.001.

Gillet, D., M.J. Rodríguez-Triana, A. Vozniuk, A. Holzer, and R. Matsuba. "Beyond ePortfolios Creating, Exploiting, and Archiving Activities, Learning Outcome, and Learning Analytics as Personal Sharable Online Spaces." *World Engineering Education Forum* (WEEF 2017), Kuala Lumpur, Malaysia, November 2017.

Gillet, D., I. Vonèche-Cardia, J.C. Farah, K.L.P., Hoang, and M.J., Rodríguez-Triana. "Integrated Model for Comprehensive Digital Education Platforms." *IEEE Global Engineering Education Conference (EDUCON)*, Tunis, Tunisia, 2022, pp. 1587-1593, doi: 10.1109/EDUCON52537.2022.9766795.

Hrastinski, S. "What Do We Mean by Blended Learning?" *TechTrends*, 63, 2019, pp. 564-569. https://doi.org/10.1007/s11528-019-00375-5.

Kimmons, R., J. Irvine. "Future Directions in OER." *In: Otto, D., Scharnberg, G., Kerres, M., Zawacki-Richter, O. (eds) Distributed Learning Ecosystems*, Springer VS, Wiesbaden, 2023. https://doi.org/10.1007/978-3-658-38703-7_10

Rodríguez-Triana, M.J., S. Govaerts, W. Halimi, A. Holzer, Ch. Salzmann, A. Vozniuk, T. de Jong, S. Sotirou, and D. Gillet. "Rich open educational resources for personal and inquiry learning: Agile creation, sharing and reuse in educational social media platforms." *International Conference on Web and Open Access to Learning (ICWOAL)*, Dubai, United Arab Emirates, 2014, pp. 1-6. https://doi.org/10.1109/ICWOAL.2014.7009219.

[9] https://www.swissuniversities.ch/en/
[10] https://belearn.swiss/en/

INGREDIENTS FOR PROFESSIONAL DEVELOPMENT OF ENGINEERING EDUCATORS

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ABSTRACT

Academic staff in engineering enter the university workforce with little experience in pedagogy and educational innovation as they are recruited mostly on the basis of the strength of their research track record (Taylor, 2006, Graham 2018). As educating is a core task, we should support our educators and offer options for continuous professional development, both at starting level as well as more advanced stages of their career. In this workshop, ingredients for such professional development will be collected, discussed and shared among participants. This includes both formal

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offerings and informal ways of improving educating competencies. Professional development can be connected to well-organised and scheduled offerings. However, similar developments can also be obtained if educators engage in educational innovation processes (Stevens et al, 2023). We'll harvest best practises and categorise them according to the four levels of the academic career framework (Graham, 2018).

Given the rapid development of technology and its impact on educational practice important questions arise such as how are educators in engineering programmes keeping up with the latest pedagogical developments? What support is provided for academic staff? And, how undertaking capacity building in education reports to their career progression if at all?

1 INTRODUCTION

Academic staff in engineering enter the university workforce with little experience in pedagogy and educational innovation as they are recruited mostly on the basis of the strength of their research domain and capabilities (Taylor, 2006). Although some universities, for instance in the UK and Australia, started years ago to recruit academic staff specifically for educational roles, aiming to drive educational innovation (Probert, 2013), the recruitment strategy for academics especially in universities with a strong focus on research activity is still mostly based on the individual's research performance (Bennett, et al., 2018). In most cases, academic staff develop their competences and skills as educators during their early academic career, partly through guided professional development programmes associated to tenure and partly through teaching practice. Once the minimal requirements for tenure have been met it is less clear how professional development in the education domain is carried out (van Dijk et al., 2020) and what opportunities for capacity building do academic staff have via recognised professional development (Graham, 2018; Edström et al, 2023).

Given the current challenging landscape in engineering education, the rapid development of technology and its impact on educational practice important questions arise such as how are educators in engineering programmes keeping up with the latest pedagogical developments? What support is provided for academic staff? And, how undertaking capacity building in education reports to their career progression if at all?

2 WORKSHOP STRUCTURE AND ACTIVITIES

In this workshop participants will consider the career development and professional development activities that can support career progression in their own context.

Part 1 (~25 min): The session will start with an introduction on the career framework for university teachers proposed by Graham (2018) and discussing the 4-levels of the framework in terms of spheres of impact and career paths (See Figure 1).

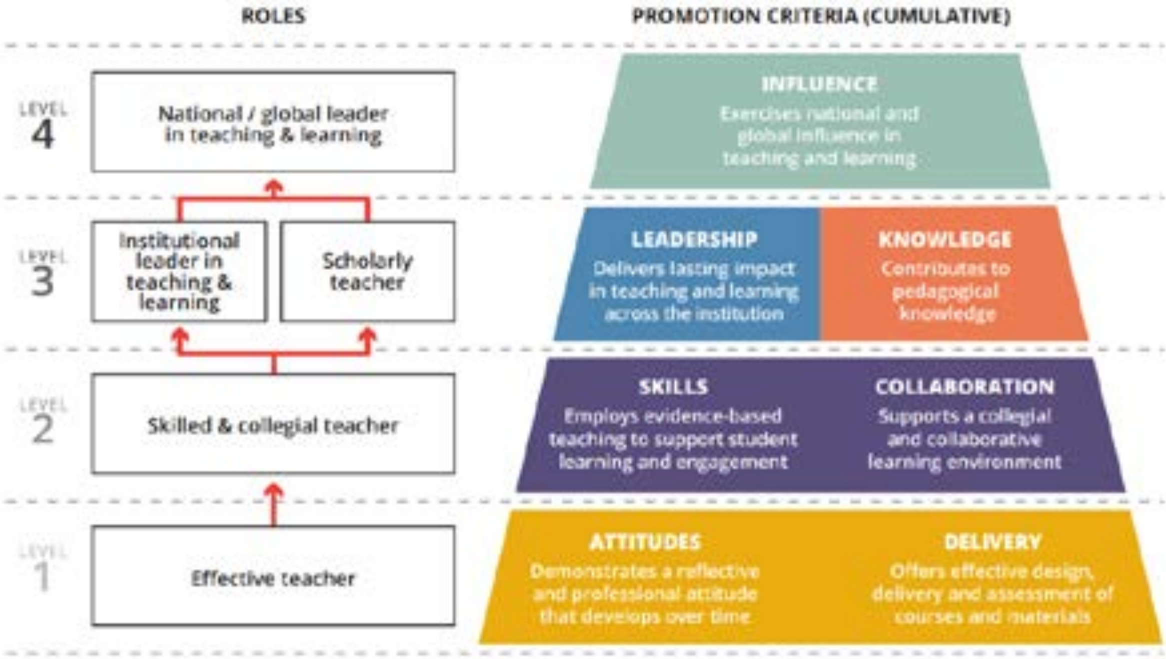

Figure 1. The Career Framework of Academic Teaching (R. Graham, 2018)

Participants will be asked to work in small groups and consider how for their own institutions each of the four levels of the framework is accompanied by continuous professional development activities.

Examples of continuous professional development activities and pathways will be presented and discussion on instances where these might or not be aligned with career progression at institutional level will be generated. Special emphasis will be made in the example of (University XXX) co-creation process to collect teachers' input through the use of Appreciative Inquiry method (Cockell, and McArthur-Blair, 2020) in dialogue sessions. The aim of the co-creation section was to develop options of pathways suitable to meet the teachers' ambitions and wishes for continuous professional development. The pathways will be shared for the purpose of inspiring other institutions and to promote sharing of experiences and learning.

Part 2 (~35 min): Participants will be asked to reflect in groups on how they balance activities related to continuous professional development and advanced teaching practice, options for scholarship of teaching and learning in which research and development are relevant and the development of educational leadership.

Finally, groups will share their examples and/or recommendations of professional development activities that support well career development and one challenge or dilemma that they see.

3 OUTCOMES AND CONCLUSIONS

Part 3: Examples and recommendations generated from the group discussions will be collected and the take-home messages from the workshop will be shared in a final flip-over to visualize the participants' input. The University XXX team will share copies of the pathways developed in order to disseminate the continuous professional development of the teachers so that this experience can serve as inspirations for other institutions.

The workshop will also provide opportunities to connect people with common interests in professional development of higher education teachers and provide a space for teachers to reflect on their own continuous professional developmental needs. Therefore, this workshop will be of interest to engineering educators and practitioners looking for professional development and networking opportunities.

4 REFERENCES

Bennett, D., Roberts, L., Ananthram, S., and Broughton, M. 2018. “What is required to develop career pathways for teaching academics?." *Higher Education* 75:271-286. https://doi.org/10.1007/s10734-017-0138-9

Cockell, J. and McArthur-Blair, J. (2020). *Appreciative Inquiry in Higher Education. A Transformative Approach* (2nd ed). Victoria: FriesenPress.

Edström, K., Poortman, C.L., Pereira, P.D. and Magnell, M. (2023). *Teaching excellence programmes – lessons learned at two universities*. SEFI2023 proceedings, p. 366-376, Dublin.

Graham, Ruth. 2018. "The career framework for university teaching: Background and overview." *London: Royal Academy of Engineering*. www.raeng.org.uk/CareerFrameworkUniversityTeaching

Probert, B. 2013. “Teaching-focused academic appointments in Australian universities: recognition, specialisation, or stratification?” 1-42. *Canberra, Australia: Office for Learning and Teaching.* http://hdl.voced.edu.au/10707/274668.

Stevens, T. M., Day, I. N. Z., den Brok, P. J., Prins, F. J., Assen, H. J. H. E., ter Beek, M., Bombaerts, G., Coppoolse, R., Cremers, P. H. M., Engbers, R., Hulsen, M., Kamp, R. J. A., Koksma, J. J., Mittendorff, K., Riezebos, J., van der Rijst, R. M., van de Wiel, M. W. J., and Vermunt, J. D., (2024). *Teacher professional development in the context of educational innovations in higher education: A typology of practises.* In: Higher Education Research and Development. Vol. 43, 2, p. 437-454.

Taylor, J. 2006. "Managing the Unmanageable: The Management of Research in Research-Intensive Universities", *Higher Education Management and Policy*, 18 (2):1-2 5. https://doi.org/10.1787/hemp-v18-art8-en.

van Dijk, E. E., van Tartwijk, J., van der Schaaf, M. F., and Kluijtmans, M. 2020. “What makes an expert university teacher? A systematic review and synthesis of frameworks for teacher expertise in higher education”. *Educational Research Review.* 31: 100365. https://doi.org/10.1016/j.edurev.2020.100365.

Workshop outcomes

Groups were asked in relation to career professional development (CPD) and using the four-level framework (Graham, 2018) to discuss the following:

- What do you do in your university? What is in place?
- What activities would help career development?

Groups reported one at least one positive experience and one challenge they encounter in their institution. The following themes were prominent, not necessarily at all universities of particpants present at the workshop.

Positive experiences	**Challenges**
• Some professional development is in place at basic level, • A structured approach to develop Scholarly of Teaching and Learning competencies and activity, • Good and clear links of CPD to promotion, • Communities around education, • Kick-start for teaching and mentoring, • First learning opportunities for PhD's on education related topics, • Support for innovation in education, • Using teacher expertise and specialisation in teaching, • Mentoring colleagues when they enter new educational roles.	• Staff buy-in into CPD, in particular going beyond the basic level, • Bringing people together – how beyond the already engaged pioneers? • Providing alternatives for demonstrating competencies, • Having programmes that can be tailored to individual developmental needs, • Rewarding Educational activities and acknowledging them at a par with research. • Expecting individuals to be good at everything is not working good, • Adequate support for new educational roles should be organised.

Professional development options were identified per group via hand-outs showing the four levels for academic teachers (Graham, 2018). In addition to the above overview the following paragraphs summarize the collected information.

What's next

Clearly one expects that continued professional development should extend beyond the basics, acknowledging learning on the job, aiming for opportunities to network via academies for learning and teaching, teaching & learning labs, communities of learning, lunch lectures, fellowship opportunities and programs related to relevant educational topics, combining theory and practice in meaningful ways. Fellowship programs can allow some teachers to spend extra time in the scholarly teaching and learning domain, this also helps to build a community beyond the educational researchers and trainers. A challenge mentioned is how to make a good connection with the faculty level and teacher context, allowing for content specific innovation and learning on top of general didactics shared across all subjects. For those interested in educational leadership, dedicated trajectories exist in some universities, allowing academics to develop this together with other academics opting for educational leadership positions.

Continued professional development linked to HR policies.

Successful completion of the basic educational professional development requirements is often linked for tenure or promotion to a next career position. Beyond the basic level, participants agreed that education tasks and related professional development should be a substantial part of career conversations such as annual interviews. All universities, even research-intensive ones, should realize that human capacity building through excellent education is their biggest contribution to society (Crawley et al, 2020). Good teaching should be rewarded beyond teaching prizes.

Shared career frameworks help identify how universities can fill in some blanks. Also, for academics it is helpful if certain qualifications or certificates are recognized across universities and can be brought to a new job at another institute. Examples for some countries already exist in the UK, Australia, Sweden, Finland, Germany and the Netherlands were given.

Look beyond your own institute

Several participants pointed at the opportunities to also learn from what happens elsewhere. Looking at what your colleagues are doing, in your own institute or elsewhere, can inspire and accelerate educational innovations. Local networks, mentoring programs, ad hoc workshops and knowledge exchanges via European consortia or Erasmus+ were mentioned as opportunities that also support professional development. Some countries have national mentorships programs. Briefly we discussed the opportunities for SEFI to play an even larger role in this domain.

Graham, R. (2018). Teaching Career Framework. https://www.advancingteaching.com

Crawley , E., Hegarty, J., Edström, K. & Garcia Sanchez, J.C. (2020). Universities as Engines of Economic Development: Making Knowledge Exchange Work. Springer. ISBN 978-3-030-47548-2.

What conflicts does sustainability bring to engineering education? An exercise to uncover systemic and institutional barriers as well as ways to overcome them

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1 BACKGROUND AND MOTIVATION

The need for sustainability in engineering education is increasingly urgent as society grapples with environmental challenges like climate change, resource depletion, pollution and social inequalities. Engineers play a pivotal role in shaping the built environment and socio-technological systems that profoundly impact our planet and societies. Therefore, educating engineers with a solid foundation (e.g., knowledge and competences) in, and for sustainability is essential for creating a more resilient and ecologically sound future. Organizational and political frameworks, like UN’s Sustainable Development Goals [1] or the European Green Deal [2], can act as drivers in creating awareness and actions to integrate sustainability comprehensively and holistically in engineering education. Even though the momentum and sense urgency does exist, it might not be enough to accelerate the integration of sustainability competence into engineering education, which has been characterized as a slow process for several reasons [3][4]. For example, traditional engineering curricula focus on technical proficiency and cultural inertia within the engineering community that prioritizes conventional approaches and resists change, or accreditation standards and regulatory frameworks that traditionally emphasized technical aspects of engineering rather than sustainability criteria [5][6]. Ultimately, overcoming the inertia in engineering education requires concerted efforts from academia, industry, accreditation bodies, and policymakers to prioritize sustainability and foster a culture of innovation and adaptation within the engineering profession. European Society of Engineering Education (hereafter SEFI), through its Special Interest Group on Sustainability (hereafter SIG on Sustainability), as a professional community plays a pivotal role in creating awareness, building capacity and engage engineering educators, institutions and other stakeholders transform engineering education research and practice towards a more sustainable education. Additionally, by equipping future engineers with the knowledge, skills, and mindset to address sustainability challenges, we can ensure that engineering continues to serve society's needs while safeguarding the planet for future generations.

That said, SEFI SIG on sustainability proposes a workshop in participants discuss challenges engineering education practitioners and researchers experience in integrating sustainability education in their context and envision plans for action.

2 OBJECTIVES AND TARGET AUDIENCE

The workshop welcomes all SEFI community attending the annual conference and its members, and comprises the following objectives:

1. Share experiences on integrating sustainability education in engineering education.
2. Discuss perceived barriers in integrating sustainability education in engineering education.
3. Prioritize barriers: most relevant and least relevant to act upon.
4. Outline of suggested actions to address most relevant barriers listed.

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3 WORKSHOP OUTLINE, SCHEDULE AND OUTCOMES

With a 1-hour duration, the workshop takes the shape of a structured brainstorming exercise and takes inspiration on techniques used on creative thinking and participatory design approaches. For example, the workshop exercises are inspired by '1-2-team' technique to foster individual brainstorming and create spaces for participation, and future workshop approach to co-create collective meaning and envision actions to address contextual barriers.

Table 1 Workshop Schedule

Time	Exercise	Expected outcomes
14.15 - 14.25	Introduction and warm-up exercise	Workshop overview. Working teams (max. 4 members).
14.25 - 14.30	Individual brainstorm on: What conflicts does sustainability bring to engineering education?	Individual experienced, or perceived barriers.
14.30 - 14. 50	Rank, sort and group to create meaning.	Barriers grouped in broad groups, or themes. Prioritize and match between working groups and barriers.
14.50 - 15.05	Non-utopian divergent discussion: What kind of actions could address the barriers the group chooses?	Collective maps/schematics with proposal actions to address chosen barriers.
15.05 - 15.15	Elevator pitch: share different maps. Follow-up through SIG action plan 2025.	Proposal to follow up with outcomes of the workshop (e.g., call for practice examples, storytelling, etc.)

4 OUTCOMES AND CONCLUSION

Overall, the workshop was successful and attracted between 40 to 50 colleagues who actively engaged in project activities. Such engagement and active participation led to a list of twelve topics that illustrated the "conflicts" sustainability brings to engineering education. The topics are listed in the box below (table 2). These twelve topics not only illustrate conflicts but also concerns, opportunities, and "musts" to better integrate and educate engineers for a sustainable future. Additionally, the topics hint at the transformative, holistic, and multistakeholder perspectives required to change towards a more sustainable education, which can be challenging for the traditional context and mindset of engineering education and practice.

Table 2. Topics outlined by participants and as result of their individual brainstorm, pair sharing and group discussions.

• Contextualization of sustainability in subject • Industrial needs for sustainability (competence) VS how industry operationalized • Affordability versus sustainability • Green solutions being promoting • Teacher agency to bring content (mindset and skills) • Frameworks and metrics: who decide and why? • Life cycle and circular economy (content) • Cultural shift and mindset • Curriculum structures/ rational and pedagogies • Complexity versus simplicity of traditional approach to problem solving • Resources (incl. human resources, time, money) for change • Capacity building

Finally, we recognize that the workshop was ambitious regarding tasks for the time given, and for this reason, the elevator pitch was not completed, and the non-topic divergent discussion was adjusted in the session.

The workshop integrates the SEFI SIG on Sustainability and therefore, its outcomes were shared and discussed as part of the SIG General Meeting, which took place during the conference on September 2, from 17.00-18.00 (CEST). The idea to "conclude" the workshop in the SIG meeting enable to participants to sort and rank feasible actions following by big group brainstorm on how they can integrate/ be disseminating through the SIG action plan for 2025. We expect this SIG workshop to create momentum for its members and strengthen their engagement as well as to raise awareness among the broad SEFI broad, allowing the SIG on Sustainability to fulfil its mission and goals.

In conclusion and considering the workshop objectives and target audience, we conclude that the workshop fulfilled them in full.

REFERENCES

United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. Available at: https://sustainabledevelopment.un.org/post2015/transformingourworld

European Commission (2020). *The European Green Deal Striving to be the first climate-neutral continent*. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Wals, A. E. J. (2012). *Shaping the Education of Tomorrow: 2012 Report on the UN Decade of Education for Sustainable Development*. Paris: UNESCO

Wals, A. E. J. (2014). Sustainability in higher education in the context of the un DESD: A review of learning and institutionalization processes. *Journal of Cleaner Production*, 62. https://doi.org/10.1016/j.jclepro.2013.06.007

Gamage, K. A. A., & Silva, E. K. de. (2022). Barriers, New Developments, and Emerging Trends in Sustainability in HE.In K. A. A. Gamage & N. Gunawardhana (Eds.), *The Wiley Handbook of Sustainability in Higher Education Learning and Teaching* (pp. 453–459). Hoboken, NJ: Wiley. https://doi.org/10.1002/9781119852858.CH22

Guerra, A. (2017). Integration of sustainability in engineering education: Why is PBL an answer? *International Journal of Sustainability in Higher Education*, 18(3). https://doi.org/10.1108/IJSHE-02-2016-0022

BEYOND "JUST PLAY WITH IT!": A RUBRIC TO HELP TEACHERS DESIGN JUPYTER NOTEBOOKS FOR INSTRUCTIONAL EFFICIENCY

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***Keywords**: Computational thinking, Jupyter Notebooks, Teaching and Learning Quality, Rubric*

ABSTRACT

Jupyter notebooks offer multiple pedagogical scenarios for teaching computational competences in sciences and engineering courses. In this workshop, we want to help teachers design educational Jupyter notebooks so that their students go beyond “just playing” with code and a graph or animation. This workshop centers on a set of criteria, in the form of a rubric, which can be used to ensure that Jupyter notebooks are designed to effectively reach the intended students’ learning goals. Participants will work with two different educational Jupyter notebook examples to gain familiarity with pedagogical scenarios for using Jupyter notebooks, learn to identify quality criteria, evaluate instructional quality using the rubric, and propose improvements. The session will foster collaboration and reflection and enable educators to design didactically powerful instructional notebooks that teach disciplinary and computational thinking in the most efficient ways. Overall, the rubric offers a systematic approach to enhance the effectiveness of instructional Jupyter notebooks, contributing to improved teaching and learning outcomes in computational thinking skills embedded in disciplinary education.

1 INTRODUCTION

Computational Thinking (Curzon et al. 2019), i.e. data driven methods and algorithmic approaches to problem-solving that are based on principles inherent to computer science, are now at the heart of engineering and permeate all STEM disciplines. Jupyter notebooks, interactive documents that embed executable code snippets, have been shown to provide valuable features to teach computational thinking in context (Lee et al. 2024). Indeed, they provide an environment in which computational thinking and disciplinary thinking can be taught together. However, designing notebooks that are instructionally efficient is a challenge, in particular because of cognitive load issues (Robins 2022; Merrienboer, Kirschner, and Kester 2003). To ensure a positive impact of their notebooks on student learning, instructors should apply a range of instructional design principles that span from textbook design (Behnke 2021) to interactive visualization design (Mayer 2014), in addition to general principles from learning sciences such as active learning (Freeman et al. 2014) and feedback (Hattie 2009). This workshop introduces participants to a self-assessment rubric that they can use to evaluate their notebooks against such principles, including guidance and examples to improve their instructional design.

2 WHAT ARE RUBRICS?

Rubrics are a set of criteria, performance levels and descriptors linked to learning objectives. They are widely used in higher education for evaluating student performance, peer assessments, and self-evaluation (Jonsson and Svingby 2007; Reddy and Andrade 2010; Brookhart and Chen 2015). Rubrics to analyze teaching practice have also been proposed (St-Pierre, Bédard, and Lefebvre 2012). Research consistently shows positive effects on academic performance, self-regulated learning, and self-efficacy, regardless of factors like age, gender, or educational level (Panadero et al. 2023). Controlled experiments demonstrate that using rubrics leads to more accurate self-evaluation (Krebs, Rothstein, and Roelle 2022) and can enhance teachers' diagnostic skills (Smit et al. 2017). We recommend that educators incorporate rubrics during the design and revision of computational notebooks to align them effectively with intended learning goals, including improved conceptual and computational thinking.

3 THE JUPYTER NOTEBOOKS FOR TEACHING AND LEARNING RUBRIC

Our Jupyter Notebooks for Teaching and Learning (JNTL) rubric has been designed in the context of the "Jupyter Notebooks for Education" project at EPFL, Switzerland. Two of the authors have performed an extensive literature review to identify the criteria used to evaluate interactive online learning material and the components of computational thinking relevant to science and engineering practice (we provide example references below). This review has also been shaped by work performed by some of the authors on experiential learning in higher education (Tormey et al. 2021). This review led to a preliminary list of criteria that could be used to evaluate five different use cases for notebooks in education namely interactive virtual demonstrations, interactive textbooks, exercise worksheets, project and lab reports and graded assignments. After the selection of a first set of criteria, two independent raters have assessed notebooks produced in four different courses at the institution. The rubric has been further refined based on the level of interrater agreement, in particular by clarifying the criteria and adding examples. Finally, the rubric has been interactively improved through interaction with teachers in notebook development projects. This work has resulted in the publication of an online guide for designing Jupyter notebooks for education (https://go.epfl.ch/notebooks), where the rubric is publicly available under a Creative Commons Attribution license (https://go.epfl.ch/notebook-rubric).

In its current version, the JNTL rubric includes 15 criteria organized into 6 categories:

1. **Structure:** learners need clear learning goals to direct their learning (Hattie and Donoghue 2016) and an explicit segmentation with a logical progression in the notebook to navigate the material.
2. **Disciplinary thinking:** explicitly modeling disciplinary thinking and embedding learning into disciplinary-relevant content is likely to maximize transfer (Hattie and Donoghue 2016).
3. **Computational thinking:** students can only learn computational thinking if it is modeled explicitly in the notebook, which can be done through “computational narratives” (Granger and Pérez 2021), i.e. code (if adequate with respect to learning goals) associated with explanation.
4. **Supporting representations:** since notebooks support multiple types of representation, a careful choice and design of representations is necessary to avoid cognitive load issues (Ainsworth 2006).
5. **Learning activities:** notebooks should actively engage students in processing information at a deep level, by including activities with scaffolding (Quintana et al. 2004), providing feedback – to students and to teachers (Hattie and Timperley 2007) – and including reflection questions (Ryan 2013).
6. **Assessment:** to ensure the fairness and validity of graded assignments, notebooks should include a description of the assessment criteria as well as performance level indicators (Hattie and Donoghue 2016).

Not all criteria apply to all notebooks of course, but the rubric is designed to provide a complete and seamless guide to evidence-informed design of high-quality instructional notebooks for all five use cases scenarios.

The JNTL rubric is now used by pedagogical advisors at two large engineering institutions in Switzerland to provide feedback to teachers developing notebooks for education. This workshop is an opportunity to share the rubric and the associated evidence-informed best practices more widely, but also to get feedback from participants on the usability and usefulness of the rubric.

4 LEARNING GOALS

This workshop will introduce participants to Jupyter Notebooks and demonstrate five pedagogical scenarios for using notebooks in the engineering curriculum. Participants will apply the rubric to assess two example notebooks. The workshop will feature examples from our two engineering institutions.

At the end of this workshop, participants should be able to:

- Describe five pedagogical scenarios where Jupyter Notebooks provide useful features for teaching computational thinking to engineers.
- Identify and explain relevant quality criteria for Jupyter notebooks in the different pedagogical scenarios.
- Evaluate the instructional quality of Jupyter notebooks in two of the pedagogical scenarios using a rubric.
- Propose improvements to increase the instructional quality of Jupyter notebooks using information in the rubric.

5 FACILITATION PLAN

Total duration: 60 min.

Introduction (10 min.):
- Presenting five pedagogical scenarios for developing engineers' Computational Thinking with Jupyter Notebooks
- Identifying the challenge of cognitive load in notebooks
- Introducing the categories and underlying principles of the rubric

Group activities with the rubric (45 min.):
- Evaluating a demonstration notebook and coming up with suggestions on how to improve the notebook, using the following set of criteria from the rubric (15 min, groups of 2-3): Code visibility (criteria #6), Learning activities (#10), Feedback to students (#12).
- Sharing findings (5 min, plenary)
- Evaluating an interactive textbook notebook and coming up with suggestions on how to improve the notebook, using the following set of criteria from the rubric (15 min, groups of 2-3): Disciplinary embedding (#3), Expert thinking modeling about computational problem solving (#5), Learning activities (#10)
- Sharing findings (5 min, plenary)
- Reflection and feedback on using the rubric: difficulties, challenges (5 min, plenary)

Conclusion (5 min.): take home messages, filling out a feedback form.
Participants will need a laptop and Wi-Fi connection to participate in the activities.
We will provide free access to the JupyterLab platform of our institution.

6 SUMMARIZATION OF THE RESULTS

Twenty-one participants attended the workshop. While none of them considered themselves experts about Jupyter Notebooks in teaching and learning, a bit more than half of the participants reported using notebooks regularly. Around one third had seen or used a notebook only once or a few times, while the remaining participants had no prior experience with notebooks.

The demonstration notebook that participants analyzed in the first activity included a simulation of the diffusion process based on a random walk algorithm together with a set of exploratory questions. Applying the rubric, a majority of participants suggested improving the notebook by providing solutions to the questions, so that the students get feedback. We took the opportunity to discuss the various possibilities to provide feedback in Jupyter Notebooks, e.g. using interactive quiz questions.

The interactive textbook example was an introduction to Machine Learning and Data Processing for Food Sciences. The notebook included explanatory text with illustrations as well as code demonstrating the different steps for preparing data for a machine learning task. Participants reported that this example was a little more difficult to work with, as the notebook was longer and more complex. Nevertheless, the participants used the time well to work through it with a different set of criteria from the rubric. More than 70% suggested including questions with automated feedback in the notebook in order to improve student learning. We took the opportunity to discuss how to design automated tests for students to self-evaluate their code.

All the respondents to our survey (80% of the participants) found the content of the workshop interesting and felt there were adequate opportunities to ask questions. Most of the participants found valuable the experience of applying the rubric to example notebooks. The level of difficulty to apply the rubric to Jupyter Notebooks was perceived to be easy to medium. About 80% of the participants reported that they were likely to use what they learned in the workshop in their own teaching.

REFERENCES

Ainsworth, Shaaron. 2006. “DeFT: A Conceptual Framework for Considering Learning with Multiple Representations.” Learning and Instruction 16 (3): 183–98. https://doi.org/10.1016/j.learninstruc.2006.03.001.

Behnke, Yvonne. 2021. “Well Designed Digital Textbooks–Users’ Requirements.” In Textbooks and Educational Media: Perspectives from Subject Education, edited by Péter Bagoly-Simó and Zuzana Sikorová, 180–92. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-80346-9_14.

Brookhart, Susan M., and Fei Chen. 2015. “The Quality and Effectiveness of Descriptive Rubrics.” Educational Review 67 (3). https://doi.org/10.1080/00131911.2014.929565.

Curzon, Paul, Tim Bell, Jane Waite, and Mark Dorling. 2019. “Computational Thinking.” In The Cambridge Handbook of Computing Education Research, edited by Anthony V. Robins and Sally A. Fincher, 513–46. Cambridge Handbooks in Psychology. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108654555.018.

Freeman, Scott, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. 2014. “Active Learning Increases Student Performance in Science, Engineering, and Mathematics.” Proceedings of the National Academy of Sciences 111 (23): 8410–15. https://doi.org/10.1073/pnas.1319030111.

Granger, Brian E., and Fernando Pérez. 2021. “Jupyter: Thinking and Storytelling With Code and Data.” Computing in Science & Engineering 23 (2): 7–14. https://doi.org/10.1109/MCSE.2021.3059263.

Hattie, John. 2009. Visible Learning: A Synthesis of over 800 Meta-Analyses Relating to Achievement. London ; New York: Routledge.

Hattie, John, and Gregory M. Donoghue. 2016. “Learning Strategies: A Synthesis and Conceptual Model.” Npj Science of Learning 1 (1): 1–13. https://doi.org/10.1038/npjscilearn.2016.13.

Hattie, John, and Helen Timperley. 2007. “The Power of Feedback.” Review of Educational Research 77 (1): 81–112. https://doi.org/10.3102/003465430298487.

Jonsson, Anders, and Gunilla Svingby. 2007. “The Use of Scoring Rubrics: Reliability, Validity and Educational Consequences.” https://doi.org/10.1016/j.edurev.2007.05.002.

Krebs, Rebecca, Björn Rothstein, and Julian Roelle. 2022. “Rubrics Enhance Accuracy and Reduce Cognitive Load in Self-Assessment.” Metacognition and Learning 17 (2). https://doi.org/10.1007/s11409-022-09302-1.

Lee, Hsin-Yu, Ting-Ting Wu, Chia-Ju Lin, Wei-Sheng Wang, and Yueh-Min Huang. 2024. “Integrating Computational Thinking Into Scaffolding Learning: An Innovative Approach to Enhance Science, Technology, Engineering, and Mathematics Hands-On Learning.” Journal of Educational Computing Research 62 (2): 431–67. https://doi.org/10.1177/07356331231211916.

Mayer, Richard E., ed. 2014. The Cambridge Handbook of Multimedia Learning. 2nd ed. Cambridge Handbooks in Psychology. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.

Merrienboer, Jeroen J. G. van, Paul A. Kirschner, and Liesbeth Kester. 2003. “Taking the Load Off a Learner’s Mind: Instructional Design for Complex Learning.” Educational Psychologist 38 (1): 5–13. https://doi.org/10.1207/S15326985EP3801_2.

Panadero, Ernesto, Anders Jonsson, Leire Pinedo, and Belén Fernández-Castilla. 2023. “Effects of Rubrics on Academic Performance, Self-Regulated Learning, and Self-Efficacy: A Meta-Analytic Review.” Educational Psychology Review 35 (4): 113. https://doi.org/10.1007/s10648-023-09823-4.

Quintana, Chris, Brian J. Reiser, Elizabeth A. Davis, Joseph Krajcik, Eric Fretz, Ravit Golan Duncan, Eleni Kyza, Daniel Edelson, and Elliot Soloway. 2004. “A Scaffolding Design Framework for Software to Support Science Inquiry.” Journal of the Learning Sciences 13 (3): 337–86. https://doi.org/10.1207/s15327809jls1303_4.

Reddy, Y. Malini, and Heidi Andrade. 2010. “A Review of Rubric Use in Higher Education.” Assessment & Evaluation in Higher Education 35 (4): 435–48. https://doi.org/10.1080/02602930902862859.

Robins, Anthony V. 2022. “Dual Process Theories: Computing Cognition in Context.” ACM Transactions on Computing Education 22 (4): 41:1-41:31. https://doi.org/10.1145/3487055.

Ryan, Mary. 2013. “The Pedagogical Balancing Act: Teaching Reflection in Higher Education.” Teaching in Higher Education 18 (2): 144–55. https://doi.org/10.1080/13562517.2012.694104.

Smit, Robbert, Patricia Bachmann, Verena Blum, Thomas Birri, and Kurt Hess. 2017. “Effects of a Rubric for Mathematical Reasoning on Teaching and Learning in Primary School.” Instructional Science 45 (5). https://doi.org/10.1007/s11251-017-9416-2.

St-Pierre, Lise, Denis Bédard, and Nathalie Lefebvre. 2012. “Enseigner Dans Un Programme Universitaire Innovant : De Nouveaux Rôles à Apprivoiser, Des Actes Pédagogiques à Diversifier.” The Canadian Journal for the Scholarship of Teaching and Learning 3 (1). https://doi.org/10.5206/cjsotl-rcacea.2012.1.6.

Tormey, Roland, Siara Isaac, Cécile Hardebolle, and Ingrid Le Duc. 2021. Facilitating Experiential Learning in Higher Education: Teaching and Supervising in Labs, Fieldwork, Studios, and Projects. London: Routledge. https://doi.org/10.4324/9781003107606.

FROM CODE OF CONDUCT TO BEHAVIOR IN CONTEXT: ACTIVELY ENGAGING WITH A/SEFI CODE OF CONDUCT TO FOSTER RESPONSIBLE AND INCLUSIVE BEHAVIOR.

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Conference Key Areas*: 8. Diversity, equity, and inclusion in our universities and in our teaching, 11. Engineering skills, professional skills, and transversal skills*
Keywords*:* Responsibility, Diversity and Inclusion*, Code of Conduct, Reflection, Co-creation*

ABSTRACT

How to make a Code of Conduct (CoC) supportive for responsible and inclusive behavior? Historically CoC's were mostly legalistic in nature (Rezaee, Elmore, and Szendi 2001), describing a 'low road approach': naming what is NOT allowed. Today, the discourse in CoC's is more focused prescribing how we should behave, which can be described as a 'high road approach' (e.g. (Walsh et al. 2023). A CoC that is merely signed for notice, or even left forgotten in a drawer, will not make people behave differently. Its potential significance remains unreached when individuals just know about it, without understanding or engaging with it. Buff and Yonkers demonstrate that students can enhance their comprehension of CoCs

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(Code of Conduct) by actively participating in their development and implementation (Buff and Yonkers 2005).

In our university we designed a workshop that creates the conditions where the sensitive topics of a CoC and behavioral changes can be addressed. This CoC and workshop collectively become a catalyst for cultivating responsible and inclusive behavior. In short, participants first deconstruct their CoC and then collaboratively (re)create it. In this process, participants identify their own perspective on the CoC, empathise with each other's perspective and together negotiate a new or improved set of values. The emphasis is not on the iteration of the CoC, but on the exchange of perspectives and interpretations of the existing CoC. This impactful personal learning experience can be applied beyond the workshop.

The workshop is relevant for all SEFI participants.

1 INTRODUCTION

1.1 Context

In engineering education, and society at large, there's growing recognition of the need for socially safe environments and that this is shaped by how people behave towards each other. Therefore companies, and (educational) institutions refer to describing both unwanted and endorsed behavior in a Code of Conduct (CoC).

While CoCs can contribute to realising responsible and inclusive behavior, they are not a comprehensive solution by themselves. In our university we often see that CoCs remain overlooked or underutilized, residing in drawers or merely serving as legal documents for students to sign and never look back on. Hence, CoCs alone will not foster a more inclusive environment. A CoC holds little significance if individuals adhere to it without fully understanding it or engaging themselves.

1.2 Cultivating responsible and inclusive behavior by using a CoC as catalyst in a workshop.

To cultivate responsible and inclusive behavior in practice, a CoC requires endorsement of the CoC from individuals, teams, and the wider community. This does not happen automatically but requires effort. A workshop can serve as an initial catalyst for generating endorsement. Therefore, we created a workshop for students in our university, in which they identify their own perspective on a CoC, empathise with each other's perspective and together negotiate a new or improved set of values to adhere to. In our workshop participants deconstruct the CoC to understand its meaning and then improve it based on their deeper understanding of it. This workshop offers a safe space to address sensitive issues such as desirable and undesirable behavior. Anyone in the SEFI conference is welcome to join. The workshop structure is detailed below.

1.3 Relevance of this workshop

The beforementioned workshop is adapted to the audience of SEFI. The primary purpose of the workshop is to demonstrate a practical and accessible format for activating the content of a CoC and with that shaping responsible and inclusive behavior in engineering education.

1.4 Outcome / Objectives

- Participants will experience that co-creating a CoC is a valuable step in the manifestation of responsible and inclusive behavior in a community / group of peers / groups of students that the CoC is addressing.
- Participants will become aware of their individual perspective and the perspective of others on a code of conduct, and that this leads to different interpretation, explanation, and emphasis of the content of a CoC.
- Participants will become aware of the conduct that is expected at SEFI.
- Participants will feel empowered to improve a CoC and/or change the way people engage with it.
- The materials will introduce participants to the concept of using a CoC as a tool.
- We will also gather anonymized feedback on the SEFI code of conduct.

2 THEORETICAL BACKGROUND

Research from (Rezaee, Elmore, and Szendi 2001) shows that CoC’s were mostly related to conflict of interests, compliance with university's policies, tenure and promotion policies, and financial fraud and fraudulent conduct in research and scholarly activities. Most codes of conducts were legalistic in nature (2001) and described as having a 'low road' approach; describing what is NOT allowed and were not with a 'high road' approach; describing how we should behave. The discourse around CoC’s today is more about ethical behavior (e.g. (Walsh et al. 2023), diversity & inclusivity, and artificial Intelligence (Sinha et al. 2023).

Yet, even in medicine, where one might expect a fair degree of ethical professional behavior, a recent scoping review on knowledge awareness and use of professional CoC's, shows that most medical professionals found themselves unaware of the content of the CoC and did not use them regularly in practice. (Collings-Hughes, Townsend, and Williams 2022).

Already decades ago, Loeb (Loeb 1971) showed that in assuring effectiveness of a CoC, consensus of participants in the CoC is a major consideration. Buff and Yonkers showed that by involving students in developing CoC’s, they can improve their understanding of how and why codes of conduct are developed, designed, and implemented in the workplace (Buff and Yonkers 2005). Yet at our university CoC’s are often overlooked or underutilised, left forgotten in drawers or merely signed without further consideration. Research on students' reflections on professional engineering codes of conduct suggested that a scaffolded discussion, where there was a space for different voices to be heard about the code, lead to a more cohesive interaction with the code. It is suggested that if students contributed as maker-of-meaning instead of recipient of knowledge, it gave a power and agency. (Gwynne-Evans 2021)

This leave us to conclude that the conversation on the CoC is critical for a CoC to have impact. That is why we created a carefully designed workshop that involves different voices and makes individuals as makers-of-meaning and in that way incorporates their diversity in knowledge, experience, mental models, interpretations, norms, culture, and values.

3 WORKSHOP SETUP (METHOD)

3.1 Theoretical underpinning

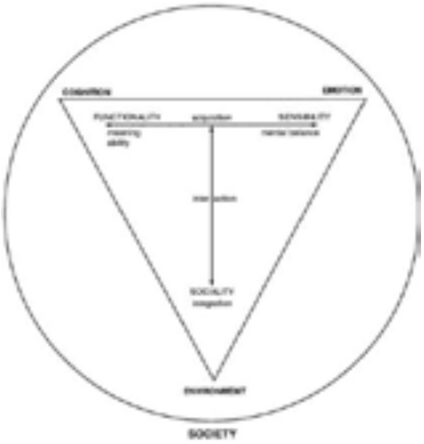


Fig 1: The processes and dimensions of learning according to Illeris

The main principle behind the setup of the workshop is the learning theory by Illeris (Illeris 2003) (depicted in Fig. 1) that describes that learning is initiated by external impulses and always takes place with the integration of two processes (1&2) and three dimensions (A-C):

1. An **external interaction process** between learner and their social, cultural, or material environment (vertical line).
2. An **internal psychological process** that is an interplay between cognition and the emotional function of an individual (horizontal line).

A. The **Cognitive learning dimension** covers for example learning content, existing knowledge, and skills and where the learner builds up their understanding and ability.
B. The **Emotional dimension** entails mental energy, feelings, and motivation.
C. The S**ocial dimension** is the dimension of external interaction such as collaboration and co-operation.

Our workshop is a context specifically designed reflective impulse (Hermsen et al. 2023; Illeris 2003) that triggers both processes and addresses all three dimensions. In short, the setup is as follows:

First, participants deconstruct the SEFI CoC in segments, next they respond from their personal perspective and experience to these segments in relative anonymity. Afterwards they discuss the similarities and differences in these responses, and finally they collaboratively iterate on the CoC. In this way both the **external interaction process** and the i**nternal psychological process** are activated.

To support the **cognitive dimension**, we provide clear instructions and worksheets, that scaffold and guide participants to explore their personal beliefs, opinions, and gaps in understanding regarding the CoC. In the **emotional dimension** we design visually appealing material and scaffold workshops steps to support participants' learning. We create an environment where knowledge gaps can be anonymously shared, encouraging honesty and genuine responses. On the **social dimension** we create a collaboration spirit by taking the time to connect and we deliberately create space for all voices and facilitate collaborative creation of meaning.

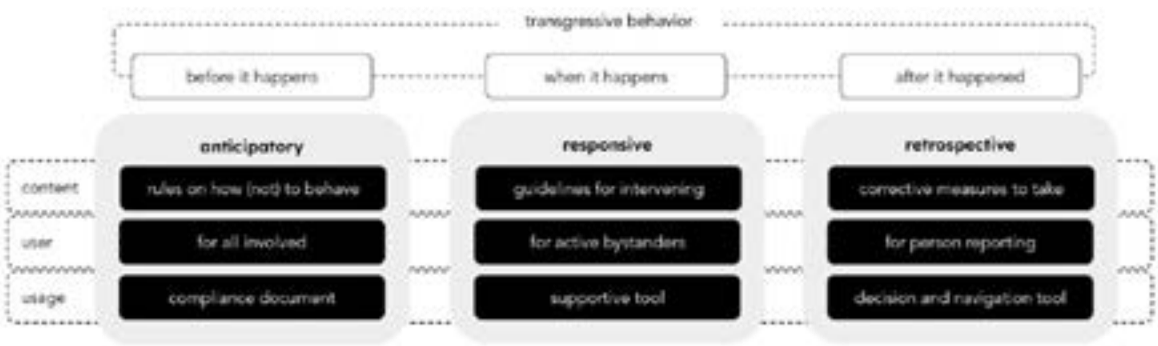
3.2 Detailed setup of workshop

Introduction to (and familiarity with) SEFI 2024 Code of Conduct (5 min)

We will introduce the general context of Codes of Conduct in engineering and education, along with the SEFI 2024 CoC. Through a brief plenary inventory, we will question participants' awareness and opinions on the SEFI 2024 CoC, aiming to highlight the diversity of perspectives.

Framing the CoC as a tool (10 min)

We will introduce that in the workshop participants will experience that a CoC can (only) be a vessel for responsible collaboration, if it is used to discuss human interaction. By using our framework on anticipatory, responsive, and retrospective use of a CoC, we contextualize the SEFI CoC and offer a (systematic) user perspective on CoC's in general.



Activating Rules for Engagement (30 min)

Our workshop setup initially assumed that understanding the SEFI Code of Conduct (CoC) would require effort, and that we would need to take time for that, before we could go into activating its content and fostering ownership. However, the 2024 SEFI CoC proved to be straightforward. Despite this, aligning actual behavior with the CoC still relies on activating and applying its principles in real-life contexts. Consequently, at the conference we dedicated more time to experiencing building consensus around rules for engagement in small groups.

First, we presented participants a realistic and ambiguous situation, where creating consensus on rules for engagement is important to understand how to move forward. We only imply a supportive use of the SEFI CoC, by having it available at the table.

Next, the participants form groups of 3 to 4 and are provided with templates and instructions, that boil down to this:

1. Individually, participants note down their observations / thoughts / feelings on this situation.
2. Individually, participants imagine themselves as a participant in this situation and answer the question: what would you do?
3. As a group, they compare and discuss perspectives on the situation and what each of them would do. We provide them with prompts to stimulate including

thinking about overrepresented / underrepresented people / power balance / distribution of privilege etc.

4. As a group, they agree on how they would deal with the situation, both from the responsive perspective as well as the retrospective perspective (see framework).
5. As a group, they take on the anticipatory perspective, by extrapolating what behavioural guidelines they would agree on if they were doing a project together. In this way, the exercise closes with the creation of a mini CoC that is actionable and suitable for responsive use in this small project group.

Conclusion: (10 min)

First, we will get a sample of the experience and insights of participants, with particular interest in:

- If and how this CoC workshop created a shared understanding of responsible and inclusive behavior.
- If and how the conversation on the CoC helps to embody responsible and inclusive behavior.
- The SEFI CoC is a comprehensible CoC that only needs a conversation on how to make it actionable.
- Frequently, students experience a comprehension gap, where they do not fully understand the CoC. In that case, deconstructing and iterating on the CoC is useful to gain shared understanding of responsible and inclusive behavior.

Furthermore, we share our take home messages:

  - Personal values and knowledge and perspective affect how you engage with a CoC and each other.
  - The conversation on the responsive level of a CoC help students to be more responsible and inclusive (for example in collaboration).
  - A CoC is not a comprehensive solution. It is a tool that needs additional work.

Closure

We invite the participants to leave constructive feedback on a plot of the SEFI's CoC.

4 RESULTS

Participants experienced that merely having a code of conduct is not enough to help students behave inclusively.

Several participants noted that the conversation in this workshop provided them with a much clearer understanding of how to interact with each other than they would have gained from merely reading a Code of Conduct.

Innovative ideas on how to shape that interaction were shared, as for example the use of "different hats" in discussion or providing props with which people can share their feelings and reactions non verbally.

Participants appreciated our approach of guiding the conversation through structured exercises and the use of a worksheet.

5 DISCUSSION AND IMPLICATIONS

Worth noting is that a group pointed out that our example situation presented a stereotype and they felt nudged into a certain train of thoughts. In hindsight this situation was more neutral than they experienced it. This illustrates that in case of dealing with situations of transgressive behavior, everyone is influenced by a biased perspective, and it is in conversation where we can bridge theses biases and perspectives.

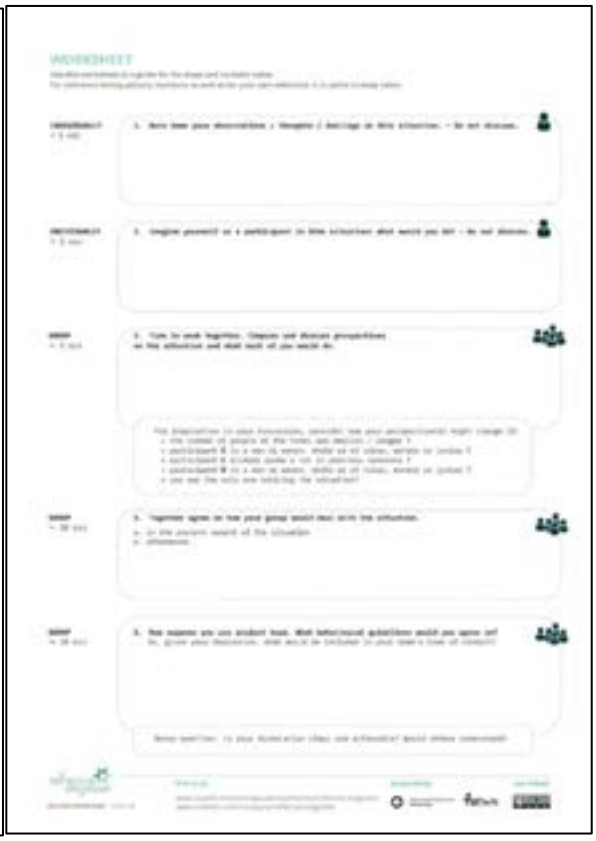
As Donna Riley emphasized in her keynote on day 4: we need to keep the consensus moving. It is now up to the SEFI community to engage in continuous conversation about the meaning and implications of the SEFI CoC, and how it can be applied in practice, both in and beyond the conference setting.

Educators interested in the CoC workshop design for students or this SEFI workshop are encouraged to contact us.

6 ACKNOWLEDGEMENTS

We would like to thank SEFI group that developed the CoC for excellent work, and in particular Iñes Direito for providing us with the draft version of the CoC which enabled us to prepare.

7 MATERIALS USED



REFERENCES

Buff, Cheryl L, and Virginia Yonkers. 2005. "Using student generated codes of conduct in the classroom to reinforce business ethics education." *Journal of Business Ethics* 61: 101-110.

Collings-Hughes, Derek, Ruth Townsend, and Brett Williams. 2022. "Professional codes of conduct: A scoping review." *Nursing ethics* 29 (1): 19-34.

Gwynne-Evans, Alison. 2021. "Student reflection on engineering responsibility exemplified in a professional code of conduct." REES AAEE 2021 conference: Engineering Education Research Capability Development: Engineering Education Research Capability Development.

Hermsen, Pleun, Sjoerd van Dommelen, Paula Hueso Espinosa, and Maartje van den Bogaard. 2023. "The Power Of Perspective Dialogue: Unlocking Transformative Reflection In Engineering Education (Practice)."

Illeris, Knud. 2003. "Towards a contemporary and comprehensive theory of learning." *International journal of lifelong education* 22 (4): 396-406.

Loeb, Stephen E. 1971. "A survey of ethical behavior in the accounting profession." *Journal of Accounting Research*: 287-306.

Rezaee, Zabihollah, Robert C. Elmore, and Joseph Z. Szendi. 2001. "Ethical Behavior in Higher Educational Institutions: The Role of the Code of Conduct." *Journal of Business Ethics* 30 (2): 171-183. https://doi.org/10.1023/A:1006423220775.

Sinha, Anurag, NK Singh, Ayushman Srivastava, Sagorika Sen, and Samarth Sinha. 2023. "Cloud computing security, risk, and challenges: a detailed analysis of preventive measures and applications." *Machine intelligence, big data analytics, and IoT in image processing: practical applications*: 225-267.

Walsh, Jennifer, Reed Bowman, Jeffrey D Brawn, Kristen M Covino, Katie M Dugger, Robert C Fleischer, Jennifer L Houtz, Sean M Mahoney, Melinda Pruett-Jones, and Corey E Tarwater. 2023. "Professional ethics survey identifies strengths and areas for improvement in the American Ornithological Society." *Ornithology* 140 (1): ukac053.

WORKSHOP
STUDENTS TAKING RESPONSIBILITY FOR THEIR LEARNING

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***Conference Key Areas**: Engineering skills, professional skills, and transversal skills*
***Keywords**: student responsibility, learning agency, self-regulated learning, transversal skills, engineering education*

1 INTRODUCTION

Current global challenges are putting pressure on educational systems. Issues such as climate change, global health issues, social injustice, and rapid AI developments are reshaping the landscape of engineering education. Universities are challenged to think afresh about how they can participate in the project of rethinking the responsiveness and relevance of their curriculum and mode of pedagogy regarding those environmental, social, and political realities (Mostafavi 2020).

The central question within this challenge for universities revolves around preparing students with future-proof competencies to take agency and responsibility, that transcend traditional boundaries and equip them for the future (learning for life). What implications does this hold for engineering education, students, and the learning environment they inhabit? Are the university teachers skilled and equipped at guiding students in this direction? Do these learning environments have the flexibility and agility to foster students' autonomy?

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Educational theories have evolved, emphasizing interactive, collaborative, and transformative learning experiences, where learners actively engage in knowledge construction. VUCA (Volatile, Uncertain, Complex, Ambiguous; Kamp 2016) and BANI (Brittle, Anxious, Non-Linear, Incomprehensible; Cascio 2020) worldviews and pedagogical frameworks such as the CDIO standards (http://cdio.org) and the Engineering for One Planet framework (https://engineeringforoneplanet.org/) highlight the need for skills beyond the technical domain, stressing resilience, flexibility, and intra- and interpersonal competencies. Engineering education often involves complex concepts and problem-solving skills, and when students are actively engaged in their learning process, they are more likely to understand and retain information effectively (Biwer et al. 2020). However, many of the engineering degree programs still lack the flexibility to facilitate student agency, focusing on specific learning objectives that relate mostly to technical skills or competencies, while neglecting the development of personal and interpersonal skills. In addition, failure as an opportunity to learn is often not acknowledged and the pressure of the assessment system often inhibits students' willingness to take responsibility for their learning.

From a students' perspective, not all students are prepared to take on such responsibility and some may have different expectations from the curriculum. Additionally, the freedom to make choices in learning can lead to moral dilemmas when conflicting obligations arise (Van den Hoven et al. 2012). From the teachers' perspective, many teachers struggle to relinquish control, steer too much and by that hinder student autonomy. Lastly, it remains largely unclear what kind of pedagogical approaches and interventions really 'work' and how they can be adapted to diverse educational contexts.

Addressing these challenges and reconceptualize curricula to foster responsibility is crucial. As part of the broader research programme to which this workshop contributes, we aim to improve our understanding of the theme at hand, and develop evidence-supported strategies, interventions and concrete tools for students, teachers, and the educational organization. The ultimate goal is to empower engineering students to take control of their learning trajectory and professional development within a supportive learning environment that values personal and interpersonal growth.

2 LEARNING OBJECTIVES

The workshop aims to familiarize participants – using input from the workshop organizers as well as from each other – with concrete ideas on how to further enhance their current approaches in engineering education and to stimulate students to take responsibility for their own learning process. For this, we will make use of an action plan template. The template untangles both the pedagogical principles of their current teaching practices at course design level or lesson delivery level or the programme and organizational principles they abide by and the intended interventions for improvement. Second, participants will learn to position those practices and ideas for intervention. This exercise is based on our framework that structures pedagogies and will improve their understanding of the broadness and complexity of the students-taking-responsibility (STR) theme. Third, this workshop introduces them to a network of people interested in the responsibility theme.

As workshop organizers, we aim to learn ourselves as well. We will learn how the participants are currently tackling the responsibility theme, how open they are to making changes in their teaching practices, and how they perceive the challenges in achieving this goal. Additionally, we aim to build an international network around this theme, as a sounding board for the TU Delft Innovation in Delft Engineering Education (IDEE) research and innovation program.

3 WORKSHOP STRUCTURE

The workshop will be structured across 3 stages (Figure 1): an introductory stage (Steps 1), an analysis stage (Steps 2-5), and a reflective stage (step 6). Involvement across the three stages varies from individual (stage A), to working group (stage B), to the entire group (stage C). One template will be shared with each participant at the beginning of the workshop to collect their personal information. Another template will then be distributed amongst the groups to guide the workshop process by [a] supporting participants to make explicit and document their thinking, and [b] capturing the information exchanged during the workshop so that organizers can further elaborate and reflect on the input received by the participants. The individual and group templates will be collected upon the workshop's completion. Participants who wish to receive more information about the workshop findings will be given the opportunity to fill in their email address in which case a summary of the workshop findings can be sent to them later.

Fig. 1. Workshop structure across stages and steps

STAGE A – SETTING THE STAGE (5’)

Step 1 | Participants will be asked to introduce themselves on the **first (individual) template** using one to three keywords. They will also be asked to specify their professional capacity in the institution they represent e.g. learning developers, educators, researchers, program coordinators, etc., and asked for their consent. In addition, they will be asked to provide us with a tentative definition of what the theme ‘Students Taking Responsibility for their Learning’ stands for and to also identify how relevant it is for them (on a scale from 0-10).

Afterwards, participants will be split into groups of 4 individuals and be given the second (group) template.

STAGE B – REPORTING FROM EXPERIENCE (OR *IMAGINING*) (40')

Step 2 | Participants have a short round of introduction within their group. They are asked to come up with a **case from their personal experiences** where they were challenged to assign students with more responsibility for their learning and pitch it to their group. If there is no real example they can refer to, participants will be invited to sketch a potential case/idea. They can focus on STR on any of the following levels: [a] **organization/program** level; e.g., customizing study program per student, [b] **course** level, e.g., developing multiple online and on campus learning environments, and/or [c] **lesson** level, e.g., experimenting with diverse modes of feedback [12', max 3' each]

Step 3 | For this step, participants will pick one of the examples presented within their group and describe this case in more depth on the **second template** collectively [3'].

Step 4 | They will then be asked to dissect their idea across several points related to planning and implementation as presented on the second template [10']:

- What was/is your motivation in increasing students' responsibility over their learning process? What inspired you to try this idea? (a book, an article, a policy?)
- How were the students' roles changed? (or *how would you like them to be changed?*)
- Were there any additional measures taken by you or your institution to support the changes? (or *would there have to be additional measures taken by you or your institution to support the changes?)*
- Can you identify any (potential) challenges?

Step 5 | After completing the intervention of step 4, participants will collectively reflect on the (projected) results of their chosen example [15'].

- Was their intervention successful? (or alternatively, *what would make the intervention successful?*)
- What did/didn't work? (or *what could hinder implementation?*)
- Was there a way to measure before/after? If yes, how? If not, why and what could it be?
- How did the students react to said changes? (this applies only to real case examples) or *how can student satisfaction from applying STR approaches be measured?*

STAGE C – PLENARY SESSION: WEAVING THE LESSONS LEARNED (15')

Step 6 | During this last stage of the workshop, one person per group will share one main finding of the group (2'-3'' per group, for a maximum of 3 groups, max. 10' in total) with the others. Then, workshop organizers will wrap up (5') the workshop and share information about the IDEE program so that participants who are interested in this project can reach out in the future.

4 EXPECTED RESULTS – COMMUNICATION OF RESULTS

Workshop organizers will collect the templates from the participants and synthesize their input. Based on the workshop structure and the information on the template, several outputs can be harvested:

- Output 1: tentative definitions of STR by participants (stage A, step 1)
- Output 2: an approximation of how relevant this theme is to the workshop participants (Likert scale from 1-7) (stage A, step 1)
- Output 3: examples of different approaches to STR across different levels (stage B)
- Output 4: challenges to implementing STR in education across levels (stage B)
- Output 5: examples of additional measures/features that can support STR practices (stage B)
- Output 6: recommendations to implementing STR (stages B and C)

This workshop will be mostly based on participants' real case experiences or their imaginaries for STR so, it is expected that nuanced interpretations of what STR means to participants can be harvested and further elaborated on the day of the workshop but also during the assessment of the workshop results. The workshop output can be a first step to build a Pedagogical Pattern Language (PPL): a structured framework for capturing, organizing, and sharing effective teaching and learning practices in Engineering Education. The real time cases that will be discussed during the workshop can further be used to populate IDEE's own PPL across all three levels respectively (organization-course-lesson).

5 RESULTS OF WORKSHOP

Seventeen conference attendees participated in the workshop. To define STR, participants distinguished 4 aspects of STR: students [1] willing to search, explore and experiment with learning; [2] taking ownership for their learning; [3] being able to identify their needs, strengths, weaknesses and [4] taking action (e.g. setting goals; seeking help; suggesting learning activities). Organizations and teachers can help them by creating opportunities and provide students with sufficient confidence, skills and means to find a learning path that suits them best.

All participants endorsed the importance of STR (7.6 out of 10); lecturers and course developers (8.1) more than participants that indicated themselves as researchers (5.6).

Most participants are interested in STR on different levels (lesson, course, program, and organization). Nonetheless, they described STR experiences mainly at lesson or course level. These included their experiences of [a] peer-learning, [b] critical reading and reflection as part of their lessons, [c] to implement self-guided parts in their courses, and [d] to add reflection meetings as part of the course. Only one of the praticipants described an example of STR on curriculum level and related STR as a direct effect of a curriculum that is open in content and flexible in its time limitations. Participants also raised interesting questions like: to what extent is it the students' responsibility to fight for more autonomy and self-regulated learning? And: under what conditions can students take responsibility?

In the second stage of the workshop, as an example, one of the smaller groups advocated for the increase of STR interventions through (a) making lectures more lively, (b) letting students pick their own case and do framing themselves, (c) letting students pick their own team to work with and (d) allowing for a more question-based or consultation-base teching approach. They also stressed the importance of monitoring the success of these interventions through constant feedback, the assessment of the quality of the projects, and students' reflections on the matter. They also acknowledge that teachers might react that it is more work than traditional education and that students already have a lot on their plate.

6 REFLECTION

The workshop results confirm that no one widely accepted definition of STR exists and that educators assign different attributes to STR. Nonetheless, they are intrigued by the concept and most have already experimented with it using various pedagogical approaches. On the downside, they are challenged by the level of uncertainty as to whether STR approaches are effective or not with some of the participants raising concerns on whether students are well equipped for taking responsibility. Reception of the STR project during the workshops, and the heated discussions reinforce our belief that a Pedagogical Pattern Language (PPL) is a timely and relevant endeavour.

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REFERENCES

Biwer, Felicitas. 2020. "Fostering Effective Learning Strategies in Higher Education – a Mixed-Methods Study". *Journal of Applied Research in Memory and Cognition*, *9* (2), 186-203. https://doi.org/10.1016/j.jarmac.2020.03.004.

Cascio, Jamais. 2020. "Facing the Age of Chaos." Medium. Published April 29, 2020. https://medium.com/@cascio/facing-the-age-ofchaos-b00687b1f51d.

Kamp, Aldert. 2016. "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher Engineering Education." *Repository.tudelft.nl.* http://resolver.tudelft.nl/uuid:ae3b30e3-5380-4a07-afb5-dafd30b7b433.

Mostafavi, Mohsen. 2020. "How will we teach next? Notes for a conversation on the futures of architectural education". *urbanNext.* Published October 1, 2020. https://urbannext.net/how-will-we-teach-next/

Van den Hoven, Jeroen, Gert-Jan Lokhorst, and Ibo Van de Poel. 2011. "Engineering and the Problem of Moral Overload." *Science and Engineering Ethics 18* (1): 143–55. https://doi.org/10.1007/s11948-011-9277-z.

CREATING EXPERIENTIAL ACTIVITIES TO TEACH TRANSVERSAL SKILLS IN YOUR COURSE WITH A BACKWARD DESIGN TEMPLATE

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ABSTRACT

Providing authentic experiential learning activities is an important part of educating responsible engineers. In addition to disciplinary knowledge and skills, it is important that our graduating engineers achieve fluency in transversal skills. The trident framework developed by 3T PLAY helps educators ensure that they are maximising students' transversal skill development (https://doi.org/10.5281/zenodo.13328581). The framework targets three distinct but interrelated evidence-informed pedagogical

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aspects of skill development: knowing (strategies and models to implement the skill), experiencing (opportunities to apply the skills and encounter relevant difficulties) and learning by experience (meta-cognitive/emotional reflection to promote transfer). In this workshop, participants will experience an activity developed using the trident framework and analyse it to identify the operationalisation of these three aspects. Following this orientation, participants will then work in small groups to develop activities that target transversal skills that are relevant in their own contexts. The facilitation team will provide scaffolded guidance and materials to help in developing these prototype activities (https://doi.org/10.5281/zenodo.10992806). Finally, participants will be provided with additional resources to further support their efforts and invited to participate in an online platform for sharing activities that teach transversal skills.

1 BACKGROUND AND RATIONALE

An important consideration of educating responsible engineers is providing them with authentic disciplinary experiential learning activities. In response to calls to integrate more of these practices in the curriculum, the number of project and challenge-based courses offered in engineering have increased. Rooted in disciplinary contexts, these types of activities provide an excellent opportunity to facilitate development of transversal skills (Gallagher and Savage 2023).

A limitation to the effectiveness of these contexts is that students may not identify that, in addition to the explicit objective of completing their project, there is often a more implicit goal of transversal skill development (Tormey and Isaac 2022). The result is that students fail to perceive the various pedagogical aspects relevant to transversal skill development (instruction, feedback, assessment) of their courses (Isaac, de Lima, Jalali, Rossi, Tormey, et al. 2024; de Lima, Isaac, and Dehler Zufferey 2024b; 2024a). The need to explicitly support transversal skills is further supported by studies showing that students do not develop these skills by simply engaging in activities where they practise these skills, but rather they need clear and direct instruction (Lehmann et al. 2008; Picard et al. 2022). An additional obstacle is that, when thinking about the learning affordances of experiential activities, teachers often focus on the disciplinary knowledge and overlook transversal skill development (Isaac et al. 2023).

In experiential learning, the focus is on students constructing their own knowledge (Christie and de Graaff 2017) and therefore it is essential that they have opportunities to learn from their experiences by engaging in meta-cognitive and meta-emotional reflection (Steele 2018; Turns et al. 2014; Veine et al. 2020). Recognising the value of reflection in enhancing learning gains (including that of transversal skills) several engineering educators include reflections as one of the mandatory learning activities for in their courses (Hirsch and McKenna 2008; Shekar 2007). Such meta-thinking activities help students to construct meaning from their experiences and facilitate transfer of learning to new contexts (Leberman and Martin 2004).

Our trident framework is designed to assist educators ensure that they are maximising students' learning potential by explicitly addressing the above-mentioned issues (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024). This is done by consciously integrating three important pedagogical aspects when designing activities:

- Knowing - including information about the skill, its relevance, and associated strategies
- Experiencing - implementing the skill
- Learning from experience - meta-cognitive and meta-emotional reflections

Educating responsible engineering students involves supporting their development for a broad set of transversal skills applicable in a wide range of contexts. In practice, this means engineering educators must identify specific skills relevant for their students and integrate effective learning experiences. This workshop provided a structured approach, based on the trident framework, for instructors to improve their teaching of transversal skills. Building from example activities that address transversal skills such as collaboration (de Lima and Isaac 2024a), emotional self-regulation (Isaac and de Lima 2024a), skills that promote sustainability (Isaac and de Lima 2024b), and coaching and peer teaching skills (de Lima and Isaac 2024b), participants were introduced the trident framework (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024) and engaged in collaborative, scaffolded activities (Isaac and de Lima 2024c) to develop their own teaching activity focusing on a transversal skill relevant to them.

2 LEARNING OBJECTIVES

This workshop was designed for engineering educators and pedagogical advisors interested in creating or refining activities to teach transversal skills. Prior knowledge of transversal skills, or experience in teaching transversal skills was not required.

By the end of the hour participants had:

- Analysed an existing activity. to identify operationalisation of key pedagogical aspects of the trident framework.
- Selected relevant transversal skills for students in a specific context (i.e., their own course).
- Designed or co-designed a first prototype of an activity based on the trident framework.
- Established collaborations with other educators.

3 WORKSHOP DESIGN

Integrating principles of constructive alignment (Biggs 1996) and backward design (Wiggins and McTighe 2005), educators designed a prototype of an experiential learning activity that targeted students’ transversal skill development.

The facilitation team had four members and therefore was able to provide personalised attention and scaffolding to the participants.

Time	Activity	Description

15’	Welcome, Introduction, Experience of activity	<u>Plenum:</u> • Welcome the participants. • Explain the aims and functioning of the workshop. • Introduce the 3T PLAY Trident and its theoretical foundations. • Accelerated experience of an activity developed using the framework
10’	Analysing the activity	<u>Small groups (max 3 per group):</u> Participants will use the trident framework to analyse the activity with a specific focus on identifying where, when, and how the three aspects of the framework were operationalised.
5’	Which skills are most relevant for me?	<u>Individual activity:</u> • Work through a checklist with a to identify individual skills (as opposed to personality characteristics or groups of skills) • Select two skills from the list that are most relevant to each participant's individual context (considering the needs of their students, institutional context, etc.) • Respond to a reflective worksheet to identify opportunities for students to implement these skills and potential obstacles.
15’	Learning from Experience	<u>Small groups (max 3 per group):</u> Participants will form small groups based on the skills they are interested in targeting, so that each group is focusing on one common skill of interest to all the members. Using principles of backward design, this phase focuses on making the learning outcomes of the prototype activity explicit. During this step participants will be guided through a scaffolded approach to clarify: • What do they want the students to walk away with? • How can they facilitate students’ transfer of the skill to a different context?
10’	Learning experiences	<u>Small groups (max 3 per group):</u> This step is about creating an experiential activity to allow students to implement the transversal skill in a low-stakes environment.

		Continuing with the scaffolded guiding, participants will design a short activity (or repurpose a prior activity) that allows students the opportunity to practise the target skill. Examples of activities will be provided.
5’	Planning continued collaboration	Plenum: Participants will be encouraged to continue developing or co-developing these activities after the conference. They will be provided with additional resources and worksheets to facilitate further development and prototyping of the activity.

4 OUTCOMES OF THE WORKSHOP

At the end of the workshop, the participants had designed a prototype of an activity. Additionally, because they were encouraged to work collaboratively in small groups formed by shared interest in a specific transversal skill, we expect that these collaborations will continue beyond the conference contributing to development of professional practitioner networks. As mentioned before, participants were provided with additional resources and worksheets to facilitate further development and prototyping of their activities.

The online open-source repository of activity guides for teaching transversal skills is both publicly available and open to additional contributions. Workshop participants were encouraged to share their activities with the engineering education community via this repository.

This workshop was based on 3T PLAY trident framework that explicitly incorporates *Knowing*, *Experiencing* and *Learning from experience* during activity design (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024). The 3T PLAY team have used this framework to develop several activities targeting specific transversal skills (3T PLAY 2024). Additionally, we have also developed an open access self-guided self-paced activity to help educators use the trident framework and develop activities that target transversal skills that are relevant in their contexts (Isaac and de Lima 2024c). All these open-access resources are available online: https://zenodo.org/communities/3tplay/records

REFERENCES

3T PLAY, ed. 2024. *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10392281.

Biggs, John. 1996. ‘Enhancing Teaching through Constructive Alignment’. *Higher Education* 32 (3): 347–64. https://doi.org/10.1007/BF00138871.

Christie, Michael, and Erik de Graaff. 2017. ‘The Philosophical and Pedagogical Underpinnings of Active Learning in Engineering Education’. *European Journal of Engineering Education* 42 (1): 5–16. https://doi.org/10.1080/03043797.2016.1254160.

de Lima, Joelyn, and Siara Isaac. 2024a. ‘Chapter 2: How to Support Students to Develop Skills That Improve Collaboration, Including Retrospective Discussions’. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.13328621.

de Lima, Joelyn, and Siara Isaac.2024b. ‘Chapter 5: How to Support Students to Develop Coaching and Peer Teaching Skills’. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10931765.

de Lima, Joelyn, Siara Isaac, and Jessica Dehler Zufferey. 2024a. ‘Distinctly Human - Students’ Perception of Transversal Skills in Engineering Curriculum’. In *Proceedings of the 20th International CDIO Conference*.

de Lima, Joelyn, Siara Isaac, and Jessica Dehler Zufferey.2024b. ‘Transversal Skills Priorities and Curricular Support as Experienced by Engineering Students on Their Path to Becoming Responsible Engineers’. In *Proceedings of the 52nd Annual SEFI Conference*.

Gallagher, Silvia Elena, and Timothy Savage. 2023. ‘Challenge-Based Learning in Higher Education: An Exploratory Literature Review’. *Teaching in Higher Education* 28 (6): 1135–57. https://doi.org/10.1080/13562517.2020.1863354.

Hirsch, Penny L., and Ann F. McKenna. 2008. ‘Using Reflection to Promote Teamwork Understanding in Engineering Design Education’. *International Journal of Engineering Education* 24 (2): 377–85. http://www.scopus.com/inward/record.url?scp=42349106540&partnerID=8YFLogxK.

Isaac, Siara, and Joelyn de Lima. 2024a. ‘Chapter 3: How to Support Students Giving Each Other Constructive Feedback, Especially When It Is Difficult to Hear’. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10392344.

Isaac, Siara, and Joelyn de Lima.2024b. ‘Chapter 4: How to Support Students to Develop Skills That Promote Sustainability’. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10731771.

Isaac, Siara, and Joelyn de Lima.2024c. ‘Chapter 8: How Teachers Can Use the 3T PLAY Trident Framework to Design Activities That Develop Transversal Skills’. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10992806.

Isaac, Siara, Joelyn de Lima, Yousef Jalali, Valentina Rossi, Samuel Schmid, Roland Tormey, and Jessica Dehler Zufferey. 2024. ‘Chapter 1: How to Develop Engineering

Students' Transversal Skills.' In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.13328581.

Isaac, Siara, Joelyn de Lima, Yousef Jalali, Valentina Rossi, Roland Tormey, and Jessica Dehler Zufferey. 2024. 'Exploring Engineering Students' Perception of Sustainability and Ethics in Their Curriculum Across Disciplines'. In *2024 IEEE Global Engineering Education Conference (EDUCON)*, 01–05. https://doi.org/10.1109/EDUCON60312.2024.10578603.

Isaac, Siara, Natascia Petringa, Yousef Jalali, Roland Tormey, and Jessica Dehler Zufferey. 2023. 'Are Engineering Teachers Ready to Leverage the Power of Play to Teach Transversal Skills?' In *Proceedings of the SEFI 2023 Conference*. https://doi.org/10.21427/QP3D-B914.

Leberman, Sarah I., and Andrew J. Martin. 2004. 'Enhancing Transfer of Learning through Post-Course Reflection'. *Journal of Adventure Education and Outdoor Learning* 4 (2): 173–84. https://doi.org/10.1080/14729670485200521.

Lehmann, M., P. Christensen, X. Du, and M Thrane. 2008. 'Problem-Oriented and Project-Based Learning (POPBL) as an Innovative Learning Strategy for Sustainable Development in Engineering Education'. *European Journal of Engineering Education* 33 (3): 283–95. https://doi.org/10.1080/03043790802088566.

Picard, Cyril, Cécile Hardebolle, Roland Tormey, and Jürg Schiffmann. 2022. 'Which Professional Skills Do Students Learn in Engineering Team-Based Projects?' *European Journal of Engineering Education* 47 (2): 314–32. https://doi.org/10.1080/03043797.2021.1920890.

Shekar, Aruna. 2007. 'Active Learning and Reflection in Product Development Engineering Education'. *European Journal of Engineering Education* 32 (2): 125–33. https://doi.org/10.1080/03043790601118705.

Steele, Alan L. 2018. 'Developing Student Meta-Cognition in a Design Course.' *Proceedings of the Canadian Engineering Education Association (CEEA)*, December. https://doi.org/10.24908/pceea.v0i0.13031.

Tormey, Roland, and Siara Isaac. 2022. *Facilitating Experiential Learning in Higher Education Teaching and Supervising in Labs, Fieldwork, Studios, and Projects*. Key Guides for Effective Teaching in Higher Education. Routledge.

Turns, Jennifer A., Brook Sattler, Ken Yasuhara, Jim L. Borgford-Parnell, and Cynthia J. Atman. 2014. 'Integrating Reflection into Engineering Education'. In , 24.776.1-24.776.16. https://peer.asee.org/integrating-reflection-into-engineering-education.

Veine, Sven, Martha Kalvig Anderson, Nina Haugland Andersen, Thomas Christian Espenes, Tove Bredesen Søyland, Patric Wallin, and Jonathan Reams. 2020. 'Reflection as a Core Student Learning Activity in Higher Education - Insights from Nearly Two Decades of Academic Development'. *International Journal for Academic Development* 25 (2): 147–61. https://doi.org/10.1080/1360144X.2019.1659797.

Wiggins, Grant P., and Jay McTighe. 2005. *Understanding by Design*. Virginia, USA: Association for Supervision and Curriculum Development.

Engineering Non-technical Skills Behavioral Taxonomy: A Sort and Grid Workshop

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ABSTRACT

Non-technical skills (NTS) such as teamwork, communication, and leadership are increasingly vital in engineering. As part of a phd project, we are developing the General Engineering Non-Technical Skills Taxonomy (GENTS) to systematically assess and train these skills in engineering graduates. Derived from an extensive literature review that compiles over 400 expected skills from engineers, GENTS aims to outline high-performing engineers' non-technical skills and behavioural markers.

This workshop elicits experts' knowledge in teaching, hiring, or managing engineers to refine and enhance the GENTS taxonomy. Participants will undertake tasks including sorting and categorising skill statements, providing feedback on the proposed taxonomy, and commenting on behavioural markers from interviews with industry experts. A round-table discussion will facilitate reflection on the taxonomy's comprehensiveness, clarity, and applicability, including considerations of future-

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proofing and cultural differences. This knowledge elicitation workshop aims to align engineering education with the profession's evolving demands by providing a systematic tool for assessing and training NTS.

1 INTRODUCTION

Behavioural marking systems (BMS) are used in different disciplines and industries, such as aviation and surgery. They consist of critical non-technical skills associated with observable and identifiable behaviours (Naweed and Murphy 2022). These systems often have a hierarchical structure, including skill categories, sub-categories (elements), and behavioural examples associated with each taxonomy element (Hamlet et al. 2023). Research has shown that Non-Technical Skills (NTS) interventions and feedback can have a positive impact on team performance (Moll-Khosrawi et al. 2019), and Behavioral marking systems are reliable tools that can assess and facilitate training for NTS in a repeatable way (Ravindran et al. 2021).

At King's College London's engineering department, we are developing a behavioural taxonomy to outline how an ideal engineer behaves and what markers of excellent or poor performance are for engineers. Based upon this all-encompassing behavioural taxonomy, we are creating a behavioural marking system to assess non-technical skills in engineering graduates. The first step in developing a BMS is determining the skills and competencies expected from engineers. As part of a PhD project, we have reviewed academic papers between 2018 and 2022, reports from the Royal Academy and UK Engineering Council, and surveys from the Institution of Engineering and Technology (IET). From this literature review, we have compiled a list of over 400 expectations from engineers in the form of statements or phrases. We seek participant's knowledge and expertise to help us sort these statements into relevant groups of skills and sub-skills.

1.1 Motivation & Learning Outcomes

Experts in teaching, hiring, or managing engineers in this knowledge elicitation workshop will collaborate to refine and enhance the 400 skills presented as a General Engineering Non-Technical Skills Taxonomy (GENTS). We aim to communicate foundational concepts of behavioural marking systems and their importance in assessing engineering non-technical skills. Expert participants will also critically analyse and categorise over 400 engineers' expectations into coherent groups of skills and sub-skills, leveraging their knowledge regarding expected engineering non-technical skills. Exposure to various non-technical skills also facilitates discussing, training, and developing pedagogical interventions for engineering non-technical skills. Engineering educators can also conceptualise and think about implementing non-technical expectations in their teaching.

1.2 Background and Rationale of the Session

The engineering profession increasingly recognises the importance of non-technical skills, such as teamwork, communication, and problem-solving, alongside technical expertise from different points of view. From an employability perspective, soft skills are crucial for engineering students, with non-technical skills prioritised by some employers over academic credentials (Noordin & Nordin, 2018; Pang et al., 2019; Tadjer et al., 2020). Given the rapid evolution of technology, these skills remain relevant across various contexts, while specific hard skills may quickly become outdated (Martins et al. 2021). Another important aspect of soft skills in engineering can be seen through the lens of safety and reducing the impact of human errors. According to (Nadeem and Biglari-Abhari 2020), lack of appropriate communication has been one of the major causes of significant engineering failures in projects such as the Space Shuttle Challenger disaster and the NASA Mars Climate Orbiter loss. Trends towards a competency-based model of engineering education also emphasise the importance of soft skills (Caggiano et al. 2020).

2 FORMAT OF THE WORKSHOP AND ENGAGEMENT OF PARTICIPANTS

During the 60-minute ethically approved workshop, experts will complete two tasks in part one and participate in a discussion group in part two. The tasks in the first part of the workshop are as follows:

TASK 1 Sort and name from scratch: Participants will put 40 sample skills extracted from the literature review into small and medium parcels as replicators of their suggested categories and taxonomy elements and name them accordingly.

TASK 2 Comment on a suggested taxonomy of non-technical skills for engineers: Participants will be presented with a proposed framework where all 400 statements have been sorted into 15 categories and around 100 elements. They will provide feedback on the sorting and names to refine and improve the framework, considering the following design criteria: a. Categories and elements should have maximum mutual exclusivity with minimal overlap. b. The terminology used should be recognisable to engineers (Butler et al., 2020).

TASK 3 Comments on a sample of poor and good performance behaviours linked to the taxonomy: We have interviewed twelve senior managers from world-leading engineering companies (so far), including AWE, ARM, Jaguar Land Rover, BAE Systems, IQE, Dyson, and Mott MacDonald. This diverse industry input and valuable insights from engineering lecturers at the University of Edinburgh, Aston University, and professors of practice at the Royal Academy of Engineering have focused on eliciting knowledge from expert engineers. The aim is to identify good or poor performance behaviours for each taxonomy category. Participants will comment on the behaviours extracted from an abductive thematic analysis of the interviews for one of the taxonomy categories.

The remainder of the workshop will be a round table discussion using the Delphi Method. This discussion will allow expert participants to reflect on the content of the taxonomy and voice any concerns about inconsistencies or comprehensiveness in the framework. We are interested in hearing participants' thoughts on questions such as:

- Do you think the framework is comprehensive and reflects the skills engineers need?
- Is there any required further refinement to categorise skills more understandably?
- How do you think we can future-proof the framework?
- To what extent cultural differences might affect the framework?

The workshop will follow a timeline of activities as follows:

Table 1. Workshop Timeline: Key Activities and Milestones

Activity	Time	Cumulative Time	Presenter
Intro and Principles of BMS Categories	10	10	Claire
Task 1: Sorting from scratch	10	20	All
Task 2: Individual Framework Sorting	10	30	All
Task 3: Comments on Behavioural Markers of "Contextual Awareness" Category	10	40	All
Round table	20	60	Claire & Francesco

2.1 Significance for Engineering Education

We hope this workshop represents a pivotal step in aligning engineering education with the evolving demands of the engineering profession. Providing an assessment tool for engineering non-technical skills prepares engineering graduates to excel technically and thrive in collaborative, multidisciplinary, and globally diverse work environments. The development and refinement of non-technical engineering skills taxonomy can also serve as a critical tool for curriculum development and professional development for academia and industry, ensuring that engineering education remains relevant, comprehensive, and forward-looking.

3 RESULTS

The expert participant comments on three tasks yielded valuable insights into developing and refining the General Engineering Non-Technical Skills (GENTS) Taxonomy. In Task 1, participants demonstrated a consensus on the main categories of non-technical skills for engineers. The most frequently identified categories included personal development, interpersonal skills, professional responsibilities, and project management. This alignment with the existing framework reinforces the relevance and importance of these skill areas in the engineering profession.

In Task 2, Participants emphasised the need for clarity, suggesting that the role and identity of future engineers ("problem owner"," tech expert", coordinator", etc,.) and the intended use of the taxonomy should be more explicitly defined. Additionally, participants recommended consolidating some categories to reduce overlap and improve overall coherence. This suggestion aligns well with the design criteria of mutual exclusivity and recognisable terminology for behavioural marking systems (Butler et al., 2020). The feedback also highlighted the importance of inclusivity within the taxonomy. Specifically, participants suggested explicitly including attitudes and skills relevant to gender (or tackling gender biases) in the Equity, Diversity, and Inclusion (EDI) category. Furthermore, participants proposed a practical taxonomy application by mapping it against learning outcomes in engineering programs. This approach would identify potential gaps in current curricula and provide opportunities for integrating non-technical skills more effectively into engineering education.

Task 3 focused on the behavioural markers extracted from interviews with industry experts. A key theme that emerged was the importance of emphasising observable actions rather than abstract concepts. Participants stressed the need to focus on concrete actions or verbal questions instead of less tangible attributes like "awareness" or "understanding". To enhance the practical application of the taxonomy, experts suggested incorporating established frameworks such as stakeholder analysis and PEST analysis to observe and assess behaviours. This recommendation provides a foundation for developing relevant assessment scenarios that can be integrated into existing engineering practices and education programs. Moreover, participants questioned the inclusion of poor performance behaviours in the framework, suggesting a focus on positive, observable actions instead. This perspective aligns with a strengths-based approach to skill development and assessment, potentially leading to more constructive and motivating feedback for engineering students and professionals. However, some undesired behaviours in categories such as risk and security might be easier to observe as negative statements.

3.1 Summery and Next Steps

The expert participants' feedback on developing a behavioural marking system and taxonomy for training and assessing non-technical skills reinforced the importance of non-technical skills in engineering while providing constructive suggestions for improvement. Key outcomes include greater clarity in defining the taxonomy's purpose and intended use, the importance of focusing on observable behaviours, and the potential for integrating established frameworks to enhance assessment practices. The workshop also highlighted the significance of inclusivity, particularly in addressing gender-bias-related attitudes and behaviours within the EDI category. Based on the expert feedback and workshop outcomes, we will take the following key steps to refine and implement the GENTS Taxonomy:

1. Refine the GENTS Taxonomy: We will revise the framework to improve clarity, reduce overlap between categories, and ensure comprehensive coverage of essential non-technical skills for engineers.

2. Enhance EDI Integration: In our next round of expert consultation, we will try to explicitly incorporate poor and good performance behaviours relevant to gender equality and address gender biases within the Equity, Diversity, and Inclusion (EDI) category.

3. Develop Assessment Scenarios: We will create practical assessment scenarios incorporating established frameworks like stakeholder and PEST analysis to observe and evaluate behaviours effectively.

4. Focus on Observable Actions: We will revise behavioural markers to emphasise concrete, observable actions rather than abstract concepts, improving the assessment tool's objectivity and applicability.

5. Pilot Implementation: We will conduct pilot studies using video scenarios to test the practical application of the GENTS Taxonomy and gather feedback for further refinement.

REFERENCES

Caggiano, Valeria, Teresa Redomero-Echeverría, Jose Luis Poza-Lujan, and Andrea Bellezza. 2020. 'Soft Skills in Engineers, a Relevant Field of Research: Exploring and Assessing Skills in Italian Engineering Students'. Ingenieria e Investigacion 40 (2): 81@91. https://doi.org/10.15446/ing.investig.v40n2.83717.

Hamlet, Oliver E.D., Amy Irwin, Rhona Flin, and Nejc Sedlar. 2023. 'The Development of the Helicopter Non-Technical Skills (HeliNOTS) Behavioural Marker Systems'. Ergonomics. https://doi.org/10.1080/00140139.2023.2194591.

Martins, Helena, Ana Freitas, Inês Direito, and Ana Salgado. 2021. 'Engineering the Future: Transversal Skills in Engineering Doctoral Education'. In 2021 4th International Conference of the Portuguese Society for Engineering Education, CISPEE 2021. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/CISPEE47794.2021.9507210.

Moll-Khosrawi, Parisa, Anne Kamphausen, Wolfgang Hampe, Leonie Schulte-Uentrop, Stefan Zimmermann, and Jens Christian Kubitz. 2019. 'Anaesthesiology Students' Non-Technical Skills: Development and Evaluation of a Behavioural Marker System for Students (AS-NTS)'. BMC Medical Education 19 (1). https://doi.org/10.1186/s12909-019-1609-8.

Nadeem, Muhammad, and Morteza Biglari-Abhari. 2020. 'Analysing Engineers Writing for Non-Engineers'. In Proceedings of 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering, TALE 2020, 281–86. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/TALE48869.2020.9368361.

Naweed, Anjum, and Philippa Murphy. 2022. 'One-Track Mind: Investigating Positive and Negative Applications of Non-Technical Skills in Rail Network Control'. Applied Ergonomics 106 (January). https://doi.org/10.1016/j.apergo.2022.103840.

Noordin, Muhammad Khair, and Mohd Safarin Nordin. 2018. 'Project-Based Learning (PjBL) Framework in Developing Non-Technical Skills for Engineering Students'. Advanced Science Letters 24 (6): 4515–18. https://doi.org/10.1166/asl.2018.11640.

Pang, Elvy, Michael Wong, C H Leung, and John Coombes. 2019. 'Competencies for Fresh Graduates' Success at Work: Perspectives of Employers'. Industry and Higher Education 33 (1): 55–65. https://doi.org/10.1177/0950422218792333.

Ravindran, Srivathsan, Adam Haycock, Katherine Woolf, and Siwan Thomas-Gibson. 2021. 'Development and Impact of an Endoscopic Non-Technical Skills (ENTS) Behavioural Marker System'. BMJ Simulation and Technology Enhanced Learning 7 (1): 17–25. https://doi.org/10.1136/bmjstel-2019-000526.

Tadjer, Houda, Yacine Lafifi, Hassina Seridi-Bouchelaghem, and Sevinç Gülseçen. 2020. 'Improving Soft Skills Based on Students' Traces in Problem-Based Learning Environments'. Interactive Learning Environments. https://doi.org/10.1080/10494820.2020.1753215.

PROMOTING AND FACILITATING A HUMAN RIGHTS-BASED APPROACH TO AI DEVELOPMENT: A WORKSHOP FOR AN ENGINEERING AUDIENCE

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ABSTRACT

Artificial intelligence (AI) engineers often lack awareness of the negative impact that AI systems can have on individuals' Human Rights and practices that can help to prevent such adverse consequences. Consequently, AI systems that contradict Human Rights values are common (e.g. Heikkilä 2022; Obermeyer et al. 2019). This workshop is designed to teach AI engineering educators about this shortcoming by focusing on four main outcomes. First, a real-life case study exercise demonstrates the potential of AI systems to harm the Human Rights of individuals and help participants identify the structural inequities of such systems. Second, participants are introduced to their role in creating Human Rights-respecting AI systems and fundamental considerations supporting this. Third, participants collaboratively identify bottlenecks they would face when implementing such considerations. Finally, based on these insights, we derive concrete interventions to overcome these roadblocks, from immediate actions to long-term goals and open questions. We hope that this

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workshop further aligns the Engineering practice with a Human Rights-based approach to AI development.

1 INTRODUCTION

1.1 Section 1

This workshop demonstrates the importance of developing artificial intelligence (AI) systems in line with Human Rights and collaboratively explores mechanisms that facilitate such a Human Rights-based approach to AI development. Through discussing case study examples, we evidence that AI systems have real-world impacts on the Human Rights of individuals. This is accompanied by an analysis of the structural mechanisms that cause these negative Human Rights impacts. In a second part, the participants reflect on their role in advancing Human Rights-based considerations, identifying current bottlenecks and blind spots. Harnessing their lived experience, we collaboratively identify technical and non-technical interventions to overcome the obstacles currently impeding the creation of Human-Rights centric AI systems. Our workshop aims at advancing the creation of technology centering equality and inclusion, thus extending beyond compliance to ultimately empower human beings and the public good.

The following sections provide more detail on the workshop's learning outcomes, content outline and timings, its relevance for Engineering educators, methods of interactivity, as well as the expected range and format of results.

2 LEARNING OUTCOMES

Our workshop is designed around the following learning outcomes:

- Understanding the core relationship between Human Rights and the creation and deployment of AI systems by exploring real-life examples where individuals' Human Rights were affected,making explicit the connection between the social, the technical and socio-technical, to address lack of familiarity with Human Rights frameworks and concepts in this context.
- Analyzing the mechanisms causing such Human Rights contradictions by reflecting on the objectives, impacts, and biases of existing systems (including those related to biased datasets, algorithmic design, and strategic choices) and through sharing a cohesive AI life cycle approach (Objectives & Team Composition, System Requirements, Data Discovery, Model Selection, Testing & Interpretation, Deployment & Auditing).
- Addressing the lack of focus on Human Rights concepts in engineering curriculum through familiarization with the Universal Declaration of Human Rights and professional codes of ethics (IEEE, ACM)
- Identifying promising technical and non-technical solutions and requirements that would facilitate the creation of AI systems centered around Human Rights, sharing resources with participants on fairness metrics, explainability techniques, human-centered design approaches, and multi-stakeholder engagement.

- Bridging the gap between technical and social science disciplines by demonstrating that these approaches are both complementary and necessary in the creation of Human Rights-compliant AI systems and by introducing the necessary technical and non-technical vocabulary for multi-disciplinary conversations.

3 OUTLINE: CONTENT & TIMINGS

Content Block I: Introduction to Human Rights - 10 minutes

- Speaker introduction
- The core values of Human Rights
- Introduction to the Universal Declaration of Human Rights

Exercise I: Case Studies Exploring Human Rights Contradictions of AI - 15 minutes

- Group exercise (3 to 6 participants per group)
- Each group reads SyRI case study* (see below) and are asked to discuss:
  - Which article(s) of the Universal Declaration of Human Rights were harmed?
  - What might be the cause of this impact? Think beyond biased datasets!
- Each group presents their insights briefly (2 minutes per group)
- As a group, we are locating entry points of bias along the AI development lifecycle

Content Block II: The Role of Engineers in Upholding Human Rights - 5 Minutes

- Introduction to professional codes of ethics that include respect for Human Rights, IEEE & ACM Code of Ethics
- Discussion on the responsibilities of engineering educators in teaching ethical practices and the educational challenges in engaging engineering students with ethical questions of this type

Exercise II: Reflecting on Required Information, Skills, and / or Tools - 25 minutes

- Group exercise: each group selects one stage of the AI lifecycle
- For this stage, they receive a list of reflective questions designed to support engineering educators in proactively protecting and promoting Human Rights in their work and teachings
- Groups discuss & reflect on:
  - Which of these Human Rights questions are easy to answer?
  - Which are hard or impossible? Why / What are the obstacles?

    - Which insights are required to reflect on these?
- Quick presentation of key insights of each group (3 minutes per group)

Summary - 5 minutes

- Summarizing learnings and introducing our free online course for interested participants
- Distribution of anonymous feedback form

Using the SyRI case study as a concrete example, we hope to provide workshop participants with practical insights and a clear understanding of how to integrate Human Rights considerations into their teaching. SyRI is an automated risk assessment system used to identify individuals who the system determined were more likely to commit benefits fraud (AlgorithmWatch, 2020). The system was deemed unlawful for violating the right to privacy under the European Convention of Human Rights (U.N. 2020) and for its impact on the Right of Social Service (Article 25) by employing a hidden algorithmic risk model exclusively targeting neighborhoods with mostly low-income and minority residents (Alston, 2020). The SyRI case also raises questions about bias in algorithm design and strategic choices such as lack of transparency and accountability that can hinder individuals from understanding and challenging AI-generated outcomes.

Overall, the SyRI case study provides a valuable opportunity for engineering educators to engage with the broader social and ethical implications of AI and to explore the role that they and their students can play in shaping the development of these technologies in a way that promotes Human Rights and social justice.

4 THEORETICAL FOUNDATIONS

A Human Rights approach to AI development centers the Human Rights principles of universality, indivisibility, equality and non-discrimination, participation and accountability at the core of algorithms (Fund 2005; Group 2020). Our goal is to integrate Human Rights principles into Engineering in order to advance the creation of AI technology that is aligned with Human Rights values rather than unwittingly harms them.

4.1 Why not Ethical AI?

Ethics, which are crucially important, are also situational (Jobin, Ienca, and Vayena 2019; Sadek et al. 2024). Ethical AI guidelines, authored by a wide range of bodies (e.g. academia, civil society organizations, research institutes, governments, and private sector organizations), are the currently most common response to concerns around the ethics of AI (Jobin, Ienca, and Vayena 2019). However, they are under major critique, both from academia (McNamara, Smith, and Murphy-Hill 2018; Munn 2023; Sadek et al. 2024) as well as the AI practice (Ibáñez and Olmeda 2022; Rakova et al. 2021). Their abstract nature allows for diverging interpretations and implementations, impeding or even undermining the determination of non-adherence and thus accountability.

We avoid this ambiguity by focusing on Human Rights: Human Rights are an agreed body of international (and national) law and reflect a universal understanding of aspects required to ensure human dignity (Assembly 1949; Rights 2024). Human

Rights thus provide a common and concrete starting point to align different actors, disciplines, and cultures. Consequently, we decided to center this workshop around Human Rights rather than AI ethics.

5 RELEVANCE FOR ENGINEERING EDUCATION

AI systems have an ever-increasing impact on all parts of society, including those connected to Human Rights. Examples include decisions around the detention of criminal defendants (Dressel and Farid 2018), social services and welfare (Chouldechova et al. 2018; Kawakami et al. 2022); recruiting decisions (Drage and Mackereth 2022; Mujtaba and Mahapatra 2019); or healthcare related matters (Obermeyer et al. 2019). Often, this can result in discriminatory outcomes, harming the Human Rights of individuals (Drage and Mackereth 2022; Obermeyer et al. 2019). Thus, it is essential that all roles involved in the development of such systems are aware of their responsibility and the mechanisms that can cause such harmful outcomes. This requires an understanding of how biases can enter the system along its entire pipeline (not just the training data), i.e. how the real world interacts with the technical measures that are an inherent part of AI development.

The second half of the workshop is dedicated to Human Rights-based considerations along the AI pipeline to equip the engineering educators with the tools and mindset to counteract such adverse Human Rights outcomes. To increase their actionability, this chapter is interwoven with reflections and discussions around their responsibility as well as the information, skills, and tools required to be able to act upon such Human Rights-based considerations. We believe that a deep understanding of the complementary nature of the different disciplines is required to enable a smooth collaboration - an essential condition for the development of Human Rights-respecting AI systems. The creation of technology is a multidisciplinary effort, strengthened by consultation, consensus, and diverse disciplinary perspectives including the lived experiences of the people affected by AI systems.

6 METHODS & INTERACTIVITY

The workshop is designed to address the specific challenges that engineering educators face in integrating Human Rights considerations into their work and teachings. These challenges include students' lack of familiarity with Human Rights frameworks, the perception of Human Rights as a non-technical or "soft" topic; difficulty in bridging the gap between technical and non-technical disciplines; and limited exposure to real-world AI applications and their impacts.

To address these challenges, the workshop employs interactive exercises that follow the Active Learning Theory (Fuson 2009). Theoretical content blocks I & II address the lack of the familiarity of the Human Rights frameworks and concepts, and are immediately put into practice into the next sections. The first exercise utilizes the SyRI case study as a real-world example (Herrington and Herrington 2006) to illustrate the potential impact of AI systems on communities. This addresses the limited exposure to real-world AI applications and their impacts (Buckley and Kukhareva 2021) helps to make the material more concrete and is a strong rebuttal to the perception of Human Rights as a non-technical or "soft" topic.

To bridge the gap between technical and non-technical disciplines, the workshop employs interdisciplinary collaboration (Yanitsky 2020) in a content block on the role of engineers in upholding Human Rights that promotes a more holistic and integrated understanding of the material. During the second exercise, we harness the lived experience of engineering educators to reflect on the challenges they experience in past and ongoing projects with regards to Human Rights considerations during the development of AI systems. We collect and aggregate current bottlenecks; an exercise required to understand current challenges, foci, and mindsets of AI Engineers. This knowledge can be used to create tailored interventions such as tools (Gebru et al. 2021; Holland et al. 2018; Mitchell et al. 2019), involving more Social Scientists to engage with affected communities, or setting longer timelines to be able to engage in reflective exercises. The exact interventions will depend on the bottlenecks that will be identified during the workshop.

This exercise also allows engineering educators to voice concerns regarding the practicability of a Human Rights-based approach to AI development. We believe that it is essential to involve all parties and affected communities in the creation of novel approaches to AI development to ensure that the resulting recommendations are actionable for all. Utilizing the Theory of Change (Brest 2010), the participants are incentivised to reflect on how they can promote Human Rights through their own projects. This spans aspects from identifying the desired Human Rights outcomes to actually planning the technical steps required to achieve those outcomes.

Through collaboratively summarizing the insights at the end of the session, we stress the ‘So What?’ of the session and derive concrete action points. We will use the last minutes of the workshop to introduce participants to our growing community that offers a free online course in Human Rights & AI, biweekly reading groups and meet-ups, as well as talks and community publications. We aim to be a multi-disciplinary community that is creating and trialing best practices for a Human Rights based approach to AI development in practice.

7 RESULTS

The following section provides an overview over the outcomes of the workshop held at the SEFI Conference on September 4th, 2024, with 12 participants working in or along engineering education.

We clustered our findings into three categories, which correspond to a step-wise action plan comprising recommendations for AI practitioners, regulators, and academia.

Immediate Actions. Insights in this category are interventions that could be introduced immediately by teams of AI practitioners. Our workshop participants reported that the real-world examples were promising in equipping AI practitioners with the sense of urgency and the critical mindset required to reflect about the risks of AI systems for Human Rights principles which could potentially be supported by tools such as AI Blindspots (Calderon et al. 2019). Here, the participants stressed the value of extending a risk-based approach (i.e. stressing the potential for harm of AI systems) to include a Human Rights-promoting approach, i.e. to focus on the ability of AI systems to help duty-bearers and rights-holders to realise and support Human Rights principles. Further, more technical and thus engineering-specific tools such as tools supporting data or model documentation (Gebru et al. 2021; Mitchell et al. 2019) were recommended by our participants to enable engineers to anchor the learned content more concretely in their daily practice and to motivate consistent application. Further, concrete reflections about the environmental impact of training algorithms on large datasets were considered to be useful to create a general awareness that code does affect the world we live in.

Longer-Term Actions. This category describes reactions that require some type of culture change or more planning and thus has more delayed outcomes. Our participants recognized the importance of community engagement but noted its difficulty to be applied in current design practices due to time and resource constraints (also found by Cave and ÓhÉigeartaigh 2018). Longer timelines, especially in initial stages of the AI pipeline such as during objective setting would be required to involve affected communities to reflect on their needs and collaboratively decide on the objective of a system. Further, teaching such community involvement was reported as challenging since most courses are classroom (vs project-) based, i.e. of theoretical nature. Encouraging students to consider non-technical solutions (i.e. how could the objective be achieved without or additionally to a technological solution?) was identified as a beneficial teaching method to unlock a less techno-centric approach.

Additionally, we found a severe lack of awareness regarding the requirements of recent regulations such as the Human Rights Impact Assessment (HRIAs) in the EU AI Act: participants with a very technical background were familiar with technical tests and audits but had not considered HRIAs. Since HRIAs are ideally conducted prior to creating any code (Leslie et al. 2022), the workshop participants concluded that a shift in focus and time allocation is required, i.e. to move from a main focus on code and technical measures towards early and ongoing involvement of affected communities. Here, the link to regulatory requirements was perceived as crucial to inflict such change.

Open Questions for Future Research. This category concerns open questions that have to be answered by academia before targeted interventions can be derived. Participants raised the concerns that the abstract nature of some Human Rights questions may not seem immediately relevant to technical tasks, potentially hindering student engagement. Human rights principles might be seen as too generic to be readily integrated into IT and software engineering training. Thus, we invite future research to identify pedagogical strategies that make Human Rights considerations more engaging and relevant to AI students, as well as more specific and actionable.

By identifying key considerations, barriers, and potential interventions, the workshop contributes to the further alignment of engineering practice with a Human Rights-based approach to AI development.

8 SUMMARY

Engineering educators have an especially crucial role in helping students develop ethical AI through their technical work and in teaching best practices to the next generation. The take-home message for session participants is that a Human Rights-based approach to AI development is essential for creating AI systems that are ethical, fair, respectful of human dignity. With the knowledge and skills provided in this workshop, participants will be able to integrate Human Rights considerations into their teaching and research, and contribute to the creation of AI systems that benefit society.

REFERENCES

Assembly, United Nations General. 1949. *Universal Declaration of Human Rights*. Vol. 3381. Department of State, United States of America.

Brest, Paul. 2010. “The Power of Theories of Change.” *Stanford Social Innovation Review* 8:4751. https://doi.org/10.48558/NPZS-C374.

Buckley, Carina, and Maria Kukhareva. 2021. “Making Inspiration Mainstream: Innovative Pedagogies for the Real World.” In *Applied Pedagogies for Higher Education: Real World Learning and Innovation across the Curriculum*, edited by Dawn A. Morley and Md Golam Jamil, 269–97. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-46951-1_12.

Calderon, A., D. Taber, H. Qu, and J. Wen. 2019. “AI Blindspot: A Discovery Process for Spotting Unconscious Biases and Structural Inequalities in AI Systems.”

Cave, Stephen, and Seán S. ÓhÉigeartaigh. 2018. “An AI Race for Strategic Advantage: Rhetoric and Risks.” In *Proceedings of the 2018 AAAI/ACM Conference on AI, Ethics, and Society*, 36–40. AIES ’18. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3278721.3278780.

Chouldechova, Alexandra, Diana Benavides-Prado, Oleksandr Fialko, and Rhema Vaithianathan. 2018. “A Case Study of Algorithm-Assisted Decision Making in Child Maltreatment Hotline Screening Decisions.” In *Proceedings of the 1st Conference on Fairness, Accountability and Transparency*, edited by Sorelle A. Friedler and Christo Wilson, 81:134–48. Proceedings of Machine Learning Research. PMLR. https://proceedings.mlr.press/v81/chouldechova18a.html.

Drage, Eleanor, and Kerry Mackereth. 2022. “Does AI Debias Recruitment? Race, Gender, and AI’s ‘Eradication of Difference.’” *Philosophy & Technology* 35 (4): 89. https://doi.org/10.1007/s13347-022-00543-1.

Dressel, Julia, and Hany Farid. 2018. “The Accuracy, Fairness, and Limits of Predicting Recidivism.” *Science Advances* 4 (1): eaao5580. https://doi.org/10.1126/sciadv.aao5580.

Fund, UN Populations. 2005. “Human Rights Principles.” https://www.unfpa.org/resources/human-rights-principles.

Fuson, Karen C. 2009. “Avoiding Misinterpretations of Piaget and Vygotsky: Mathematical Teaching without Learning, Learning without Teaching, or Helpful Learning-Path Teaching?” *Cognitive Development* 24 (4): 343–61. https://doi.org/10.1016/j.cogdev.2009.09.009.

Gebru, Timnit, Jamie Morgenstern, Briana Vecchione, Jennifer Wortman Vaughan, Hanna Wallach, Hal Daumé III au2, and Kate Crawford. 2021. “Datasheets for Datasets.”

Group, UN Sustainable Development. 2020. “Human Rights-Based Approach.” https://unsdg.un.org/2030-agenda/universal-values/human-rights-based-approach.

Heikkilä, Melissa. 2022. “Politico: Dutch Scandal Serves as a Warning for Europe over Risks of Using Algorithms.” https://www.politico.eu/article/dutch-scandal-serves-as-a-warning-for-europe-over-risks-of-using-algorithms/.

Holland, Sarah, Ahmed Hosny, Sarah Newman, Joshua Joseph, and Kasia Chmielinski. 2018. “The Dataset Nutrition Label: A Framework To Drive Higher Data Quality Standards.”

Ibáñez, Javier Camacho, and Mónica Villas Olmeda. 2022. “Operationalising AI Ethics: How Are Companies Bridging the Gap between Practice and Principles? An Exploratory Study.” *Ai & Society* 37 (4): 1663–87.

Jobin, Anna, Marcello Ienca, and Effy Vayena. 2019. “The Global Landscape of AI Ethics Guidelines.” *Nature Machine Intelligence* 1 (9): 389–99.

Kawakami, Anna, Venkatesh Sivaraman, Hao-Fei Cheng, Logan Stapleton, Yanghuidi Cheng, Diana Qing, Adam Perer, Zhiwei Steven Wu, Haiyi Zhu, and Kenneth Holstein. 2022. “Improving Human-AI Partnerships in Child Welfare: Understanding Worker Practices, Challenges, and Desires for Algorithmic Decision Support.” In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. CHI ’22. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3491102.3517439.

Leslie, David, Christopher Burr, Mhairi Aitken, Michael Katell, Morgan Briggs, and Cami Rincon. 2022. *Human Rights, Democracy, and the Rule of Law Assurance Framework for AI Systems: A Proposal*. Zenodo. https://doi.org/10.5281/zenodo.5981676.

McNamara, Andrew, Justin Smith, and Emerson Murphy-Hill. 2018. “Does ACM’s Code of Ethics Change Ethical Decision Making in Software Development?” In *Proceedings of the 2018 26th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering*, 729–33.

Mitchell, Margaret, Simone Wu, Andrew Zaldivar, Parker Barnes, Lucy Vasserman, Ben Hutchinson, Elena Spitzer, Inioluwa Deborah Raji, and Timnit Gebru. 2019. “Model Cards for Model Reporting.” In *Proceedings of the Conference on Fairness, Accountability, and Transparency*. FAT* ’19. ACM. https://doi.org/10.1145/3287560.3287596.

Mujtaba, Dena F., and Nihar R. Mahapatra. 2019. “Ethical Considerations in AI-Based Recruitment.” In *2019 IEEE International Symposium on Technology and Society (ISTAS)*, 1–7. https://doi.org/10.1109/ISTAS48451.2019.8937920.

Munn, Luke. 2023. “The Uselessness of AI Ethics.” *AI and Ethics* 3 (3): 869–77.

Obermeyer, Ziad, Brian Powers, Christine Vogeli, and Sendhil Mullainathan. 2019. “Dissecting Racial Bias in an Algorithm Used to Manage the Health of Populations.” *Science* 366 (6464): 447–53.

Rakova, Bogdana, Jingying Yang, Henriette Cramer, and Rumman Chowdhury. 2021. “Where Responsible AI Meets Reality: Practitioner Perspectives on Enablers for Shifting Organizational Practices.” *Proceedings of the ACM on Human-Computer Interaction* 5 (CSCW1): 1–23.

Rights, UN Office of the High Commissioner for Human. 2024. “International Human Rights Law.” https://www.ohchr.org/en/instruments-and-mechanisms/international-human-rights-law.

Sadek, Malak, Emma Kallina, Thomas Bohné, Céline Mougenot, Rafael A Calvo, and Stephen Cave. 2024. “Challenges of Responsible AI in Practice: Scoping Review and Recommended Actions.” *AI & SOCIETY*, 1–17.

U.N. 2020. “Landmark Ruling by Dutch Court Stops Government Attempts to Spy on the Poor – UN Expert.” *U.N. Special Rapporteur on Extreme Poverty and Human Rights*, May 2, 2020. https://www.ohchr.org/en/press-releases/2020/02/landmark-ruling-dutch-court-stops-government-attempts-spy-poor-un-expert?LangID=E&NewsID=25522.

Yanitsky, Oleg. 2020. “Toward the Interdisciplinary Theory and Research.” *Creative Education* 11 (03): 206–19. https://doi.org/10.4236/ce.2020.113015.

SORTING SKILLS: CURRICULUM PROFILES AND THE FORTHCOMING SEFI HANDBOOK

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ABSTRACT

Building on the coherency of activities within the Special Interest Group (SIG), Engineering Skills SIG proposes a workshop with three distinct goals: (1) explore the usefulness of a method for determining the relative importance of different skills for future engineers, (2) discuss the skills framework proposed in the forthcoming SEFI handbook on teaching competencies & skills in engineering, and (3) generate "curriculum skills profiles" that can be further used to guide curriculum development. Participants of the workshop will be asked to sort skills proposed by the forthcoming handbook in a pre-set grid, and then reflect on their choices, definitions and implications in terms of the impact on teaching and coherence in institutional leadership. We will experiment with a hands-on method inspired by educational research, through which we will gain individual and collective insights. This will make the basis for a pertinent discussion on clustering and categorising skills. To generate results that we can all discuss within the workshop time, a simple visual analysis will be done aiming to create "curriculum skills profiles" that can inform curriculum development tailored towards educating a responsible engineer.

1 INTRODUCTION

Over several years, the Engineering Skills Special Interest Group (SIG) has engaged in understanding: the skills that students need to prepare them for the future, the stakeholders involved in skill development; and how different methods of teaching skills have been successful in different settings.

Following the skills survey launched by the Engineering Skills SIG during SEFI 2021, the SIG workshops facilitated at SEFI 2022 and 2023 focused on gathering insight into: the most relevant skills and the challenges involved in their teaching through joint discussions on “what”, “who” and “how” perspectives[1]. This work resulted in an overview of the most important professional and technical skills regarding the disciplinary background of the participants and the country of their home institution. Most needed are communication skills and system thinking skills - across all disciplines. We also inquired which skill might be least relevant and found that these are skills that can be delegated to a specific position, i.e. data, cyber, and network security might be provided by a professional and therefore must not be ensured by everybody within an organisation. Lastly, we discussed which skills are emerging and will become most relevant in the future. Here, we found that results rely more heavily on context but generally may be clustered as interdisciplinary and teamwork skills as well as professional responsibility including ethical, social, technological, intellectual, and global responsibility.

Within the SIG, through a collective generation of knowledge, we are also aware that there are other skills frameworks, each fitting their purposes, for instance:

- OECD Key Competencies [2]
- Future Skills [3]
- Education for Sustainable Development [4]
- European Commission’s Lifecomp [5]
- European Unions’ GreenComp [6]
- Inner Development Goals [7]

While these frameworks work well in their context and for the intended purpose, evidence from education sciences points both to the necessity to combine the context with the reform, and to the role of stakeholder engagement in enacting changes to teaching [8]. With this in mind, the workshop proposed an experimental technique to potentially profile the specific engineering discipline, or an entire institution, and provided an appropriate proposal of skills development based on the evidence-based profile.

In the workshop, we combined two things: a list of skills proposed in SIG’s forthcoming SEFI “Handbook on Teaching Competencies & Skills in Engineering” (working title), and an experimental workshop design for sorting skills to understand how they can be clustered and spring the conversation towards potential disciplinary or institutional profiling.

2 WORKSHOP DESIGN

Inspired by Q methodology [9], the workshop used Q sorts to inspire participants' subjective reflection on how to assign importance to a set of skills in a sorting tool (Figure 1). The tool works with fixed distribution and invites participants to place the input where they find it best suited.

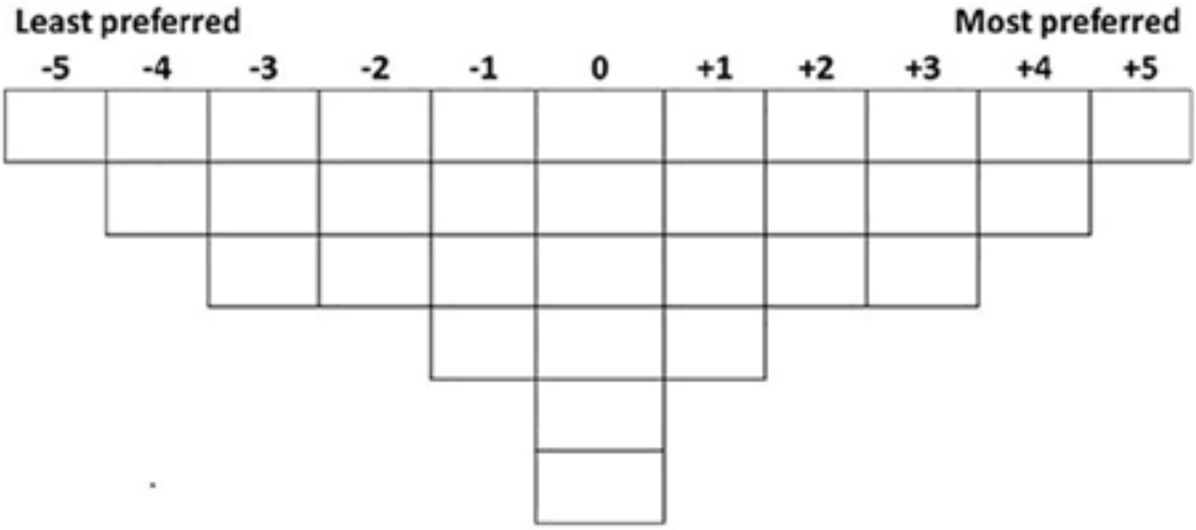

Fig 1. The distribution grid for Q sorts

We used the input of one of the core activities of the SIG, the forthcoming Handbook proposal, and instead of statements (which would be the usual approach in Q-methodology) we asked participants to sort skills based on their subjective understanding of the skill and terminology. The input was the skills selected by the Handbook working group.

The skills were colour-coded based on skill groups suggested within the Handbook. This stimulated the discussion about the different clustering and profiling of skills.

Workshop outline:

Activity	Description	Time
Introduction	Welcome to the session and a brief introduction to the Engineering Skills SIG and the outline of the workshop.	5’
Sorting	Participants receive pre-prepared sorting grids and sets of skills as input for the sorting activity. Participants take time to individually sort the skills.	10’
Arranging	Each participant lays out their input so that there is an overview of all of them (depending on the physical space, it can be a table, floor or empty wall)	5’
Collaborative analysis	First glance at the outcomes and thoughts on what the input can show us	10’

Discussion	Deeper discussion on meaning of skills, skill combinations, profiling	20’
Closure	Take-aways for individuals, Engineering Skills SIG, and institutions	10’

3 RESULTS

This workshop aimed to attract practitioners, researchers and students who wish to reflect on our choices when assigning importance to certain skills and how those choices might help us describe curriculum profiles. It also invited participants to peek into the forthcoming Handbook and support its further quality through a peer discussion.

Typically, the results of the Q-sort involve a physical distribution of sorted objects, and they can be followed up with a 'think-out-loud' narrative or a discussion. Even though we had an engaging group discussion to try to visually cluster the “curricular profiles” after the individual Q-sorting was done, we did not document all of the group discussions systematically. We thus focused on the collected skills Q-sorts from 25 participants. The workshop participants included engineering education practitioners, researchers, and a few students. We used a free web tool for visualizing clustering of multivariate data called ClustVis [10], to generate heatmaps and identify potential clusters among the skills profiles as well as skills groupings. The tool itself also creates a Principal Component Analysis (PCA) plot, which shows no obvious clusters, mostly because the data shown here contains only 18 points (Figure 2).

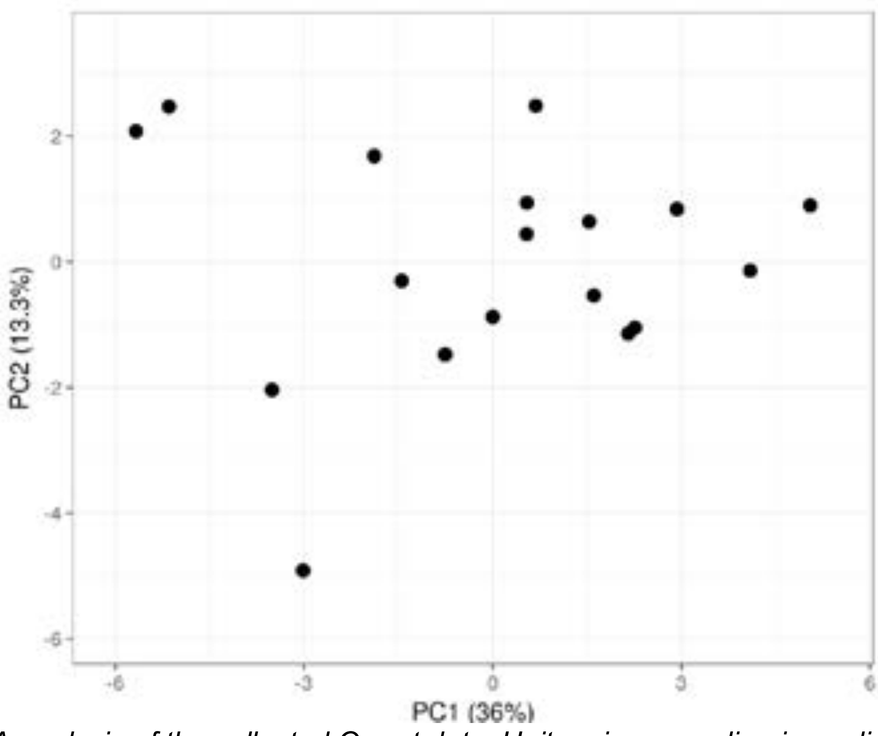

Fig 2. PCA analysis of the collected Q-sort data. Unit variance scaling is applied to rows; SVD with imputation is used to calculate principal components. X and Y axis show principal

component 1 and principal component 2 that explain 36% and 13.3% of the total variance, respectively. N = 18 data points, corresponds to the 18 skills given as an input for Q-sort

We proceeded to do a hierarchical clustering of the data, using the Euclidean distance and Ward's method, often recommended for Q-sort normally distributed data because it focuses on minimizing variance, which aligns with the distribution characteristics. The clusters of both dimensions (skills and respondents) were merged based on minimizing the increase in total within-cluster variance after merging, allowing us to see compact clusters. The use of Euclidean distance is sensitive to outliers and emphasizes differences in magnitude, which we assume we might have both when thinking of a diverse set of 25 respondents, and the 18 skills that were proposed. Finally, we forced the creation of 4 clusters, on both axes. Other combinations can easily be deciphered from looking at the dendrograms, tree-like linkage visualisations between different skills and respondents.

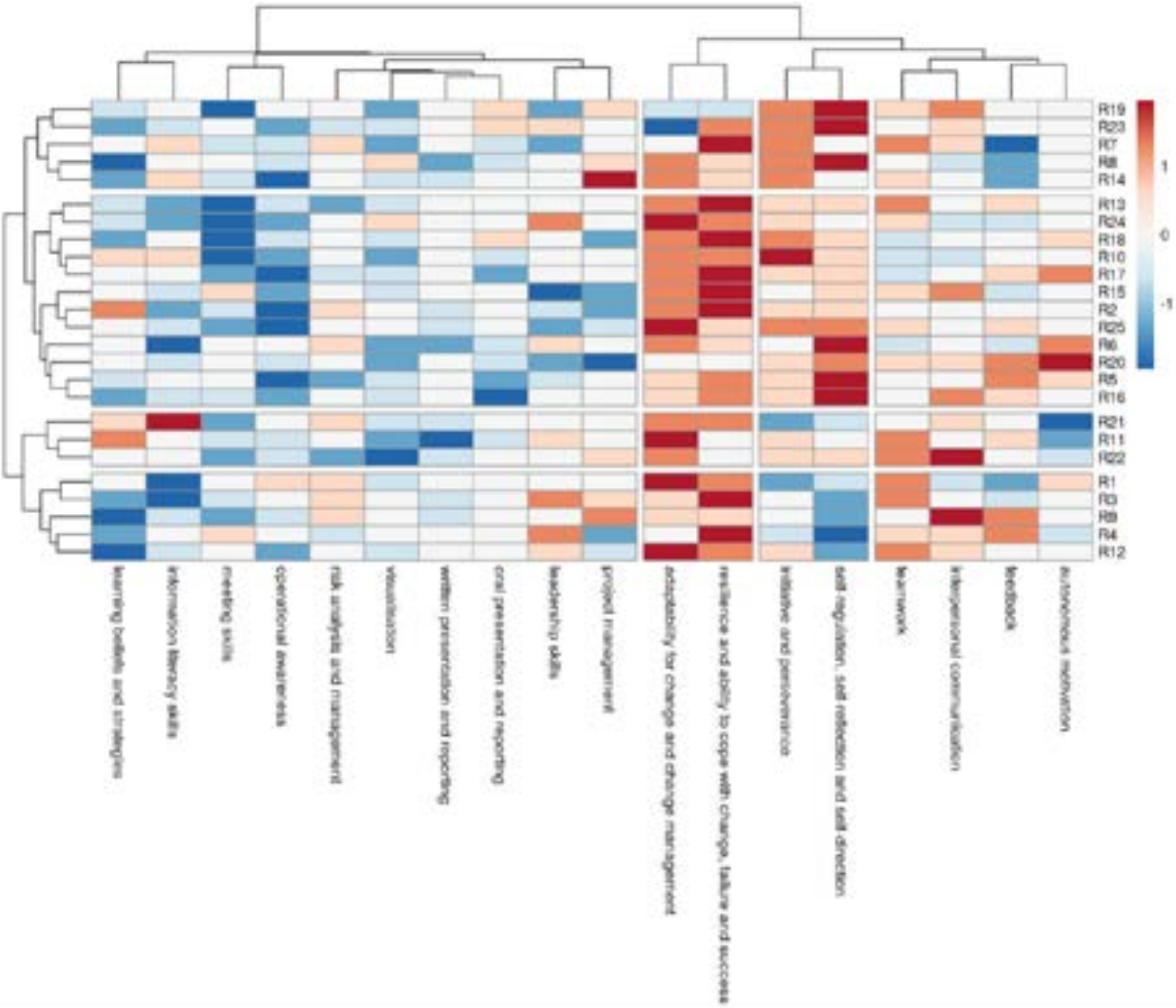

Fig 3. Hierarchical clustering of the collected Q-sort data. Euclidean distance and Ward's method were used to generate the heatmap and dendrograms to force the clustering of skills and respondents into 4 clusters each. The heatmaps represent the answers of each respondent - from dark red which indicates greatest importance (+3), over white (0), to dark blue which indicates the lowest importance (-3) for each of the 18 skills

As seen in Figure 3, the clustering of the 18 skills into 4 clusters based on the data collected through Q-sorting shows the following:

1. **Adaptability for change** and **resilience** are grouped together and shown to be by large the skills respondents found the most important
2. **Initiative/perseverance** and **self-regulation** are also grouped together and deemed important, though only by roughly ⅔ of respondents
3. **Teamwork**, **interpersonal communication**, **feedback** and **autonomous motivation** are grouped together, and mostly deemed slightly important or relatively less important
4. **Learning beliefs**, **information literacy**, **meeting skills**, **operational awareness**, **risk analysis**, **visualisation**, **written and oral presentation** and **leadership** and **project management** are grouped together in the final cluster, which is deemed less important.

This clustering reveals that some of the skills proposed in the Handbook might be merged, as they might be considered very similar or indistinguishable. It might also be used to revise the suggested grouping of skills proposed for the Handbook.

Looking at the potential "curricular profiles" that we might decipher from the 4 clusters of respondents, we can see the following:

1. The most different group (5 respondents) highly values **initiative/perseverance** and **self-regulation,** followed by **teamwork, interpersonal communication, feedback and autonomous motivation**.
2. The group that is very closely related (3 respondents) differs from the previous one because of their emphasis on **learning** and **self-regulation**.
3. Large cluster that contains two groups (12 respondents and 5 respondents) put a lot of emphasis on **initiative/perseverance** and **self-regulation,** and **adaptability for change** and **resilience.** The difference between these two groups is the relative importance of **teamwork**, **interpersonal communication**, **feedback** and **autonomous motivation.**

We can start to suggest that if we take out the overall perceived high importance of dealing with change in all groups, "curricular profiles" could be focusing more on self-regulation, self-reflection and self-direction on one hand, or on skills related to the capacity to work in a team.

The workshop provided individual participants to experience and explore the simplified Q-sort method applied to working with engineering skills, as well as discuss attitudes, definitions and general implications when it comes to skills selection. Another outcome was also examining potential skills profiles, ways of clustering and making frameworks and how the method for sorting can help institutions set an aligned approach towards skills, which was done in a discussion.

For the Engineering Skills SIG, the participants of the workshop contributed with giving first-hand feedback on how the skills proposed in the anticipated Handbook are perceived by a larger SEFI community, generating the first examples of skills profiles that could serve as templates to rethink curriculum design, as well as exploring which skills are seen as the most important ones towards educating a responsible engineer. Beyond these, the workshop showed the potential to test the skills discussed in the forthcoming Handbook as valid for other participants who are not part of the Engineering Skills SIG.

REFERENCES

Cooke, N., Manzini, R., Benedetti, M. D., Wint, N., Griffiths, J., Torres, F., Johannsen, T., Winkens, A.-K., Tilley, E., Hawwash, K. and Morar, N. (2023), Who, What, How? Tackling Skills Challenges: Future Relevance, Stakeholder Differences, And Teaching Hurdles

Weinert, F. E. (2001), Concept of competence: A conceptual clarification. Defining and selecting key competencies, Hogrefe & Huber, pp. 45–65

Ehlers, U. (2020), Future Skills: Lernen der Zukunft - Hochschule der Zukunft

Rieckmann, M. (2012), Future-oriented higher education: Which key competencies should be fostered through university teaching and learning?, *Futures* Vol. 44, No. 2, pp. 127–135

Sala, A., Punie, Y., Garkov, V. and Cabrera, G. M. (2020), LifeComp: The European Framework for Personal, Social and Learning to Learn Key Competence. https://publications.jrc.ec.europa.eu/repository/handle/JRC120911. Accessed 30 Apr 2024

Bianchi, G., Pisiotis, U. and Cabrera, G. M. (2022), GreenComp The European sustainability competence framework. https://publications.jrc.ec.europa.eu/repository/handle/JRC128040. Accessed 30 Apr 2024

Jordan, T., Reams, J., Ståine, K., Greca, S., Henriksson, J., Björkman, T. and Dawson, T. (2021), Inner Development Goals: Background, method and the IDG framework. https://drive.google.com/file/d/1s_TQbFreKH13kruxss8aQsbWlxKVFsfK/edit?usp=embed_facebook. Accessed 30 Apr 2024

Viennet, R. and Pont, B. (2017), Education policy implementation: A literature review and proposed framework, OECD, Paris

Duncan Millar, J., Mason, H. and Kidd, L. (2022), What is Q methodology?, *Evid Based Nurs* Vol. 25, No. 3, pp. 77–78

Metsalu, Tauno and Vilo, Jaak. Clustvis: a web tool for visualizing clustering of multivariate data using Principal Component Analysis and heatmap. Nucleic Acids Research, 43(W1):W566–W570, 2015. doi: 10.1093/nar/gkv468

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ESTABLISHING CENTRA FOR ENGINEERING EDUCATION DEVELOPMENT – SHARING EXPERIENCES

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ABSTRACT

At the SEFI conference in Dublin 2023, we presented a paper on our experiences over a period of seven years in setting up a centre for educational development at the Norwegian University of Science & Technology (Lyng et al., 2023). The paper identified barriers and success factors found to be particularly important for establishing and successfully running such a centre. Taking our experience as a starting point for this workshop we will explore what needs, challenges, and opportunities are common to such initiatives.

In two group activities during a one hour workshop participants discussed expectations, experiences, challenges, and opportunities for achieving positive impact. We rounded off the workshop with a list of perceived obstacles and challenges among staff at our university, which we discussed in plenum.

The objective of the workshop was to initiate the establishment of an informal network of educational development units and other interested parties, and to learn from each other in order to promote even more positive impact of such centra.

1 INTRODUCTION

1.1 A Centre for Engineering Education Development – Rationale

At the SEFI conference in Dublin 2023, we presented a paper on our experiences over a period of seven years in setting up a centre for educational development at the Norwegian University of Science & Technology (Lyng et al., 2023). The centre, named Centre for Science & Engineering Education Development (SEED) had originally (in 2016) been very small with only one person associated with it, and had grown slowly over the period.

Among the outcomes of the strategic development project Technology Education of the Future running over several years for the University's STEM-portfolio, the responsible faculties identified a need to improve the educational quality and strengthen the educational competence among academic staff (Øien & Bodsberg, 2022; FTS, from the Norwegian: Fremtidens Teknologi Studier). Top quality engineering education requires that the academic staff be given opportunities to continuously develop their competence, not only in their research fields, but also, critically, with respect to their pedagogic skills and competences. The existing educational support and training had been valued but fell short of the ambitions for the redesign of the educational quality culture. The existing unit for educational support (SEED) was re-organized, upgraded, and more resources allocated.

Considering the range of factors that affect the quality of higher education, it is desirable to share experiences about issues such as capacity and recruitment challenges, coping with diverse faculty cultures, and the need for a shared vision in which to anchor activities and resource use. In our work two particularly pertinent factors for establishing the centre have been identified (Øien & Bodsberg, 2022):

- Who should be invested in the centre's mandate and responsibilities? Which are the interested parties, from the leadership on down, that need to agree on what the engineering programme portfolio and closely related education programmes should achieve?
- How can such a centre be closely aligned and in continuous dialogue with the pedagogical development strategies of the university's study programmes?

Given these two factors, an educational development centre needs to strategically plan and prioritize its resources, and develop its own capacity and competence, to provide support for education-related competence development. To this end, the university needs to develop its systemic and administrative routines to actively support educational quality development, with the centre being able to provide advice in this work. This is in line with Havnes & Stensaker (2015): 'the educational development centre is on its way to be transformed from a merely technical activity focusing on how individuals become good teachers, into having a broader focus in which the organisation, frameworks and infrastructure surrounding the teaching and learning experience is addressed.'

This workshop aimed to set our experiences into perspective as we continue to discuss experiences from the initial stages of recognizing the need for such a centre, to the on-going requirements of successfully running an established education development unit. We also discussed the matter from the perspective of the university's academic staff and perceived obstacles to change.

2 WORKSHOP STRUCTURE

2.1 Intended Learning outcomes and Motivation

The participants in this workshop discussed and reflected upon the need and use for a Centre for Engineering Educational Development, as well as the requirements and challenges of running such a centre, in order to establish a common ground for discussion during the workshop of perceived obstacles and challenges for continuous educational development. The workshop consisted of an introduction to the issues at hand, followed by individual work, group discussions and plenum discussions, before a summary.

First activity (10 minutes):

The participants were asked to discuss in groups and write down their suggestions on:

- What do you expect from an Engineering Education Development centre?
    - What are the specific functions and competences needed in order to establish an Engineering Education Development centre? What staff competences are desired or needed? What staff support is desired or needed? How can such support be provided?

The activity was designed to focus the participant's minds on the question of the desired functions and support of such a centre. Among the suggestions discussed were:

- A general recognition of the desired practical support for teachers, including *"Teaching practical skills to teachers"*, establishing a *"Mandate to teachers to develop"*. It was pointed out that this included the need to *"Scaffold and support [of] new teachers with a team to begin with"*, and that the centre needed to *"Be available both to individual teachers and programs/departments"*.
- It was also recognized by the participants that it was desirable to work towards *"Changing attitudes towards teaching"*, simultaneously recognizing that there often is *"Not more money for good education – (only) for research"*.
- A third point made was the need for a centre to be seen as *"Collaborators"*, and that this required both having *"Critical mass"*, and being *"Credible – […] Academics will listen more to physicists (say) teaching physics than education specialists"*.
- Finally it was considered necessary to have *"Faculty buy-in"*.

Second activity (25 minutes):

The participants were again asked to discuss in groups and write down their suggestions on:

- If you wish to develop the teaching competence of educators and the overall quality of education… What may the practical barriers & challenges be?

After the group discussions we discussed the (many) points made before continuing with a presentation in plenum of our own experiences from asking the staff at our university the very same question. The participant's engagement made for a lively discussion where the second part of the workshop became a dialogue on the subject. We presented the outcome of a similar exercise at our university, where we had asked teachers, study program leaders, heads of departments, and faculty leadership about their views on barriers and challenges. Here we present the answers from our staff at NTNU together with the comments from the workshop at SEFI.

The most common perceived barriers and challenges identified by SEED at NTNU can be grouped in five categories:

1. Lack of *time* and *resources*
2. Unsuitable *administrative routines and systems*
3. Too few systemic *arenas* or *fora* for organizational dialogue
4. Strong tradition for *course- and content-driven* development
5. Culture for privatized and individualized course development and execution

The comments made by the participants at the workshop were in good agreement with these categories, as can be seen below.

Lack of *time* and *resources* – both on a systemic level and for individual educators (teachers and programme managers).

When we looked closer at the comments made by staff at our university we found that the stated lack of time and resources could to some extent be understood as vicarious arguments for other underlying phenomena, at least partly, such as a lack of prioritization ('Research is more important'); or a lack of education-related competence ('We don't know what to do, or how to do it'); or a lack of understanding of the overarching FTS message ('The FTS reports are so long and complicated'); or, finally, a lack of motivation ('I don't think this is really necessary'). Or possibly, a mix of all of these underlying phenomena.

The points made by our staff was clearly reflected in the comments made by the participants during the group session in the second activity:

- *"Time: Teachers don't have time to work on education innovation"*
- *"Academics don't want to spend time on teaching –give me skills to do 'just enough'."*
- *"Resistance to collaboration, because it takes time"*

The participants also identified the challenges involved in reaching teaching staff with offers of support: *"We always get the usual suspects – hard to get those who need it"*,and *"Difficult to get attendance to trainee".*

It can be argued that there is a need to further investigate the underlying aspects of "Lack of time and resources" if support is to be tailored to the actual needs of staff and organisation.

Unsuitable *administrative routines and systems*

This includes unclear roles and responsibilities in some educational quality processes, and mismatch between roles, mandates, and responsibilities and the time, resources, and incentives available, in particular for study programme directors. Also mentioned was the design of current support systems, quality system routines, and process deadlines which do not support and sometimes even counteract, the desired systemic changes outlined in the project Technology Education of the Future (the FTS project).

The participants at the workshop echoed this, identifying the need for:

- *"Silos for edu[cational] support, innovation, and research [that] borders faculties"*
- *"Status of education"; "Reward and recognition"; "HR and rewarding"*

This is an aspect that has also been highlighted by the work on Curriuculum Agility, published by Suzanne Brink et al. (2024), where several organisational aspects of Curriculum Agility have been identified as important aspects of educational development.

Too few systemic *arenas* or *fora* for organizational dialogue

An aspect identified by our staff is the need for systemic meeting places for organisational dialogue, which effectively hinders learning across departments and faculties about educational development, in turn contributing to a lack of common understanding and hindering development of a common quality culture.

The participants at the workshop identified the need for

- *"Bringing teachers together to take initiatives together"*
- *"More talking and dialogue to get people together to form a culture"*
- *"Platform for sharing knowledge" and "Network[ing]"*

Strong tradition for *course- and content-driven* development

In addition our staff acknowledged a strong focus on courses and contents, rather than the *programme- and competence-driven* development advocated in the FTS-project recommendations.

The participants at the workshop recognized this or similar challenges as follows:

- *"Atomisation of courses"*
- *"Course [lacks] link to curriculum"*
- *"Segregation of courses makes overall quality development time-consuming"*
- *"Difficult to get good connections between courses – due to autonomy (closed doors)"*

This tradition is also strongly associated with a culture characterized by strong individual teacher autonomy, leading to what might be called ‘privatisation’ of teaching duties and course development:

Culture for privatized and individualized course development and execution

Here the participants were clear that often occurring mindsets presents additional challenges:

- *“Barrier – Culture of individual lecturing”*
- *“No one should tell me what to do and how to do it!”*
- *“Thinking that you have to teach the way you were taught (or that is the only way).”*

The participants also pointed out challenges that arose from the need for teachers to engage in lifelong learning as teachers, as exemplified by *“Students being more advanced in AI, etc.”*, *“Teachers with limited competence outside their discipline”*, and *“Teaching out of area”*, as a result of the focus on content within the teachers discipline only, rather that the need for our students to master the discipline in the context of their professional learning outcomes for the programme.

Overall, the comments made by the participants and the comments we collated from our staff were in good agreement with respect to perceived obstacles and challenges for educational support and development. It is clear to us that there is a need not only for such educational support units that we have established, but also that it is necessary to address also systemic and organizational obstacles and challenges for lasting and sustainable development to take place, and also that creating a network of educational support units between universities is desirable.

Final activity (5 minutes):

We collected contact information and invited the participants to contact us in order to initiate the sharing of experiences on all aspects of establishing, running, and developing an educational support centre. We are happy to report that a first meeting will take place during October of this year, and that we hope to come back with a report from our activities at the next SEFI conference in 2025.

REFERENCES

Brink, S.C. , de Hei, M., Sjoer, E., Carlsson, C.J., Georgsson, F., Keller, E., McCartan, C., Enelund, M., Lyng, R. & Admiraal, W (2024) “Curriculum Agility principles for transformative innovation in engineering education”, European Journal of Engineering Education, https://doi.org/10.1080/03043797.2024.2398165

Havnes, A. & Stensaker, B. (2006). “Educational Development Centres: From Educational to Organisational Development?”. *Quality Assurance in Education*, 14 (1): 7–20.

Lyng, R., Korpås, G. S., Hansen, G., & Øien, G. E. D. (2023). “Realising A Centre for Educational Development: Experiences, Challenges, Lessons Learnt, and Future Ambitions”. Proceddings of the 51st Annual Conference of the European Society for Engineering Education 2023, 2409-2417. https://doi.org/10.21427/Z7VC-AG22

Øien, G.E.D. and Bodsberg, N.R. (2022). “A Roadmap for Engineering and Technology Education Reform at the Norwegian University of Science and Technology (NTNU)”. Paper presented at *SEFI 2022: 50th Annual Conference of The European Society for Engineering Education*, Barcelona, Spain, Sept. 2022. https://doi.org/10.5821/conference-9788412322262.1255

DEVELOPING EFFECTIVE PRACTICES FOR SUPPORTING ENTERING DOCTORAL STUDENTS

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Conference Key Areas: *Diversity, equity and inclusion in our universities and in our teaching, Building the capacity and strengthening the educational competences of engineering educators*
Keywords: *graduate students, advising, diversity*

ABSTRACT

Successful transition into doctoral degree programs is critical to helping students tackle the challenges germane to this degree and completing their degrees in a timely manner. However, the specific challenges vary as graduate education depends on contextual factors such as discipline, department, institution, and local, national, and international educational environments. Accordingly, a variety of resources and strategies have been implemented to support students within the transition to doctoral degrees. However, little research has emerged regarding what works in specific contexts and why. This workshop provides a starting point for developing this understanding by promoting conversations on practices currently used at both the individual advisor level and the department, college, university, etc.

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(hereafter referred to as institutional level) to support students in transitioning into doctoral degree programs.

1 MOTIVATION AND LEARNING OUTCOMES

1.1 Motivation

Doctoral education remains critical to scientific advancement across all domains, including engineering, as outcomes include people prepared to engage in research and the research products themselves (e.g., European University Association 2022; National Academies of Science Engineering and Medicine 2018). However, the doctoral journey is not always easy and requires attention as to how we support students in skill development and degree completion (e.g., European University Association, 2022; National Academies of Science Engineering and Medicine, 2018, National Science Foundation 2023). Successful transition into doctoral degree programs is critical to helping students tackle the challenges germane to this degree and completing their degrees in a timely manner. However, the specific challenges vary as graduate education depends on contextual factors such as discipline, department, institution, and local, national, and international educational environments. Accordingly, a variety of resources and strategies have been implemented to support students within the transition to doctoral degrees. However, minimal research has emerged regarding what works in what contexts and why. This workshop provides a starting point for developing this understanding by promoting conversations on practices currently used at both the individual advisor level and the department, college, university, etc. (hereafter referred to as institutional level) to support students in transitioning into doctoral degree programs. While organizations such as the Council of Graduate Schools in the United States and European University Association in Europe discuss graduate education across all disciplines there is less focus specifically on engineering.

1.2 Learning Outcomes

As a result of this workshop, participants will be able to:

- describe resource/support needs for different student populations transitioning into doctoral programs;
- articulate ways that individuals and institutions can support students transitioning into doctoral programs; and
- identify approaches to support students transitioning into doctoral programs already being used by others that may be salient to their own context.

2 BACKGROUND, RATIONAL, AND RELEVANCE

Helping students successfully complete doctoral degrees in a timely manner requires supporting students in getting off to a good start. This includes helping students understand the doctoral degree process and expectations. However, this seemingly simple idea is complicated by the fact that doctoral programs and doctoral student experiences are variable and depend on contextual factors such as discipline, department, institution, and local, national, and international educational environments (e.g., Becher & Trowler,1989; Biglan,1973; European University Association,2022; Ferrer de Valero 2001; Gardner 2009, 2010; Golde 2005). Differences in doctoral experiences are also found based on student characteristics such as background and demographics (National Academies of Science Engineering and Medicine 2018). For example, studies on graduate education in the United States have shown that doctoral engineering degree completion rates are lower and degree completion takes longer for historically marginalized students (National Science Foundation 2023). These differences mean that there is not a one-size-fits-all approach to developing resources and supports for doctoral students, consequently different approaches may be needed in different contexts and/or for students with different background characteristics.

Accordingly, a variety of support programs and resources have emerged that focus on this transition period. For example, Tufts University in the United States has a news article promoting the importance of getting off to a good start and sharing campus resources: https://asegrad.tufts.edu/news-events/news/transitioning-your-graduate-program-importance-time-management-and-self-care-graduate-students. Similarly, the University of Saskatchewan has a resources website: https://cgps.usask.ca/onboarding/transition/transitioning-to-grad-school.php. An Australian University has a program called Transition In which is embedded in their curriculum (White 2023). Columbia University has a Bridge to the Ph.D. in STEM Program (https://bridgetophd.facultydiversity.columbia.edu/) that is a support program outside of the curriculum. Recognizing the important role of the advisor in the doctoral journal, programs such as the Center for Improvement in Mentored Experiences in Research (CIMER, https://cimerproject.org/) focus on improving individual mentoring.

Because transition is recognized as critical, programs have also emerged to incentivize universities to create and provide transition support. For example, the Bridge to the Doctorate competitive funding opportunity provided by the National Institutes of Health in the United States encourages development of support programs for students. As another example, our research team has created a train-the-trainer program to help engineering colleges run a program that prepares historically marginalized doctoral students for the transition to the PhD. Our particular program [name de-identified for review] consists of workshops are intended to be held just before students start their graduate programs and into that first Fall semester. This workshop structure was designed and grounded in research on doctoral student development and has been tested across multiple institutional contexts for replicability.

Even with a structure designed to support students, and to motivate institutions to do so, what effective and appropriate support should look like remains a moving target. The graduate education landscape is constantly changing and there is a need to continually examine which students the support programs are serving, how the students are being served, and whether it is effective. To that end, this workshop provides an opportunity for researchers, educators administrators and graduate students to engage in an international sharing of practices regarding helping engineering students transition into doctoral programs. By collaborating across geographical, institutional, and disciplinary boundaries, we hope to challenge participants to think creatively and perhaps challenge perceived constraints by sharing ideas that work for students from different backgrounds and in a variety of contexts.

3 WORKSHOP DESIGN

Because graduate education is not a one-size-fits-all endeavour, this workshop has been designed to engage participants in rich, interactive discussion on effective means for helping graduate students transition into doctoral degrees in engineering. The timing and content of this 60-minute workshop are as follows:

5 min — Welcome and Overview: Introduction to the workshop and establishing a shared definition for supporting students transitioning into graduate school.

10 min — National Contexts: Input from audience members to identify national/regional contexts and demographic considerations relative to degree requirements for graduate education.

5 min — Intervention Results: Brief description of our intervention structure, outcomes to date, and challenges emergent from changing political climates in the United States.

15 min — Small Group Discussion and Sharing of Ideas and Practices:

- In your research group/lab, how do you help students transition into doctoral work? Why do you take this approach?
- What programs/resources exist in your department, college, university, etc. to help students transition into doctoral work?
- What current contextual factors, if any, are influencing your approach?
- What supports/resources do you wish existed for your students?

15 min — Reporting out from Small Groups Discussion and Sharing

- Create a collective list of individual and institutional resources and practices;
- Identify shared and unique contextual factors influencing on-boarding practices;
- Generate a list of support needs/opportunities.

10 min — Next Steps: Opportunity for networking across institutions and contexts to learn more about specific ideas or practices.

4 RESULTS OF THE WORKSHOP

Our workshop had a small but engaged group of participants from multiple universities. Country contexts included the Czech Republic, Sweeden, Switzerland, and the United States. Participants represented various roles within higher education including administrative, faculty, and graduate student.

Collectively the group identified individual support systems for helping students transition into the PhD including lab/research group meetings, setting expectations and practical guidelines for degree success, and ensuring sufficient mentoring which is sometimes scaffolded by postdocs or peer graduate students. Department, college and/or university resources included voluntary or compulsory seminars or classes for students that introduce topics such as ethics, publishing, scientific writing, and effective ways to engage with others, departmental level mentoring programs, and a welcome center focussed on supporting international students.

A common context participants considered when developing support practices are the needs of international students and helping them navigate language barriers and developing understanding differences in administrative processes. A unique context discussed extensively is one where students are hired by the University as junior colleagues and faculty advisors engage in significant training and apprenticeship before they advise such students. This sits in contrast to models where individual faculty or units fund/support students.

Regarding desired support systems for helping students transition to the PhD, participants agreed that more institutional support is needed. Specific ideas included centralized professional development, more time allocations for supervising graduate students, and offering a fellowship year so students can focus on their own needs and getting off to a solid start.

At the end of the session, we asked participants to indicate one thing they learned that they would continue to think about. Several participants indicated learning about other contexts and specifically advisor training and expectations and reasons students pursue degrees and/or drop out of degrees in different settings. Participants also recognized a need to set expectations for students and for faculty in advising processes as well as considering the tension of graduate students as students but also as University employees and how some contexts prioritize one over the other.

5 SIGNIFICANCE OF THE WORKSHOP

With constantly changing political landscapes around the world, this workshop will provide an important avenue for sharing of ideas for supporting students in the transition into engineering doctoral programs that cross local geographical, institutional, and disciplinary boundaries. We generated a collection of practical approaches that engineering education stakeholders (faculty, administrators, graduate students) can leverage and adapt for local use.

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REFERENCES

Becher, T., & Trowler, P. Academic Tribes and Territories: Intellectual Enquiry and the Cultures of Disciplines. Milton Keynes Society for Research into Higher Education, (2001).

Biglan, A. “The Characteristics of Subject Matter in Different Academic Areas.” *Journal of Applied Psychology*, 57(3), (1973).

Council of Graduate Schools. Completion, PhD and Attrition: Analysis of Baseline Program Data from the Ph.D. Completion Project, (2007).

European University Association. Building the Foundations of Research: A Vision For the Future of Doctoral Education in Europe. Geneva, Switzerland, (June, 2022).

Ferrer de Valero, Y. "Departmental Factors Affecting Time-to-degree and Completion Rates of Doctoral Students at One Land-Grant Research Institution." *The Journal of Higher Education*, 72(3), (2001), 341–367. https://doi. org/10.2307/2649335

Gardner, S. K. "Conceptualizing Success in Doctoral Education: Perspectives of Faculty in Seven Disciplines." *The Review of Higher Education*, 32(3), (2009), 383–406. https://doi.org/10.1353/rhe.0.0075

Gardner, S. K. "Contrasting the Socialization Experiences of Doctoral Students in High- and Low-completing Departments: A Qualitative Analysis of Disciplinary Contexts at One Institution." *The Journal of Higher Education*, 81(1), (2010), 61–81. https://doi.org/10.1353/jhe.0.0081

Golde, C. M. "The Role of the Department and Discipline in Doctoral Student Attrition: Lessons from Four Departments". *The Journal of Higher Education*, 76(6), (2005), 669–700. https://doi.org/10.1080/00221546.2005.11772

National Academies of Sciences, Engineering, & Medicine. *Graduate STEM Education for the 21st Century.* National Academies Press. Washington, DC. (2018).

National Science Foundation. National Center for Science and Engineering Statistics. *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2023, Special Report NSF 23-315,* (2023). Retrieved from https://ncses.nsf.gov/pubs/nsf23315/.

White, A. "The *Transition In* Framework: Supporting the Transition of Students into Postgraduate Taught Study." *Innovations in Education and Teaching International*, (2023), 1–13. doi:10.1080/14703297.2023.2216682.

SEFI ANNUAL CONFERENCE 2-5 SEPTEMBER 2024 LAUSANNE

CHASING CAREER READINESS: RAISING ENGINEERS FOR CRITICAL AND ETHICAL INFORMATION GATHERING AND ANALYSIS TO SOLVE COMPLEX PROBLEMS

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Conference Key Areas: *Professional and Transversal Skills; Digital Tools including GenAI in Engineering Education*
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ABSTRACT

In a world facing complex challenges intertwined with contradicting goals from diverse stakeholders, training responsible and career-ready engineers is paramount. Intensifying career-readiness dialogues is critical for addressing global challenges and fostering disruptive innovations. A study by NACE[3] (National Association of Colleges and Employers) and a Human Resources Development framework by Boston University[4] revealed new graduates are commonly found lacking in critical thinking competency when compared to entry level professionals; a gap it typically takes five to eight years to overcome. A SEFI 2020 Concept Paper by Kovacs et. al.

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[4] Boston University Human Resources. "Professional Individual Contributor Career Level Guide." Boston University, https://www.bu.edu/hr/manager-resources/compensation/job-framework/career-categories-and-levels/professional-individual-contributor-career-level-guide/. Accessed 1 March 2024

of the EPFL[5] further confirmed the importance of solving this challenge particularly highlighting the importance of intensifying transversal skills training.

This workshop will explore the role of information literacy and the students' ability to discern relevant sources of information responsibly for the development of their critical thinking and the overall career-readiness. The aim was that via a series of moderated discussions, participants would gain a deeper understanding of career-readiness and strategies for training responsible use today's digital tools including Extractive and Generative AI to close the aforementioned competency gaps.

The workshop was hosted and moderated by Elsevier's Mark Natanael, Senior Global Product Manager, and Marta Bracha, Account Manager/Engineering & Geoscience. This report covers the main elements of presentation, discussion, conclusions during the session and additional reflections from the workshop moderators.

1 INTRODUCTION

1.1 Rationale and Learning Outcomes

Chasing career readiness has been an elusive journey for engineers in training and their educators. "What is career-readiness?", "Am I 'Career-Ready'?", "How should one train and mentor career-ready and responsible engineers?"; this workshop is designed to host discussions surrounding the questions above. The objectives of this moderated workshop are as follows:

- Communicate findings on career-readiness study by NACE, Boston University and Elsevier
- Surface the challenges in training students to overcome the largest competency gaps between new graduates and experienced professionals
- Share innovative teaching/training methods that utilize today's digital technology landscape responsibly during the open discussion
- Produce agenda for future dialogues to address unresolved challenges.

1.2 Motivation for Attending SEFI and Organising the Workshop

For Marta the main reason for wanting to attend the SEFI conference and organise a workshop in 2024 was to learn about the importance of information literacy and critical thinking to the engineering educator community. For Mark it was essential to highlight the connection between information literacy and producing ethical and career-ready engineers in the age where responsible information gathering is necessary to combat misinformation as part of one's critical thinking competency. So, the moderators were interested to learn more about the challenges in training for information literacy and information gathering, particularly as this relates to the shared responsibility between libraries, faculties and industry.

The workshop idea came from the overlap between the NACE study on critical thinking competency gap and an Elsevier career-readiness webinar, both converging on insights from academia and industry on the importance of information literacy for

[5] *H. Kovacs, J. Delisle, M. Mekhaiel, J. Dehler Zufferey, R. Tormey, P. Vuilliomenet. (2020). Engaging, Engineering, Education, SEFI 48th Annual Conference, University of Twente (Online), 20-24 September, 2020 - 88. Teaching Transversal Skills in the Engineering Curriculum: The Need to Raise the Temperature. SEFI. Retrieved from https://app.knovel.com/hotlink/pdf/id:kt013GMSC6/engaging-engineering/teaching-transversal*

career readiness. The aim was to identify two major challenges facing educators in this area, to describe some successes and failures, and to share two readily implementable practices.

2 METHODOLOGY

2.1 Workshop Agenda

- Introduction and Springboard Presentation (5 minutes).
- Small Working Group: take inventory of what career-readiness entails in terms of skills and knowledge (word-cloud) (15 minutes).
- Small Working Groups: share examples of challenges from own practice and one success and one failure in trying to overcome it (20 minutes).
- Panel: How can we incorporate the successes into current teaching practice? (20 minutes).

2.2 Introduction and Springboard Presentation (5 minutes)

The workshop starts with a short background introduction and presentation that communicates:

- Career-Readiness definitions by NACE and Elsevier.
- Largest competency gaps between new graduates and experienced professionals as highlighted by the NACE study and various Elsevier interviews with the corporate sector.
- Boston University Professional Development framework which outlines the typical timelapse for entry level professionals to grow into an autonomous contributor in their corporate setting.
- Elsevier Career-Readiness webinar findings which highlights the importance of the following needs:
    - Student training to handle failures.
    - Specialized training to gather and process data and interdisciplinary knowledge in the Extractive & Generative AI chapter of the digital era.
    - The importance of Project-Based-Learning activities (Capstone projects, academic skill competitions, etc).

2.3 Working Groups (35 minutes)

The small group discussions are designed to surface definition discrepancies, experiences and lessons learned from current career-readiness training methods and goals. The discussions will be structured around answering the following questions:

- What does critical thinking entail? (2 sentences)
- How do you currently train students to achieve critical thinking prowess? (2 success stories and 2 failed attempts)
- What are some of the most frustrating challenges you see in training the students? What have you tried that worked well in overcoming these and what have you tried that failed?

2.4 Closing & Summary (20 minutes)

The last 20 minutes of the workshop will be a facilitated discussion of findings in the plenary group with the goal of making an inventory of successful approaches.

The facilitators will ask participants to provide feedback as well as to express their interest in interacting as a group beyond the workshop setting with a view to sharing their challenges and experience with using tools and methods in the classroom to produce career-ready engineers more effectively.

3 RESULTS

3.1 Significance for Engineering Education

As the world's problems and challenges become more complex and intertwined with contradicting goals from the involved stakeholders, training responsible and career-ready engineers becomes more crucial than ever before. A study in the United States by NACE (National Association of Colleges and Employers) and Boston University identified that it typically takes five to eight years for a new graduate to be proficient as an independent and collaborative contributor in his/her organization. Incorporating career-readiness objectives into student training, with a focus on bridging competency gaps—particularly in critical thinking and problem-solving—between students and seasoned professionals, plays a crucial role in responsibly tackling global challenges, preparing students for the future, and nurturing disruptive innovations.

This workshop is designed to raise awareness amongst knowledge solution providers, information managers, librarians and educators in support of reducing the timetable for new graduates to achieve autonomy and high level competencies in their career journeys.

3.2 Challenges Shared by the Engineering Educators in the Workshop

Attendees joined from universities, schools of applied science and technology, and from industry, in Europe, Asia and North America. The two main challenges that came to light were how to train students in reliable thinking and how to take on board their attitudes towards training in general. Students tend to see educators as "all-knowing". Many of them just expect to receive instructions, check the rubrics and then produce a deliverable. But when they go into the workplace, the deliverable is actually a part of the solution where failure may occur.

In addition, many students are accustomed to consuming, not to criticising or questioning. They want to be on the receiving end of information and this hinders critical thinking in several ways. They may consider being critical or seeking out additional information as a waste of time as they are focused on passing their tests or exams quickly and efficiently.

3.3 Failures Shared by Participants

The idea of envisaging failure as an integral part of the engineering learning process is completely alien to many students who have only ever known academic success during their university years. As a result, they are particularly ill equipped to factor it into their professional approach when they embark on their careers. Faced with these various experiences educators must develop teaching strategies that take account of this lack of awareness. “Real readiness”, as one participant said, “is knowing what to do when you don't know.”

Participants also discussed the fact that staff at university libraries felt their role in gathering and analysing information and in teaching information literacy was not sufficiently recognised or acknowledged in curricula.

3.4 Potential Practical Solutions Proposed by Participants

The workshop agreed on the need for better promotion of collaboration between libraries and faculties. It is essential to inform them that all of us share a common goal to educate students on ethical/responsible information gathering and information literacy as part of their critical thinking training. One of the ways of doing this is to raise awareness of the specialized tools that are available to support more effective and efficient training in information literacy.

3.5 Challenges Shared by the Engineering Educators in the Workshop

Attendees joined from universities, schools of applied science and technology, and from industry, in Europe, Asia and North America. The two main challenges that came to light were how to train students in reliable thinking and how to take on board their attitudes towards training in general. Students tend to see educators as “all-knowing”. Many of them just expect to receive instructions, check the rubrics and then produce a deliverable. But when they go into the workplace, the deliverable is actually a part of the solution where failure may occur.

In addition, many students are accustomed to consuming, not to criticising or questioning. They want to be on the receiving end of information and this hinders critical thinking in several ways. They may consider being critical or seeking out additional information as a waste of time as they are focused on passing their tests or exams quickly and efficiently.

4 SUMMARY AND ACKNOWLEDGEMENTS

From the discussions emerging during the workshop, it is clear that educators need to use their academic freedom to develop strategies for teaching information literacy to their students that are specifically adapted to these students’ different experiences and competency levels. At a time when the dynamics of education and training are changing, educators must also learn when to step back from the idea of being an academic authority and consider themselves as co-developers, co-educators walking the path with their students – that takes courage.

The workshop confirmed that educators find the topics of career readiness and information literacy very relevant to their work. They are looking to explore further how industry and academia can work together to bridge the critical-thinking competency gap and how we can educate students to improve their skills in information gathering and analysis.

To do this, Elsevier plan to create more forums and discussion opportunities where industry insights can be shared within the academic community, and craft an agenda for future engineering education conversations on this topic. Their hope is that educators will actively look for the resources currently available on this topic and will contribute to such resource hubs where possible. One such example already available are the articles and guidance on the UK's Engineering Professors Council Ethics Toolkit (see below) which Elsevier were able to contribute to. Mark and Marta on behalf of Elsevier would like to thank the SEFI 2024 committee for enabling this valuable discussion and thought leadership conversations and would welcome the opportunity to collaborate with other organisations in this way.

https://epc.ac.uk/toolkit/blog-knovel-information-literacy/

https://epc.ac.uk/toolkit/why-information-literacy-is-an-ethical-issue-in-engineering/

REFERENCES

Boston University Human Resources. "Professional Individual Contributor Career Level Guide." *Boston University*, (https://www.bu.edu/hr/manager-resources/compensation/job-framework/career-categories-and-levels/professional-individual-contributor-career-level-guide/). Accessed 1 March 2024.

Cogswell, Chris. 2024. "Chasing Career-Readiness in Engineering." *Webinar from Elsevier*, *Online*, May 28. Available at: https://webinars.elsevier.com/elsevier/Chasing-Career-Readiness-in-Engineering.

H. Kovacs, J. Delisle, M. Mekhaiel, J. Dehler Zufferey, R. Tormey, P. Vuilliomenet. (2020). "Engaging, Engineering, Education." *SEFI 48th Annual Conference, University of Twente (Online), 20-24 September, 2020*, 88. Teaching Transversal Skills in the Engineering Curriculum: The Need to Raise the Temperature. *SEFI*. Retrieved from https://app.knovel.com/hotlink/pdf/id:kt013GMSC6/engaging-engineering/teaching-transversal

National Association of Colleges and Employers. "Measuring Competency Proficiency: The Career Readiness Pilot Project." *NACE*, Measuring Competency Proficiency: The Career Readiness Pilot Project (naceweb.org), Accessed 1 March 2024.

Engineering Professors' Council. "Knovel Information Literacy." EPC Toolkit. Accessed October 3, 2024. https://epc.ac.uk/toolkit/blog-knovel-information-literacy/.

Evaluating and transforming you and your colleagues' assessments in an age of generative AI

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ABSTRACT

ChatGPT and other Generative AI tools (GenAI) have generated much commotion and confusion within academic circles. Many academics still need to understand the risk such tools pose on current assessment practices and how students can use them for improved grades/outcomes. Unfortunately, most studies are very generic, do not go into much detail, and are outside of the engineering education context. In addition, GenAI provides many opportunities to construct novel, authentic and/or personalised learning experiences for students.

The workshop's facilitators have completed two comprehensive studies evaluating ChatGPT's impact on engineering education assessment (Nikolic et al. 2023; Nikolic et al. 2024). While strengths, weaknesses and opportunities were outlined, it is only the starting point for much-needed conversations. This workshop introduced participants to various GenAI tools in the context of a variety of engineering assessment types and engaged participants with a range of experience levels. We guided and engaged participants in exploring GenAI capabilities, in applying a framework for evaluating security and opportunities in assessment and through this demonstrated a model for professional development that they can adapt to their own institutions.

1 INTRODUCTION

The advent of user-friendly generative artificial intelligence (GenAI) tools is disrupting the conceptualisation and practice of engineering education. These tools offer users the opportunity to generate computer programs, reports, data analysis and even technical drawings with a few lines of natural language and limited knowledge of the field. Thus, educators, institutions and governments, accreditation and professional bodies are being forced to reconsider what it means to demonstrate learning, to assure competent graduates and even what learning is required.

There is significant current debate about how GenAI should be considered and employed. This debate joins a historical discourse that has paralleled the development of artificial intelligence (Bearman, Ryan, and Ajjawi 2022). Some frame these tools as a source of harm or disintegrity (Thorp 2023; Fischer 2023), while others see them as the dawn of a “post-learning era” (Siemens 2020). Then, of course, there is a significant spectrum of nuanced views in between (e.g., Lim et al. 2023; Yusuf, Pervin, and Román-González 2024). The tools obviously have an impact on the integrity of many current assessment practices (Nikolic et al. 2023) as well as providing exciting possibilities to create new learning opportunities (Chauncey and McKenna 2023). At the same time, concerns are being raised about these tools, for example about how they may impact student agency and metacognition (Abbas, Jam, and Khan 2024; Darvishi et al. 2024).

In our first benchmarking study (Nikolic et al. 2023), we evaluated the performance of ChatGPT 3.5 against assessment tasks drawn from a wide variety of engineering subjects. We discussed the implications for how different assessment types can be used to offset the risk of GenAI undermining assessment integrity and explored opportunities for using GenAI to support student learning. Given the rapid advances in GenAI’s capabilities, we have updated and expanded our work to assess a wider range of GenAI and developed an Assessment Security & Opportunity Matrix for analysing different assessment types (Nikolic et al. 2024). In parallel, we have completed a systematic literature review which synthesises evidence from recent research literature evaluating teaching interventions using GenAI (Belkina et al. 2024). During the workshop we briefly shared key insights from these studies in the workshop and equipped participants to apply these insights to their own assessments and teaching practice.

2 RATIONALE

There is a massive need for professional development of engineering educators to meet the challenges and opportunities presented by GenAI. Typically, there is a long lead-time between the take-up of new technology by innovators and early adopters, and its translation into the practice of the vast bulk of educators. With clearly identified weaknesses in current practice, and ongoing threats from constantly improving GenAI tools, educational leaders and leading educators must ensure that all their colleagues are able to navigate GenAI-enhanced education.

This workshop sought to empower attendees with the capacity to assess the impact and opportunities of GenAI on their teaching practice, as well as demonstrating a transferable model for the professional development of teaching staff in their own institutions.

3 LEARNING OUTCOMES

The objective of this workshop was that participants would be able to

1. Perform a risk analysis of their current assessment practice with respect to GenAI using an Assessment Security & Opportunity Matrix,

2. Identify opportunities for the integration of GenAI in their educational practice, and
3. Disseminate professional development for their colleagues on GenAI in assessment practice.

4 WORKSHOP PLAN

The workshop was designed for participants with a wide range of experience with GenAI. It was organised into four parts:

1. **Welcome and introduction (10min).** After welcoming and organising them into groups, the participants responded to an online open-ended prompt: "What do you think of when you hear AI and Assessment?". The presenters explained how the workshop was designed as a model for professional development, and then gave a mini lecture explaining how GenAI works, how to interact with it, and good practice approaches to writing prompts and interpreting output. The mini lecture was designed to help less knowledgeable colleagues get up to speed.
2. **Exploring GenAI capability to complete assessments (20min).** Participants were introduced to the evaluation process employed in Nikolic et al. (2023) and then worked in pairs to evaluate one of three assessment tasks using ChatGPT. Participants were also provided with an example prompt for their task. This was followed by small-group discussion at tables and then a debrief in plenary.
3. **Managing GenAI risks in assessment (20min).** Following on from the **Part 2** discussion, participants were presented with the Assessment Security and Opportunity Matrix developed by Nikolic et al. (2024) and its associated risk assessment method. Table groups then worked to evaluate the risk of GenAI impacting the assurance of student learning, as well as discussing controls to mitigate the risk. The discussions of the various groups were then shared and compared with the whole group.
4. **Conclusion (5min).** The presenters then summarised the workshop discussions and their connections to the concepts of assurance of learning, assessment validity and resilient assessment design. Finally, participants were encouraged to use the workshop materials at their own institutions – as are you, dear reader!

5 WORKSHOP RESULTS

The workshop was attended by approximately 25 participants. These participants were distributed across 6 table groups. When asked for their thoughts about GenAI and assessment, there were 40 responses from 17 participants. The responses reflected both positive and negative sentiments. The negative sentiments centred on concerns about cheating and academic integrity, while the positive responses included new efficiencies and opportunities in assessment. The discussion provided a moment to acknowledge the way GenAI is problematised and/or idealised, and to recognise that we need to engage critically with new tools.

Participants then engaged in the evaluation activity and each table was assigned one of three assessments:

- Position Paper – students critically analyse and respond to a newspaper article about a resource development project published in the last 12 months,

- Internship Reflection – students reflect on a critical incident in an internship and use it to inform future professional development, and
- Design Quiz – students complete five short answer questions about the engineering design process.

Even though the first two tasks incorporate elements recommended to promote academic integrity (e.g. currency, higher order thinking, reflection, reference to class discussion), the participants found that all tasks could be completed to a relatively passable standard by ChatGPT. The best responses were found for the Quiz, followed by the Position Paper. Here participants noted it would be hard to "distinguish spurious responses" as they GenAI at least superficially met the criteria.

The Internship Reflection task prompted a broader range of opinions. Some found that because no reflective framework was specified it meant ChatGPT guessed how to write the reflection and sometimes these guesses were unsatisfactory. Others achieved a better response by modifying the example prompt to include a competency framework. While still others questioned whether it was really cheating if the student provided all the reflection elements as bullet points and simply asked ChatGPT to put that information in the correct structure.

The second activity, applying the Assessment Security and Opportunity Matrix, demonstrated the benefits of the risk assessment approach. Given the familiarity of risk assessments in other fields, participants were able to rapidly understand the process and apply it to evaluating assessment tasks. The Position Paper and Quiz tasks were considered highly likely to be compromised by GenAI giving them Very High risk ratings, while the Reflection task was rated Moderate. Similarly, the participants could apply the control hierarchy to redesign assessment tasks. For example, invigilating students writing the Position Paper, substituting an interactive oral assessment for the Reflection, or redesigning the Quiz so that students critique AI response or instead submit their prompt for answering the questions.

Overall, the workshop produced lively and animated discussions with all participants engaged in the activities. Several participants found the risk approach was beneficial – rather than panicking or being paralysed by the threat of GenAI, this process provides teachers with a constructive way forward ("how to rethink my assessment"). Subsequent feedback has indicated that participants have recommended the approach to colleagues – achieving the dissemination of professional development outcome. Another participant commented that "The workshop was absolutely brilliant in a few respects: Firstly, [they] had a really clever design that quickly got participants engaged in highly relevant and thought-provoking tasks. Secondly, … they were able to [rapidly] connect us with the emerging findings of this project, and the focused challenges that are facing engineering educators."

6 SIGNIFICANCE

The rate at which GenAI technologies are advancing means there's a risk of a new GenAI digital divide arising between educators and incoming students, threatening the integrity of assessments and that curriculum loses relevance for workplaces where GenAI is ubiquitous. Thus, it's imperative we usurp the typical long-term propagation pattern of technology innovation, where early adopters are using technologies far in advance of them becoming common practice. This workshop contributes to that imperative i by developing participants' understanding of the challenges and opportunities of GenAI in engineering education and equipping them to share those insights with their colleagues.

7 References

Abbas, M., F. A. Jam, and T. I. Khan. "Is it harmful or helpful? Examining the causes and consequences of generative AI usage among university students." *International Journal of Educational Technology in Higher Education* 21, no. 1 (2024): 10. https://doi.org/10.1186/s41239-024-00444-7.

Bearman, M., J. Ryan, and R. Ajjawi. "Discourses of artificial intelligence in higher education: a critical literature review." *Higher Education* 86, no. 2 (2022): 369-385. https://doi.org/10.1007/s10734-022-00937-2.

Belkina, M., S. Nikolic, S. Daniel, S. Grundy, R. Haque, G. M. Hassan, S. Lyden, P. Neal, and C. Sandison. "Implementing Generative AI (GenAI) in Higher Education: A Systematic Review of Case Studies using LCF, SAMR and TPACK Frameworks." *Computers & Education* (2024): Under review.

Chauncey, S. A., and H. P. McKenna. "A framework and exemplars for ethical and responsible use of AI Chatbot technology to support teaching and learning." *Computers and Education: Artificial Intelligence* 5 (2023): 100182. https://doi.org/10.1016/j.caeai.2023.100182.

Darvishi, A., H. Khosravi, S. Sadiq, D. Gašević, and G. Siemens. "Impact of AI assistance on student agency." *Computers & Education* 210 (2024): 104967. https://doi.*org/10.1016/j.compedu.2023.104967*.

Fischer, J. E. "Generative AI Considered Harmful." Paper presented at the *5th International Conference on Conversational User Interfaces*, Eindhoven, Netherlands, 19-21 July 2023. https://doi.org/10.1145/3571884.3603756.

Lim, W. M., A. Gunasekara, J. L. Pallant, J. I. Pallant, and E. Pechenkina. "Generative AI and the future of education: Ragnarök or reformation? A paradoxical perspective from management educators." *The International Journal of Management Education* 21, no. 2 (2023): 100790. https://doi.org/10.1016/j.ijme.2023.100790.

Nikolic, S., S. Daniel, R. Haque, M. Belkina, G. M. Hassan, S. Grundy, S. Lyden, P. Neal, and C. Sandison. "ChatGPT versus engineering education assessment: a multidisciplinary and multi-institutional benchmarking and analysis of this generative artificial intelligence tool to investigate assessment integrity." *European Journal of Engineering Education* 48, no. 4 (2023): 559-614. https://doi.org/10.1080/03043797.2023.2213169.

Nikolic, S., C. Sandison, R. Haque, S. Daniel, S. Grundy, M. Belkina, S. Lyden, G. M. Hassan, and P. Neal. "ChatGPT, Copilot, Gemini, SciSpace and Wolfram versus Higher Education Assessments: An Updated Multi-Institutional Study of the Academic Integrity Impacts of Generative Artificial Intelligence (GenAI) on Assessment, Teaching and Learning in Engineering." *Australasian Journal of Engineering Education* (2024): https://doi.org/10.1080/22054952.2024.2372154

Siemens, G. "The Post-Learning Era in Higher Education: Human + Machine." *EDUCAUSE Review* 55, no. 1 (2020): 60-61.

Thorp, H. H. "ChatGPT is fun, but not an author." *Science* 379, no. 6630 (2023): 313-313. https://doi.org/10.1126/science.adg7879.

Yusuf, A., N. Pervin, and M. Román-González. "Generative AI and the future of higher education: a threat to academic integrity or reformation? Evidence from multicultural perspectives." *International Journal of Educational Technology in Higher Education* 21, no. 1 (2024): 21. https://doi.org/10.1186/s41239-024-00453-6.

Epistemic Lenses for Designing Instruction and Supervision in the Age of Generative Artificial Intelligence: An Adaptive Gameful Approach to AI in Higher Education Pedagogy

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1 INTRODUCTION

The public availability of ChatGPT and sophisticated generative AI (GAI) models has catalysed a wave of dystopic, utopic, and ambiguous discourses in the educational sector. On the one hand, there are optimistic visions about GAI's potential to revolutionize education though personalized learning and immediate learning support, enhanced educational access, reduced teaching workload, among others (Chan and Hu 2023; Dai, Liu, and Lim 2023; Farrokhnia et al. 2023). On the other hand, critical concerns have been raised about the technology and its embedded biases, environmental costs and issues related to copyright and data privacy.

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Educational researchers also highlight the critical implications of GAI on assessment integrity and purpose, student misconduct, and negative impact on student development and growth due to overreliance (Chan and Hu 2023; Dai, Liu, and Lim 2023) as well as potential unanticipated problematic side effects like worsened discrimination and inequality (Williamson 2024). In response, some institutions have implemented bans or restrictions on GAI usage, while others have cautiously welcomed the adoption (Tlili et al. 2024). Regardless of approach, AI technologies are estimated to play an increasingly larger role in society and education (Grayling et al. 2023) as well as in addressing the pressing challenges of modern society (UNESCO 2021).

While the current body of rigorous and sustained evidence that supports practical outcomes of AI implementation in education is limited (Nemorin et al. 2023), researchers and educators are working out exactly what GAI means for teaching and learning (Miao 2023). At the same time, high levels of student GAI adoption have been reported (Chan and Hu 2023; Malmström, Stöhr, and Ou 2023; Sánchez-Ruiz et al. 2023), especially within science and engineering disciplines (Kelly, Sullivan, and Strampel 2023). This adoption is in several cases reported to be surrounded by uncertainty, issues of trust, and unclear academic integrity expectations as well as uncertainty regarding institutional policy, rules, and guidelines (Chan and Hu 2023; Malmström, Stöhr, and Ou 2023; Petricini, Wu, and Zipf 2023). Nevertheless, recent literature reviews on AI in education highlight the importance of educators adapting their teaching and assessment to ensure that students are equipped to engage with GAI technologies in a responsible and reflective manner (Bozkurt 2023; Wang 2023).

This one-hour workshop was grounded in the abovementioned complexities and uncertainties associated with GAI adoption in education, while acknowledging the diverse factors influencing the adoption of digitally supported learning, e.g., local learning environments, pedagogical approaches, institutional policies, technological advancements, discipline orientations, and the intricacies of students' interactions with content, teachers and each other (Otto et al. 2024). The primary objectives of the workshop were to:

1. Engage in a discussion and reflection on educational practices considering the disruption of GAI
2. Reimagine future educational practices by applying epistemic design lenses and explore ideas for adapting local teaching and assessment strategies

These discussions were framed and structured using methods from gameful design to create a shared language for critically evaluating and developing GAI/AI use cases that support and augment learning, teaching, and supervision. The intended audience broadly included academic staff, management, curriculum designers, instructors, students, and engineering education researchers, to foster rich multifaceted discussions on GAI in engineering education.

2 WORKSHOP DESIGN

The workshop design was grounded in principles from gameful design, utilizing and adapting *design lenses* (Deterding 2015) to the context of instructional design in engineering education. Design lenses combine a concise statement of a design principle with a set of focusing questions that helps the designer to adopt the mental perspective of the lens (Deterding 2015). The lenses utilized in the workshop were informed by insights derived from an ongoing scoping review into the integration of ChatGPT in active learning in STEM education. Each design lens begins with a description of a teaching and learning activity identified through the review, such as deliberate practice or feedback processes. These activities are first explained in general terms, without direct reference to GAI, followed by two broadly formulated focusing questions specifically addressing the potential application of GAI in relation to one's own teaching practices. Finally, the lenses provide specific examples from the literature demonstrating how these application areas can be operationalized in practice. The specific lenses used in the workshop were: "The Lens of Productive Practice", "The Lens of Interactive Scaffold", "The Lens of Targeted Feedback", "The Lens of Cognitive Offload", and "The Lens of Constructive Critique". An exemplary design lens is illustrated in Figure 1.

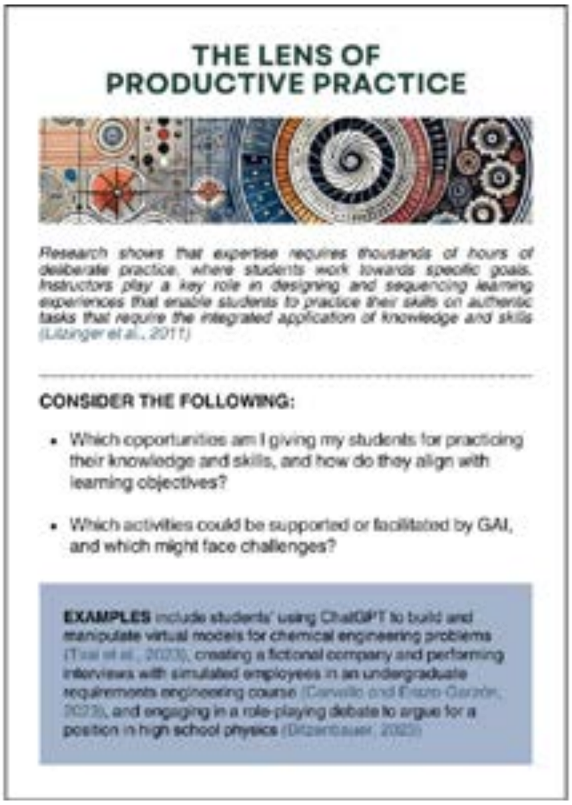

Figure 1. Exemplary design lens

The workshop followed a three-part structure (Table 1), integrating individual and collaborative brainstorms, discussions and case work to encourage active participation among the participants. At the core of these activities are the design lenses, which served not only as stimuli for ideation and perspective-taking, but also as a structuring element in conjunction with the think-pair-share model. First, participants were assigned a random design lens and asked to individually reflect and brainstorm ideas based on the perspective reflected in the lens, in relation to their local teaching practices (2.1). Second, participants formed small groups with others who had the same lens to share, exchange, and further develop each other's ideas (2.2.). Third, participants formed small groups with other participants who had different lenses to exchange highlights from the earlier steps (2.3).

After completing the think-pair-share activity, participants remained in their cross-lens groups and collaboratively worked on a case presented in plenary. The case scenario positioned each group as a team of instructors responsible for teaching and supervising an undergraduate engineering course with approximately 150 students. This course requires students to engage in collaborative, student-led project work. The task for each group was to brainstorm and develop teaching strategies that would help students effectively use GAI to enhance their collaborative project work. In addition, the groups were asked to propose strategies for guiding students in reflecting on and documenting their use of GAI throughout the project. While participants were given the option to draw on the design lenses introduced earlier in the workshop, doing so was not mandatory for this stage of the activity. Each group were asked to describe their ideas in a shared repository in Microsoft Forms.

Table 1. Workshop outline

Activity	Duration	Description
1. Introduction	10 minutes	Introduction to GAI, facilitators and agenda
2. Think-pair-share	30 minutes	2.1 Individual brainstorm with design lens 2.2 Same-lens brainstorm 2.3 Cross-lens exchange
3. Case work	20 minutes	Case work

3 RESULTS

The workshop attracted 38 participants, who formed 8 groups during the cross-lens exchange (2.3). The same groups collaborated together on the case work in order to ensure the representation of different perspectives from the previous rounds, albeit the design lenses were optional in this step. The ideas documented in the shared repository revolves around three main topics, which is elaborated in the remainder of the report.

3.1 GUIDANCE, INSPIRATION, AND FEEDBACK

Several groups addressed the importance of creating transparency and providing students with the necessary knowledge and tools to navigate guidelines and institutional policies regarding responsible GAI usage. One group emphasized the utility of a formal course policy that outlines the "*conditions and rules for using GAI in the assignment (e.g., disclosure rule and documentation)*". This group also highlighted the provision of appropriate use cases, specifically outlining three key examples: "*(a) using AI for breaking down the project in small steps (b) brainstorming initial solutions that are then critically revised and (c) obtaining targeted feedback on project productions*". These examples relate to the design lenses of targeted feedback and interactive scaffold, while an additional perspective is reflected in the brainstorming use case. Another group also stressed the importance of providing exemplary use cases but advocated for a more collaborative approach, suggesting that these use cases are co-created with students to foster a shared understanding of responsible GAI use. Additionally, multiple groups highlighted the importance of equipping students with the knowledge and skills to engage critically with GAI. Rather than adopting a passive reliance on AI-generated outputs, students should be trained to critically evaluate AI results, particularly regarding the accuracy and reliability of the sources, as articulated by one group:

"*emphasize fact checking and reliability of the sources provided by GAI*". Another group specifically linked the importance of critical engagement to the lenses of interactive scaffold and targeted feedback.

3.2 DOCUMENTATION

Different approaches to scaffold students in documenting their use of GAI was addressed by multiple groups. One group developed a use case based on short reflective videos, where students "*discuss their uses and uncertainty in a group and can get feedback from a lecturer about their use and reflection*". This idea is thus supplemented with student-teacher interaction, and according to the group, it encourages self-reflection and supports students in tracking their own journey of learning to use GAI. Another group proposed a similar idea where students would document their problem-solving process through short videos at each stage of their projects. These videos would require students to specifically reflect on how they used GAI in each step, how GAI contributed to their work, and what challenges they encountered. This idea is also supplemented by teacher-student interactions: "*During in-class sessions, we will discuss the unique and shared aspects of each project group's experience with the problem-solving process and the role of GAI therein*". Another group used the lens of cognitive offload as a source of inspiration for a use case, where students could use GAI to support their brainstorm processes and document their dialogue with GAI.

3.3 ASSESSMENT

In the context of assessment, one group proposed the use of summative assessment items that do not lend themselves to singular or definitive answers, thus reducing the risk of students offloading their cognitive efforts to GAI. Another group offered an alternative perspective on the role of GAI in assessment by suggesting that students could actively participate in the creation of exams by either 1) creating questions with ChatGPT, 2) creating their own LLM with a restricted data set that responds to questions, or 3) creating an exam using only their knowledge. The purpose of this approach is to help students critically examine the differences between AI-generated responses and their own understanding, ultimately fostering deeper reflection on the role and limitations of GAI.

4 SUMMARY

The discussions and ideas documented by each group present a wide range of inspiring perspectives on the integration of GAI in engineering education, both with and without the use of design lenses. These contributions reflect careful consideration of how GAI can be incorporated into teaching and learning environments in ways that promote responsible use, critical engagement, and reflective practice. The participants were also encouraged to test these ideas as well as design lenses in their local teaching environments and share the outcomes and experiences gathered – thus continuing the conversation initiated during the workshop.

REFERENCES

Bozkurt, Aras. 2023. "Unleashing the Potential of Generative AI, Conversational Agents and Chatbots in Educational Praxis: A Systematic Review and Bibliometric Analysis of GenAI in Education." *Open Praxis* 15 (4): 261–70. https://doi.org/10.55982/openpraxis.15.4.609.

Chan, Cecilia Ka Yuk, and Wenjie Hu. 2023. "Students' Voices on Generative AI: Perceptions, Benefits, and Challenges in Higher Education." *International Journal of Educational Technology in Higher Education* 20 (1): 43. https://doi.org/10.1186/s41239-023-00411-8.

Dai, Yun, Ang Liu, and Cher Ping Lim. 2023. "Reconceptualizing ChatGPT and Generative AI as a Student-Driven Innovation in Higher Education." *Procedia CIRP* 119:84–90. https://doi.org/10.1016/j.procir.2023.05.002.

Deterding, Sebastian. 2015. "The Lens of Intrinsic Skill Atoms: A Method for Gameful Design." *Human–Computer Interaction* 30 (3–4): 294–335. https://doi.org/10.1080/07370024.2014.993471.

Farrokhnia, Mohammadreza, Seyyed Kazem Banihashem, Omid Noroozi, and Arjen Wals. 2024. "A SWOT Analysis of ChatGPT: Implications for Educational Practice and Research." *Innovations in Education and Teaching International* 61 (3): 460–74. https://doi.org/10.1080/14703297.2023.2195846.

Grayling, Sam, Elselot Hasselaar, Till Leopold, Ricky Li, Mark Rayner, and Saadia Zahidi. 2023. Future of jobs report 2023. Geneva: World Economic Forum. https://www.weforum.org/reports/the-future-of-jobs-report-2023.

Kelly, Andrew, Miriam Sullivan, and Katrina Strampel. 2023. "Generative Artificial Intelligence: University Student Awareness, Experience, and Confidence in Use across Disciplines." *Journal of University Teaching and Learning Practice* 20 (6). https://doi.org/10.53761/1.20.6.12.

Malmström, Hans, Christian Stöhr, and Wanyu Ou. 2023. "Chatbots and Other AI for Learning: A Survey of Use and Views among University Students in Sweden.". Chalmers University of Technology. https://doi.org/10.17196/CLS.CSCLHE/2023/01.

Miao, Fengchun. 2023. *Guidance for Generative AI in Education and Research*. Paris, France: UNESCO.

Nemorin, Selena, Andreas Vlachidis, Hayford M. Ayerakwa, and Panagiotis Andriotis. 2023. "AI Hyped? A Horizon Scan of Discourse on Artificial Intelligence in Education (AIED) and Development." *Learning, Media and Technology* 48 (1): 38–51. https://doi.org/10.1080/17439884.2022.2095568.

Otto, Sofie, Lykke Brogaard Bertel, Niels Erik Ruan Lyngdorf, Anna Overgaard Markman, Thomas Andersen, and Thomas Ryberg. 2024. "Emerging Digital Practices Supporting Student-Centered Learning Environments in Higher Education: A Review of Literature and Lessons Learned from the Covid-19 Pandemic". *Education and Information Technologies*, *29*(2), 1673-1696. https://doi.org/10.1007/s10639-023-11789-3

Petricini, Tiffany, Chuhao Wu, and Sarah T. Zipf. 2023. "Perceptions About Generative AI and ChatGPT Use by Faculty and College Students." https://doi.org/10.35542/osf.io/jyma4.

Sánchez-Ruiz, Luis M., Santiago Moll-López, Adolfo Nuñez-Pérez, José A. Moraño-Fernández, and Erika Vega-Fleitas. 2023. “ChatGPT Challenges Blended Learning Methodologies in Engineering Education: A Case Study in Mathematics.” *Applied Sciences* 13 (10): 6039. https://doi.org/10.3390/app13106039.

Tlili, Ahmed, Boulus Shehata, Michael Agyemang Adarkwah, Aras Bozkurt, Daniel T. Hickey, Ronghuai Huang, and Brighter Agyemang. 2023. “What If the Devil Is My Guardian Angel: ChatGPT as a Case Study of Using Chatbots in Education.” *Smart Learning Environments* 10 (1): 15. https://doi.org/10.1186/s40561-023-00237-x.

UNESCO. 2021. *Engineering for Sustainable Development*. United Nations. https://www.un-ilibrary.org/content/books/9789214030089.

Wang, Tianchong. 2023. “Navigating Generative AI (ChatGPT) in Higher Education: Opportunities and Challenges.” In *Smart Learning for A Sustainable Society*, edited by Chutiporn Anutariya, Dejian Liu, Kinshuk, Ahmed Tlili, Junfeng Yang, and Maiga Chang, 215–25. Lecture Notes in Educational Technology. Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-5961-7_28.

Williamson, Ben. 2024. “The Social Life of AI in Education.” *International Journal of Artificial Intelligence in Education* 34 (1): 97–104. https://doi.org/10.1007/s40593-023-00342-5.

Empowering Engineering Education: Tools and Strategies for International Accreditation

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Keywords: *Quality Assurance, international accreditation, accreditation standards, accreditation processes*

ABSTRACT

This paper presents a comprehensive overview of the workshop 'Empowering Engineering Education: Tools and Strategies for International Accreditation,' held to support engineering educators in aligning with international accreditation standards. The workshop, organized in collaboration with the European Network for Accreditation of Engineering Education (ENAEE), aimed to enhance the capabilities of participants in areas such as curriculum enhancement, faculty development, student engagement, and industry collaboration. Through interactive discussions and practical tasks, the workshop provided insights into tools and strategies essential for meeting and exceeding accreditation benchmarks. The paper outlines the key learning objectives, engagement activities, and outcomes that contribute to the global standardization and quality assurance of engineering education programs.

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1 INTRODUCTION

1.1 Primary Objective

The primary objective of this workshop is to strengthen the processes of international accreditation for engineering programs, with a special focus on developing a comprehensive registry of skilled educators. This is to be achieved through the implementation of targeted tools and strategies that foster quality assurance and enhance the accreditation landscape in engineering education. Such an endeavor aligns with the growing emphasis on establishing rigorous standards and ensuring the continuous improvement of engineering programs worldwide (Patil and Codner 2007).

1.2 Key Goals

The workshop aimed to achieve several key goals that are instrumental in elevating the standards of engineering education.

1.2.1 Development and Dissemination of Tools and Resources

One of the core goals was to create and share tools and resources that support quality assurance and international accreditation. These resources are designed to guide institutions in aligning with established accreditation frameworks, such as the EUR-ACE Framework Standards and Guidelines, which have been acknowledged for their efficacy in fostering high-quality engineering programs (ENAEE 2021).

1.2.2 Enhancement of Educator Capabilities

A critical aspect of this initiative involves enhancing the capabilities of engineering educators to not only meet but also exceed international accreditation standards. By focusing on professional development and capacity building, educators will be better equipped to deliver curricula that align with the dynamic requirements of the engineering profession, thereby ensuring that students are adequately prepared for the challenges of the global engineering landscape (Guberti et al. 2015).

1.2.3 Collaboration with ENAEE for Continuous Improvement

Another significant goal was to foster collaboration with the European Network for Accreditation of Engineering Education (ENAEE) to refine a framework for the ongoing improvement and adaptation of accreditation processes. This collaboration is essential in responding to emerging educational and technological trends, ensuring that accreditation practices remain current and relevant (ENAEE and IEA 2015).

1.3 Workshop Structure

The workshop was structured to offer a comprehensive and interactive learning experience, enabling participants to gain a deep understanding of the key aspects of international accreditation in engineering education.

1.3.1 Learning Objectives

Participants gained insights into the process of continuous framework improvement for accreditation, particularly in response to the dynamic and evolving landscape of educational trends. A focus was placed on understanding the latest tools and strategies essential for achieving and maintaining international accreditation across different levels of engineering programs (Augusti 2006). This aligns with the broader goal of ensuring that institutions can adapt their accreditation processes to remain effective in a rapidly changing environment.

1.3.2 Relevance and Attraction

The workshop addressed the critical need for adaptable and contemporary accreditation practices within the field of engineering education. Given the rapid advancements in technology and the growing demand for engineering professionals who possess globally recognized qualifications, this workshop served as a timely intervention to equip institutions with the necessary strategies for achieving international accreditation standards. As highlighted by Patil and Codner (2007), such initiatives are integral to ensuring that engineering programs remain relevant and capable of meeting the needs of an increasingly globalized workforce.

1.3.3 Engagement and Interaction

To maximize participant engagement, the workshop employed interactive, collaborative discussions and hands-on problem-solving activities that are closely aligned with the established learning outcomes. These activities were designed to foster a deep understanding of quality assurance principles and encourage participants to apply the concepts in real-world scenarios, ensuring that they are better prepared to implement accreditation processes within their respective institutions.

1.3.4 Significance

The significance of this workshop lies in its potential to shape the future of engineering education. By providing educators and institutions with the tools and strategies needed to not only meet but exceed current accreditation standards, the workshop contributed to the establishment of a culture of continuous improvement in engineering education.

This proactive approach ensures that engineering programs are well-positioned to adapt to future educational requirements and technological advancements, fostering the development of a globally competent engineering workforce (ENAEE 2021). Ultimately, this proposal aims to create a dynamic and influential platform within the SEFI network for sharing, developing, and implementing best practices in engineering education accreditation. This, in turn, contributes to the global standardization and enhancement of educational quality in the field of engineering.

2 INTEGRATION OF KEY CONCEPTS FROM THE WORKSHOP PRESENTATION

One of the critical themes discussed during the workshop presentation was the concept of 'Continuous Quality Improvement in Higher Education Institutions.' This slide emphasized the importance of strategic planning, outcome-based assessment, and involving all stakeholders to ensure that engineering programs are constantly striving for excellence. It aligns directly with ENAEE's approach to quality assurance, where ongoing evaluation and improvement are crucial to maintaining accreditation standards.

The workshop also addressed the 'European Education Frameworks for Engineers,' highlighting the European Standards and Guidelines (ESG) and the EUR-ACE Framework Standards. These frameworks serve as the foundation for establishing quality assurance in engineering education, ensuring that programs are structured around well-defined learning outcomes and competencies. This reinforces the collaboration with ENAEE, as it plays a pivotal role in maintaining the integrity of these frameworks.

Another key slide presented the 'Two Pillars of ENAEE Wisdom,' focusing on Quality Assurance and Programme Outcomes. The slide underscored that ENAEE's accreditation process involves assessing the processes and procedures within engineering programs, such as teaching methods, learning outcomes, and internal quality assurance mechanisms. This underscores the importance of ENAEE’s role in defining what constitutes a high-quality engineering education.

The 'EUR-ACE Accord' was introduced as a significant milestone in fostering mutual recognition of accreditation decisions across various authorized agencies. This accord facilitates the standardization of engineering education, allowing accredited programs to be recognized internationally, which greatly benefits mobility and employability of graduates. ENAEE's role in coordinating and authorizing agencies to award the EUR-ACE label is a key factor in the success of this initiative.

Lastly, the 'EUR-ACE® Database' was highlighted as a valuable resource containing information about accredited engineering programs across the globe. This database serves as a central repository, providing transparency and accountability for programs that have met rigorous accreditation standards. It exemplifies ENAEE's commitment to quality assurance and the promotion of high standards in engineering education.

3 WORKSHOP ACTIVITIES AND COLLABORATION WITH ENAEE

During the workshop, participants engaged in a practical scenario where they were tasked with evaluating and enhancing their institution's engineering curriculum to meet and exceed international accreditation standards. This involved addressing key areas such as Curriculum Enhancement, Faculty Development, Student Engagement, and Industry Collaboration, ensuring alignment with ENAEE's quality assurance framework. Through collaborative discussions, participants proposed actionable strategies for integrating advanced technological trends, incorporating sustainable development goals, and strengthening industry partnerships to maintain program relevance and excellence.

4 CONCLUSIONS AND IMPACT

The workshop successfully equipped participants with a deeper understanding of how to implement international accreditation standards within their engineering programs. Participants completed the workshop with a comprehensive understanding of effective strategies for international accreditation, enhanced by practical experiences gained through workshop activities. This includes an in-depth appreciation of quality assurance frameworks and their application in engineering education.

Collaboration with ENAEE facilitated the exchange of best practices, resulting in actionable frameworks for continuous curriculum improvement, faculty upskilling, and industry integration. These outcomes significantly contribute to establishing a global standard for engineering education and preparing institutions to adapt to evolving technological and educational trends.

REFERENCES

Patil, Arun, and Gary Codner. "Accreditation of engineering education: Review, observations, and proposal for global accreditation." *European Journal of Engineering Education* 32, no. 6 (2007): 639-651. https://doi.org/10.1080/03043790701520594

Augusti, Giuliano. "Transnational recognition and accreditation of engineering educational programmes in Europe: Perspectives in a global framework." *European Journal of Engineering Education* 31, no. 3 (2006): 249-260. https://doi.org/10.1080/03043790600644370

Guberti, Elisa, Claudio Borri, Michele Betti, and José Carlos Quadrado. "Capacity building approach for EUR-ACE accreditation in Central Asia: QUEECA TEMPUS project advancements." Paper presented at the *Annual Conference on Engineering Education*, September 2015. https://doi.org/ 10.1109/ICL.2015.7318221

European Network for Accreditation of Engineering Education (ENAEE). *EUR-ACE Framework Standards and Guidelines (EAFSG)*. Brussels: ENAEE, 2021

ENAEE, IEA. *Best Practice in Accreditation of Engineering Programmes.* Brussels: ENAEE, 2015.

ARCHIMEDEAN OATH: A REFLECTION TOOL FOR RESPONSIBLE ENGINEERS

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***Conference Key Areas**: Teaching the knowledge, skills and attitudes of sustainable engineering (1), Engineering ethics in education (12)*

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ABSTRACT

This workshop, inspired by the Archimedean Oath, seeks to engage participants in critically reflecting on the responsibilities of engineers in society. Following the update of the content of the Oath to address contemporary challenges, the workshop aims at fostering ethical considerations among graduate students, educators, and industry professionals. Through a partially immersive experiences and thematic discussions, participants will explore various representations of the Oath and its implications for engineers who adopt it and more broadly, for the engineering practice. The workshop will provide a platform to discuss diverse perspectives, allowing attendees to understand the Oath's fundamental principles and its potential as a tool for ethical reflection. Emphasizing the importance of ethical decision-making in complex and rapidly changing environments, the proposed activities seek to use the Archimedean Oath as a tool to empower engineers to uphold principles of social responsibility and environmental stewardship, while acknowledging the need for a more scaffolded integration of ethics and sustainability throughout the engineering curriculum. By the end of this interactive workshop, participants will have gained insights into the significance of the Archimedean Oath, identified strategies for incorporating it into educational settings, and critically analysed the pertinence of the Oath as a reflection tool. The workshop will therefore provide a valuable opportunity for stakeholders to engage with the ethical dimensions of engineering and contribute to the development of practices fostering responsible engineering.

1 OUTLINE

1.1 Motivation and Learning outcomes:

Inspired by the Archimedean Oath, written at EPFL in 1990, and recently updated by a student-led effort, this workshop aims at leveraging the Oath as a tool to trigger reflection. Participants will explore multiple illustrations of the Oath and discuss the various strategies to foster active and meaningful engagement with the ideas expressed in the Oath, as opposed to oaths being passive pledges. We see the Oath as an instrument to prompt engineers to reflect on their calling to responsible engineers, and an opportunity to look back at what they have learned in their study programme through the lenses of ethics and sustainability.

To prompt critical and constructive considerations about the roles of engineers in our society, stakeholders from industry, heads of institutions, teachers and students are invited to participate in this partially immersive experience.

At the end of the workshop participants will:

1. Explain the Archimedean Oath to a larger and diverse audience, including its fundamental principles, intentions, and scope.
2. Be able to raise awareness about the multiple affordances of the Archimedean Oath as a tool to trigger ethical reflections on the role responsible engineers should have in our current and future society.

3. Be ready to answer if the Oath is an actionable practice by critically assessing it as a tool to make a curriculum fit for purpose. In doing so, participants should be able to identify the necessary ingredients to add, remove or transform the curriculum to integrate the principles of the Oath.

This workshop will be most useful for:

- Graduate students.
- Teachers interested in and/or teaching topics related to ethics, sustainability, and value-led education.
- University administrators in charge of university policies.
- Professionals who see the need for hiring engineers capable of taking ethical and sustainability challenges into account in their daily work.

1.2 Background and rationale

In the increasingly complex, interconnected and rapidly changing world, scientists, researchers, and engineers often face ethical dilemmas and moral complexities in their work within and outside academia (Shamoo et Resnik 2009). Additionally, because of the rapidly changing effects of climate change on the environment and our societies, engineers need to use their expertise to design rapidly evolving solutions (The Lemelson Foundation 2022).

Technical and engineering education institutions are increasingly focusing on nurturing students' critical thinking skills, particularly with regards to ethics and sustainability, confirming the relevance of the broader responsibilities of engineering students in addressing complex global challenges (Truslove et al. 2022; Lozano et al. 2013). For this reason, we expect students to commit to and, most importantly, reflect on the ethical consequences of their work.

In other fields, the coupling between ethical concerns and science has been perhaps more evident. In medicine, graduating doctors adopt the Hippocratic Oath. Composed over 2,400 years ago, and originally written for physicians, is the most ancient and well-known example of explicit integration of ethics in professional practice (Hulkower 2016). In ecology and environmental sciences, the publication of Rachel Carson's *Silent Spring* warned the public about the dangers of pesticides to society and eventually contributed to the beginning of the environmental movement (Shamoo et Resnik 2009). More recently, the growing complexity of information systems, urge software engineers to make an increasing number of decisions involving ethical components (Järvinen 2017).

Further practical examples of obligations from the engineering field are The Ritual of the calling of an Engineer in Canada, and the Order of the Engineer in the United States. Both involve an accreditation ceremony during which those who accept to comply with the obligation of the pledge receive a ring (The Ritual of the Calling of an Engineer 2024; Order of the Engineer 2024).

In 1990, inspired by the Hippocratic Oath, a group of four physics students from EPFL, gathered for the first time to write an oath for engineers: the Archimedean Oath. Their aim was to make an active contribution to the development of their institution and highlight their awareness of their responsibility to the positive development of the world. That year, the Oath was signed by approximately 40% of the students during their graduation ceremony before falling into disuse. Since then, the Oath has been adopted at the discretion of the faculty dean. Similarly to the Hippocratic Oath (Hulkower 2016), it has lost some of its relevance due to its outdated nature and therefore students do not easily identify with its principles. For this reason, a student association at EPFL updated the text, allowing students to better identify themselves with contemporary challenges.

The Archimedean Oath prioritizes the well-being of all and the preservation of the environment in professional practice (Figure 1). It emphasizes personal responsibility, ongoing improvement, and consideration of wider consequences on a larger scale. It cautions against military applications and commits to environmental and social preservation, equity, justice, transparent communication, and integrity.

While conceptually significant, the Archimedean Oath has not been extensively studied or discussed in academic literature compared to the more established ethical frameworks in science. We also acknowledge the limitations of an Oath requiring engineers to commit to ethical and sustainability principles for which they might not have been trained throughout their whole engineering curriculum. Nonetheless, we trust that the Archimedean Oath has the potential to trigger a reflection on ethical and sustainability aspects of the engineering profession, create a sense of belonging and empowerment, and increase accountability and responsibility in graduating engineers.

Today, I swear to the following engagements, and promise to strive to attain the ideal they represent:

- I will practice my profession with the good of all people in mind, respecting human rights* and environmental sanctity.
- I will take responsibility for my actions, having informed myself to the fullest extent, and will in no case discharge such responsibility on others.
- I will strive to perfect my professional abilities.
- In choosing and completing my projects, I will pay attention to their context and their consequences, particularly with respects to technical, economic, social, and ecological aspects, and will strive for the respect of the environment.
- I will be especially careful in regards to any military uses that my work could have.
- I will contribute to preserving the environmental and social integrity of our planet.
- I will contribute to the best of my abilities to the promotion of equity for all human beings, and will help construct a just society for all.
- I will rigorously and honestly transmit any information to carefully chosen persons, if such information represents a necessary knowledge or if holding it back puts anyone in danger. In the latter case, I will ensure that such information leads to concrete actions
- I will not let my personal or professional interests take precedence over what I deem to be just.
- I will, to the best of my ability, strive to encourage those who surround me, in both my personal and professional life, to follow the ideals of the present oath.
- I will practice my profession in a context of intellectual honesty, with conscience and with dignity.

I promise solemnly, freely, and on my honour.

* According to the UN Universal Declaration of Human Rights

Figure 1: Archimedean Oath (last updated 2023)

2 STRUCTURE OF THE WORKSHOP

2.1 Workshop plan

This workshop is part of a larger project that aims at providing higher education institutions with a tool, the Archimedean Oath, that prompts engineers to reflect on their responsibilities to society and nature during and upon the end of their studies.

Table 1: Workshop plan

Timing	Activity	Description
10'	Welcome and walk through world café	Plenary: All participants get to know the Oath and interact with its different illustrations. No official explanation. Individually: Participants are asked to indicate how they feel about implementing the Archimedean Oath.
5'	Introduction	Plenary: Facilitators introduce themselves and the functioning of the workshop.
15'	First round of discussion tables	Small groups: Participants engage in discussions from different standpoints (students, teachers, institutions, and industry employers). Discussion will be initiated by answering the question "wearing the student/teacher/head of the institution/employer hat, how would you experience/learn/adopt the Archimedean Oath?"
15'	Second round of discussion tables	Small groups: Participants have the possibility of changing the thematic table after 15min and choose to take a different perspective on the Oath. The prompt for discussion remains unchanged. Individually: Participants are asked again to indicate how they feel about implementing the Archimedean Oath by means of a "thermostat". They share with the group and discuss how it compares with the previous one.
10'	Presentation of each table discussion's outcome	Plenary: One representant per table exhibits the results of the group discussion.
5'	Conclusion, questions, and next steps	Plenary: Facilitators take questions and invite them to continue the reflections started during the workshop throughout the conference and beyond its end by, for example, adopting the Archimedean Oath in their institution as they deem relevant.

2.2 Outcomes

The main outcome of this workshop has been the increased adoption of the Archimedean Oath, and enhanced engagement with it (in education, as a reflection tool). To increase its relevance across contexts, we have collected suggestions on how to best adapt the Oath to diverse institutional, societal, and cultural contexts in which it could be potentially used. To facilitate immediate adoption, we have provided participants with the Archimedean Oath so that they continue the reflections in their institutions and raise awareness about the importance of this tool in engineers' responsible practices. Two institutions have already started implementing it.

Some of the salient points raised during the discussions highlighted the advantages and limitations of the tool and presented strategies to interact with it in different institutional and cultural contexts. Participants identified as critical issues the name of the Oath, its enforcement, how to leverage it to create a sense of belonging, and how to filter it across the curriculum. Fifteen participants expressed their interest in addressing these questions and have been invited to participate in the working group with the objective of operationalizing the Oath as a tool for reflection and accountability to responsible engineers.

REFERENCES

Hulkower, Raphael. 2016. « The history of the Hippocratic Oath: outdated, inauthentic, and yet still relevant ». Einstein Journal of Biology and Medicine 25 (1): 41-44.

Järvinen, H.M. 2017. « Ethics as a Skill of a Software Engineer? » In Conference Proceedings of SEFI 2017, edited by J.C Quadrado, J Bernardino, et J Rocha, 7. Azores, Portugal: European Society for Engineering Education SEFI. http://urn.fi/URN:NBN:fi:tty-201711292280.

Lozano, Rodrigo, Rebeka Lukman, Francisco J. Lozano, Donald Huisingh, et Wim Lambrechts. 2013. « Declarations for Sustainability in Higher Education: Becoming Better Leaders, through Addressing the University System ». Journal of Cleaner Production 48 (juin): 10-19. https://doi.org/10.1016/j.jclepro.2011.10.006.

Shamoo, Adil E, et David B Resnik. Responsible conduct of research. Oxford University Press. 2009.

The Lemelson Foundation. 2022. « The Engineering for One Planet Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education ». Portland, Oregon, USA. https://engineeringforoneplanet.org/wp-content/uploads/EOP_Framework_2023.pdf.

Truslove, Jonathan, Emma Crichton, Shannon Chance, et Katie Cresswell-Maynard. 2022. « Momentum Towards Incorporating Global Responsibility in Engineering Education and Accreditation in the UK ». In *9th Research in Engineering Education Symposium (REES 2021) and 32nd Australasian Association for Engineering Education Conference (REES AAEE 2021)*, 987-95. Perth, WA, Australia: Research in Enineering Education Network (REEN). https://doi.org/10.52202/066488-0108.

The Order of the Engineer. Inc. « Obligation of an Engineer. » The Order of the Engineer. The Order of the Engineer, Inc., 2024. https://order-of-the-engineer.org (accessed on 12.06.2024)

The Ritual of the Calling of an Engineer. « The Ritual of the Calling of an Engineer. » Corporation of the Seven Wardens, 2024. https://ironring.ca/home-en (accessed on 12.06.2024)

CODESIGNING AN EXPEDITION LEARNING SEMESTER AROUND EUROPE FOR FUTURE RESPONSIBLE ENGINEERS

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ABSTRACT

Decarbonization is a major objective of the European Union (EU) to achieve carbon neutrality by 2050. As an example, for the transport sector, shipbuilders and engine manufacturers are exploring prototypes and designs for ships powered by alternative propulsion systems to fuel energy, like wind-assisted propulsion. Higher Education Institutions (HEIs), through their science and technology curricula, must now prepare the next generation of responsible engineers to support these ecological transitions.

To guide educational program leaders and curriculum designers, the active workshop presented here permits to codesign a pan-European Master level

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semester on energy EU sovereignty and decarbonization. The context is a 5-month expedition in an imagined cruise ship, a nomadic university which provides accommodation for the students with learning and teaching workspaces. This low-carbon ship, as a floating Lab, is to travel between several European cities, to meet various academic, scientific and industrial communities during the itinerary.

This paper reviews the activities and phases of this exciting workshop, operated several times in 2024, e.g. during the SEFI 2024 conference at Swiss Federal Institute of Technology. In sub-groups, participants propose their itinerary on a given geographical map and sketch out an original joint curriculum with the aid of a canvas of nine components elaborated in a project funded by the European Commission. No prior knowledge or expertise in energy topics are needed, just openness to new ideas and creativity in collaborative curriculum design.

1 GENERAL CONTEXT

1.1 2030 Agenda for sustainable development and global risks

The context of the workshop is the challenges of climate change and sustainability, both of which are the subject of a broad consensus worldwide. According to the 2024 19th edition of the World Economic Forum (WEF, 2024), “Climate change encompasses the range of possible trajectories of global warming and consequences to Earth systems. […] Global warming pathways will still be influenced by the speed at which decarbonization takes place, and deployment of climate solutions.”

The WEF perception survey ranked by severity and the likely impacts of risks over a 10-year period. Among the 34 risks identified, the four first ranked are environmental risks: Extreme weather events, Critical change to Earth systems, Biodiversity loss and ecosystem collapse, and Natural resource shortages. Energy is a major subject as seen with the EU objective to reduce dependence on fossil fuels and its transition to renewable energies (e.g. wind solar power, overtaken gas for electricity production in the EU). Moreover, to better face future crisis and resilience, energy sovereignty is now a challenge, its ability to control, regulate, and manage its own energy resources and systems, its independency between the EU member states.

1.2 New skills of engineering students on decarbonization

The success of a decarbonization strategy requires coordinated action at all levels, in particular HEIs through their science and technology curricula when preparing the next generation of engineers. The inclusion of Environmental and Social Transformation (EST) throughout the student's curriculum enables to train future professionals capable of integrating these issues into their future careers. Engineering education must adopt a systems-based approach that incorporates both ecological principles and societal needs. An EST competency referential is to be infused into a curriculum, e.g. (i) systematically analyse the impact of human activities and industries on ecosystems and the climate, (ii) apply a historical and forward-looking approach favouring a critical stance in the face of major resource-energy-climate issues, (iii) embody individual responsibility to act collectively at international levels, and (iv) create value chains respectful of a sustainable future.

Some challenges remain: training future EU engineers, as future actors of change and transformation, students equipped with right skills for innovative energy large-scale projects, capable to facilitate effective inter-state cooperation. Future engineers in energy fields are to learn about the energetic equations of several countries, facing the challenges of the EU energy production and consumption. Several learning goals are thus to consider for a pan-European energy program, including an interdisciplinary approach with economic implications of energy independence, politics to explore energy policies and regulations, environmental Science for energy impacts, as well as social studies to analyze the social and cultural aspects of energy sovereignty. A future-oriented thinking to envision and research future energy scenarios is important also. Future graduate students could be a force in becoming European activists and ready players of pan-European energy transitions.

2 IMAGINE AN EXPEDITION LEARNING CURRICULUM

The workshop here provides an opportunity to exchange innovative perspectives between curriculum designers, on the theme of a joint European semester with strong international dimensions. No prior knowledge is presumed. The original context is an imagined cruise ship, equipped with learning and teaching workspaces, traveling to visit both universities and large industries. The workshop mission is given to subgroups of 3-5 participants.

Expedition learning is not new. Since 1912, each year, the 'La Jeanne' mission, as a final semester, marks the end of the training course for 160 engineering cadets at the French Naval Academy. With 155 days on a warship, the young engineers round the world, can cooperate with e.g. Australian, Indonesian and Singaporean armies, both at sea and on land.

The ship here is to be also a Lab. Recently in 2024, shipbuilders and engine manufacturers are exploring prototypes and designs for ships powered by more carbon-neutral systems, like wind-assisted propulsion and alternative propulsion systems to fuel energy. The International Windship association (2022) classifies wind propulsion technologies into categories including soft sails, hard sails, Flettner rotors, suction wings, kite sails, and turbines. Several large shipping companies plan such installations as part of their goal to achieve net-zero emissions. Workshop participants are given some characteristics of such a ship to host learners: 100 meters long, 3000 square meter sails, 40% fuel reduction, up to 200 cabins and a transit time of around 400 km per 24 hours.

2.1 Workshop phases in the 1-hour format

The workshop can be held in one hour only, it has been operated in three hours. After a very short context presentation of the workshop objectives and phases, two European energy maps are used as a context. With all their controversies, the first presents geographically, per country, most used energy production, the second energy source (cf. in Figure, phase on energy sovereignty). They are based on the BP statistical review of World Energy from 2024. This energy outlook considers the "major forces influencing global energy demand and supply flows, and the prospects for the energy transition out to 2050"[2].

For around 40 minutes, participants work together in subgroups. Each group elaborates on the broad lines of the final curriculum semester. Groups draw the itinerary (on a given A3 map) of the ship visiting at least 5 major universities and 5 companies around EU countries they select. Each city is to meet some EST goals, e.g. with links to strategic energy industrials activities, e.g. for decarbonization: wind power, nuclear power, geothermal or hydrogen energy. The Learning & Teaching courses can take place both during the travel at sea (ship having workspaces and invited professors and industrials on a leg) and during stopovers.

The itinerary prospection is most often done in parallel with the curriculum co-design, facilitated by a canvas with nine components (cf. Figure, phase curriculum co-design), defined in the context of a EU Erasmus+ project (Matthiasdottir et al. 2024). The canvas includes, from top-left to bottom-right: main goals and learning outcomes of the program, entry requirements, structure and contents of the program, teaching and learning methods, location of teaching and learning, interpersonal skills, assessment methods, language of instruction, and ethno- and sociographic aspects, including diversity and equity.

Fig. 1. Workshop activities and materials.

Some inputs are prefilled in the canvas, time depending and based on the profiles of participants and awareness of energy scopes. As examples, (i) areas of knowledge

[2] https://www.bp.com/en/global/corporate/energy-economics.html (consulted in September 2024).

and skills are suggested in the corresponding learning outcomes component, and (ii) broad lines of entry requirements are given. On need, 4 fully filled curriculum canvas are given for the previous semesters, somehow profiling the entry requirements, here the Building Energy Systems Engineering B.Sc. from Vilnius Tech, followed by three semesters respectively from: M.Sc. Sustainable from Reykjavik University, M.Sc. Sustainable Management Water & Energy from RWTH, or Management & Engineering of Environment & Energy from IMT Atlantique. The last M.Sc. semester on Energy Sovereignty is thus to be designed. The groups are not to fill all the component descriptions, they follow the structure to facilitate the design of their original curriculum and suggest highlights, time depending.

In the end each group displays its route and curriculum draft on the room wall. Filled Creative Commons materials are shared by email with the participants after. To close the session, in the short one hour version, remaining minutes are dedicated to group semi-structured exchange orally, before a more formal qualitative and quantitative questionnaire submitted online right after the workshop.

3 WORKSHOP ANALYSIS

The workshop has participant learning outcomes around curriculum design skills: collaborate with and learn from others, inspire others, ideate and exchange experiences, inter-connect programs, network with curriculum designers. A Likert-scale permits to verify if the participants skills were reinforced. Even though a hypothetic curriculum scenario, it has been analysed thanks to the online questionnaires and semi-directed discussions that participants of the workshop strongly appreciate the freedom that they could experience. The workshop strongly stimulates constructive and structured discussion between participants during design phases and collectively during the debriefing phase, and it "*encouraged me to think outside the box and view curriculum development in a slightly different way. The task was unusual in a good way* (verbatim)". But "*convincing academics to do things in a slightly different way than they are used to normally* (verbatim)" is seen as an obstacle for transfer in own institution context.

The workshop duration in 3 hours is more appropriate to go deeply in the canvas components, with subgroups of 3-5. At the SEFI 2024 conference, in one hour, 11 participants in 3 groups, from Australia, Czech Republic, Denmark, Ireland, and UK, actively engaged in this workshop, all phases were covered. Participants reported that "*It would have been great to have slightly longer, nevertheless, it was a fruitful hour, and we managed to get the task done and had a useful discussion. Very good session, I enjoyed it!* (verbatim)", and "*it was all right but I felt we could spend more time sharing our ideas and developments* (verbatim)".

Participants most often start from the learning outcomes component, which is the usual keystone in integrated curriculum design based on constructive alignment principles. One participant wrote "*learning outcomes, it was at the beginning, and it seemed the basis for the rest of the work* (verbatim)". For such, 4 areas of knowledge and 6 of skills and competencies are given now in the corresponding learning outcomes component of the canvas to fill. Also, the canvas has now one or two lines of description per component to answer that it "*could be helpful to add a sentence in each box with the questions to answer* (verbatim)".

Semi-directed discussion showed also that controversial skills are to be in the learning outcomes when on energy sovereignty, challenge-based learning is an adequate model, or student teams could be re-mixed on each stops of the itinerary. Semester structure with 30 ECTS prompts to a maybe large 14 weeks project as for a final thesis or internship model (Audunsson et al., 2022). Starting and ending locations can depend on the seasons (February in North or South) or on a EU region more advanced in renewable energies to favor transfer by students in other regions later.

"*It was entertaining experience* (verbatim)". Having engineering students in their last semester to travel throughout Europe to interact with universities and industries is an attractive, innovative, and exciting idea. The European Commission has proposed a blueprint for establishing a European degree, with the aim of facilitating deeper cooperation among HEIs across Europe (European University Association, 2024). In line with some SDGs and global risks, this workshop is significant in the context of educating responsible engineers and equip them with EST competencies. This context, here energy engineering, is interchangeable without modifying the workshop collaborative phases and design tools, e.g. IA, Industry 5.0 or other educational fields and sectors like STEM, business and economics, natural or social sciences, law, could be envisioned easily, could it be with rail train.

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REFERENCES

Audunsson, H., Rouvrais, S., Rudd, R., Kristjansson, R., & Moschetta, O. M. S. (2022). "Does a Master's Program in Engineering Require a Final Project?". In Proceedings of the 18th International CDIO Conference, Reykjavik University, Iceland, June 13-15.

European University Association (2024). "Challenges and enablers in designing transnational joint education provision". Thematic Peer Group Report. Learning & Teaching paper #22. 28 pages. Editors: J. De Wilde, N. Timus and A. Morrisroe, 15 March. eua.eu/component/attachments/attachments.html?id=4522.

Matthiasdottir, A., Gerwel Proches, C., Rouvrais, S., Dagienė, V., Barus, A., & Audunsson, H. (2024). "Examining best practices in curriculum design: Insights for engineering education”. In 42nd Annual Conference of the European Society for Engineering Education (SEFI). EPFL, Lausanne, 2-5 September.

Wind Ship association (2022). “Wind Propulsion for Ships: Technologies ready to decarbonise maritime transport”. 106 pages. www.wind-ship.fr.

World Economic Forum (2024). “The Global Risks Report”. Insight report, 19th edition. 124 pages. January. Available from www.weforum.org

Strengthening Student Learning: From Outcome-based to Process-based Learning

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ABSTRACT

This workshop introduces a shift towards process-level outcomes in engineering education, focusing on equipping educators with the means to foster critical thinking, reflection, and a growth mindset among students. Central to the workshop is a hands-on approach where participants actively engage in redefining knowledge-related learning objectives from existing courses into process-oriented outcomes. Educators will start crafting a rubric for self-assessment that embodies these new learning outcomes and development steps, setting the stage for the design of the educational experience. This practical exercise not only enhances the applicability of the concepts but also ensures educators leave with actionable tools to implement a more engaged, reflective learning environment. By focusing on process in addition to outcomes and by incorporating active participation in rubric creation, the workshop

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aligns with the latest educational research, promising impact on engineering education by introducing educators to new transformative ways of teaching.

1 Motivation and Learning Outcomes

This workshop was designed to activate and guide participants in redefining educational activities by describing learning outcomes on a process level—a methodology that reflects a significant shift in educational philosophy. The primary goal was to equip educators with the knowledge and tools necessary to transform traditional knowledge delivery into an exploratory, iterative process that enhances students' engagement and ability to tackle complex problems. By breaking down knowledge-based learning outcomes into distinct stages, educators were encouraged to foster an environment where learning is not just about absorbing information but actively stimulating critical thinking, reflection, and synthesis as key competencies of students.

Participants engaged in implementing process-oriented strategies (e.g., self-assessment, reflection) within the context of knowledge-based learning outcomes. They navigated and discussed the challenges that this approach presents in conventional educational settings. One strategy explored was having students self-reflect on their personal growth related to the course's learning outcomes. Studies show that self-assessment not only fosters motivation and engagement (Boud, 1991; McMillan & Hearn, 2008) but also raises academic performance (Brown & Harris, 2014). Self-assessment enhances students' learning processes by fostering self-monitoring habits that are crucial for effective self-regulation (Schmitz & Perels, 2011). Additionally, self-assessments are well-suited for measuring individual learning gains and gaining detailed insights into students' own perspectives and experiences (McGrath et al., 2015).

By the end of the workshop, educators were better prepared to design courses that not only facilitate a deeper engagement with the subject matter but also encourage students to reflect on their learning journey. This comprehensive approach promises to not only improve the reliability of assessments but also to inspire a more profound, intrinsic motivation among students towards their studies, laying the groundwork for a more effective and reflective learning environment.

2 Background and Rationale

The evolving landscape of education underscores the critical role of self-reflection in fostering growth mindsets and intrinsic motivation among learners. Inspired by findings in educational design research (Valencia et al., 2021), the workshop presented an assessment approach that shifts the focus from knowledge-based outcomes to process-based ones. This framework was centred on promoting self-awareness and facilitating the autonomous development of competencies (van der Vleuten et al., 2017), laying the groundwork for a reflective learning cycle that deeply engages students in their educational journey.

The workshop proved particularly relevant and attractive for educators and curriculum designers seeking to enhance learner engagement and motivation. No prior knowledge about process-based strategies was needed; the workshop began with a short presentation that set the scene for an inspiring discussion. By adopting a process-focused evaluation, participants implemented strategies that not only boost student engagement but also cultivate a growth mindset—a critical element in fostering intrinsic motivation to learn (Ng, 2018). This is essential for developing resilient, adaptable learners who are equipped to face the dynamic challenges of the modern world.

Participants found the workshop invaluable as it offered practical insights into integrating self-reflection and process-focused learning outcomes into their teaching practices. The focus on intrinsic motivation and the development of a growth mindset is especially pertinent in today's educational climate, where the ability to adapt and engage in lifelong learning is paramount (Ng, 2018; Schmitz & Perels, 2011). Educators left the workshop equipped with the tools and knowledge to transform their classrooms into environments that empower students, encouraging them to take ownership of their learning and preparing them for success in an ever-changing world.

3 ENGAGEMENT OF PARTICIPANTS

To ensure participants are fully engaged and able to practically apply the workshop's concepts, the program was structured around a hands-on, co-design approach to writing learning outcomes. Participants, who included educators, education designers, and professional development trainers, were encouraged to bring learning objectives from existing engineering courses to serve as the foundation for the workshop's activities. This direct application to their current teaching practices ensured the workshop's relevance and applicability. For participants without their own courses, a set of generic learning outcomes was provided to engage in the exercise.

As a central feature of the workshop, participants worked in diads on very different types of learning objectives, ranging from understanding and applying mathematical equations to redefining objectives that help educators reflect on and understand the impact of their own teaching or coaching styles. Throughout the workshop, participants focused on developing a rubric for self-assessment that incorporated both the newly defined process-level learning outcomes and distinct developmental stages. This collaborative exercise allowed participants to explore various ways to enhance students' ability to engage with, reflect on, and solve complex problems, ultimately fostering a deeper understanding of the shift from traditional, outcome-based assessments to process-oriented evaluations.

The workshop schedule was as follows:

- Introduction presentation: Presenting the main ideas of self-assessment and process-level learning outcomes, along with expected outcomes and a short creative thinking exercise (10 minutes).
- Individual exercise: Participants defined both a starting and ending level on one learning objective of their choice, indicating the level they think students have at the start and end of their course (5 minutes).
- Small group discussions: Participants discussed their ideas in small groups, refined descriptions of the levels, and picked one example for group discussion (10 minutes).
- Group sharing: Each group shared their learning objective, including intended start and end levels, with the rest of the participants. Coordinators clustered similar learning objectives together (10 minutes).
- Collective work: Participants collectively added levels to the learning objectives to reach a total of four levels on each of the learning objectives (10 minutes).
- Feasibility discussions: A group discussion covered the feasibility of the levels the participants proposed (10 minutes).
- Final insights and take-home messages: Coordinators shared final insights and take-home messages based on the discussions during the workshop (5 minutes).
- The interactive nature of the workshop, combined with the focus on practical application, ensured that participants not only grasped the theoretical underpinnings of process-level outcomes but also left with a tangible product—a beginning of a comprehensive rubric tailored to their specific course contexts. This active engagement strategy not only enhanced the learning experience for educators but also prepared them to implement a more reflective and effective learning environment for their students.

Additionally, the workshop provided a platform for meaningful professional exchanges, resulting in several participants initiating self-reflection cycles at their respective universities. As a further outcome, a chapter will be proposed to the SEFI Handbook on Transferable Competencies & Skills based on the workshop and the related conference presentation by the same authors.

4 RELEVANCE FOR ENGINEERING EDUCATION

This workshop stands at the forefront of a pivotal shift in engineering education, advocating for a transition from traditional, outcome-focused learning to a process-oriented approach that emphasizes the development of critical thinking, problem-solving skills, and self-reflection. Participants left the workshop equipped with strategies and tools to inspire a new generation of engineers by fostering a growth mindset and focusing on process-based learning objectives.

The take-home message of this workshop is clear: empowering engineering students through a reflective, process-based learning framework is essential for cultivating innovative thinkers and problem solvers who are prepared to meet the demands of the future. Several participants have already begun implementing self-reflection cycles within their courses. Moreover, the establishment of new professional contacts during the session is expected to lead to ongoing collaboration in implementing these strategies. Documenting these outcomes in a proposed SEFI Handbook chapter will further expand the workshop's impact by disseminating best practices and insights for advancing engineering education.

REFERENCES

Boud, D. (1991). Implementing student self-assessment. Higher Education Research and Development Society of Australasia (HERDSA).

Brown, G., & Harris, L. R. (2014). The future of self-assessment in classroom practice: Reframing self-assessment as a core competency.

McGrath, C. H., Guerin, B., Harte, E., Frearson, M., & Manville, C. (2015). Learning gain in higher education. Santa Monica, CA: RAND Corporation.

McMillan, J. H., & Hearn, J. (2008). Student self-assessment: The key to stronger student motivation and higher achievement. Educational horizons, 87(1), 40-49.

Ng, B. (2018). The neuroscience of growth mindset and intrinsic motivation. Brain sciences, 8(2), 20.

Schmitz, B., & Perels, F. (2011). Self-monitoring of self-regulation during math homework behaviour using standardized diaries. Metacognition and Learning, 6, 255-273.

Valencia, A., Bruns, M., Reymen, I. M. M. J., & Pepin, B. E. (2021). Defining Intended Learning Outcomes (ILO's) of inter-program CBL towards achieving constructive alignment in the context of ISBEP. In proceedings of the SEFI 49th Annual Conference Blended Learning in Engineering Education: challenging, enlightening – and lasting? (Pp. 567-578).

Van der Vleuten, C., Sluijsmans, D., & Joosten-ten Brinke, D. (2017). Competence assessment as learner support in education (pp. 607-630). Springer International Publishing.

Game On: Inclusivity in STEM teacher training through interactive play

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ABSTRACT

Addressing diversity and inclusion within engineering education is vital for nurturing responsible and innovative engineers capable of tackling societal and environmental challenges. This workshop was aimed at exploring inclusive classroom strategies through playing the game *All Inclusive.* Drawing from real-life teacher experiences, the game acts as a vehicle for thought, i.e. a conversation starter on how to utilize a diverse student cohort to increase learning potential. The workshop was structured to ensure interactive participation, with an emphasis on small group discussions and plenary sessions to foster collective insight into inclusivity strategies. By the end of the session, participants were expected to have gained a deeper understanding of diversity's potential as a resource, develop ideas for inclusive practices and take away a novel, game-based tool for application in their educational contexts.

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1 INTRODUCTION

The push for increased diversity and inclusivity throughout the educational system is becoming increasingly recognized, not just as a moral imperative, but also as a practical necessity.

Efforts to enhance diversity and inclusivity within universities aim to create environments, where all students and faculty feel supported and valued, regardless of their backgrounds. This is concerned with ensuring equitable access to resources, fostering a sense of belonging, and promoting a culture that respects and celebrates diversity. Such environments are crucial for driving innovation, enhancing problem-solving, and preparing students for a global workforce. Unlocking the potential of diversity is particularly salient within the engineering education arena, where we aim to educate the responsible, innovative engineers of tomorrow. Engineers who will take social and environmental responsibility in developing and using technologies to solve problems, we do not even know are problems yet (Rattleff and Sass 2023).

This workshop introduced participants to a game designed with the purpose of exploring how teachers can create an inclusive classroom with a diverse student cohort. Rather than an instructional manual, the game should be seen as a vehicle for thought, i.e. a conversation starter on how to utilize a diverse student cohort to increase learning potential.

1.1 Motivation and Rationale for this workshop

> "*The reason I entered my course into the EuroTeQ course catalogue was that I could see how my course could really benefit from the diverse perspectives on how health care options are organised differently, even within seemingly homogenous European countries, but I ended up finding it really difficult to engage and motivate my online exchange students in the learning activities I set up…*"

EuroTeQ Teacher

The Technical University of Denmark (DTU) is part of the EuroTeQ Alliance, a strategic academic partnership between predominantly technical universities. In this context we have a shared course catalogue in which teachers from across the alliance can offer their course to students across the alliance. The courses are offered in a purely online or hybrid format, with home students participating in-person, and EuroTeQ students participating online. As educational developers, our role within this partnership has been to support the development of innovative course formats to be offered through this course catalogue. It is in this context that three primary drivers led us to develop this game:

1) Feedback from teachers

Diversity comes in many forms, and through our work with consulting and engaging with teachers at DTU, we have experienced that teachers and consultants often lack the tools to engage with the challenges and potentials that such diversity brings to the classroom. Whilst diversity expressed through gender, academic pre-requisites, learning preferences and neurodivergence are areas that most teachers in higher education encounter, the EuroTeQ course format offers a particular view into diversity as expressed through cultural and institutional differences and multimodal participation (e.g. synchronous online/physical participants).

2) DTU Learning Lab teaching philosophy to “Teach as you Preach” (Rattleff and Sass 2023)

Being responsible for the STEM higher education teacher training at DTU, we wanted to develop an icebreaker activity feeding into a deeper conversation about diversity in all its expressions in line with the feedback we receive from our teachers.

3) Sustainability

When visiting, and receiving visits, from partners, we often ended up putting together tote bags with pens, notepads, and various gadgets. We wanted to be able to provide a EuroTeQ relevant, engineering education oriented, and sustainable memorabilia.

We consequently set out to create a tool and conversation starter, that has the potential to contribute to our efforts in flipping diversity from being a challenge to being a resource for students, teachers, and universities alike.

1.2 Learning Outcomes

The learning outcome for this workshop was to examine how we as universities can release the potential of diversity.

Together we explored classroom diversity dilemmas and inclusive approaches.

- discussed initiatives at the universities that increase the diversity potential.
- outlined a roadmap towards inclusive practices.

Participants

- reflected on diversity from a teacher and student perspective.
- developed ideas for inclusive practices.
-

2 THEORETICAL FRAMEWORK

In the pursuit of inclusive teaching within STEM higher education, educators are tasked with developing a classroom environment that actively values and leverages the diversity of its students. Inclusion means that within an educational setting, learners feel that they are valued, supported and empowered to contribute actively and meaningfully (Ahmad 2019).

To achieve an inclusive atmosphere, teachers must integrate a variety of competences into their pedagogical toolkit, including social, communicational, cultural, and psychological skills. These competences are essential for addressing and overcoming the barriers to inclusion, such as bias and stereotyping, lack of representation, discrimination, systemic inequities, cultural insensitivity and inadequate support and mentorship. (Awang-Hasim et al. 2019, Ceo-Difrancesco et al. 2019, Engelbrecht et.al 2013, Kruse et al, 2018, Molbaek 2018, European Commision 2019)

To develop and establish inclusive practices in STEM higher education, we need to consider both the cultivation of inclusive values and skills and approach inclusion from the perspectives of institutions, teachers, and students.

Following this line of thought, this game consists of three primary segments through which the teacher is asked to reflect on different approaches to diversity and inclusivity in the STEM Higher Education classroom: Dilemmas, Competences and Characters.

2.1 Dilemmas

The 17 dilemmas selected for this game are based on real life dilemmas experienced by our teachers at DTU. They have been selected to represent the range of diversity that our teachers encounter, not only within EuroTeQ, but perhaps more visible in that context. As such there will be dilemmas related to diversity as expressed though cultural differences, learning preferences, neurodivergence, gender, academic pre-requisites, and participation forms, i.e. online, hybrid or physical.

2.2 Competences

Three factors played into the selection of the 17 competences included in this game.

The competences identified in the literature review, as referred to above, provided the first round of narrowing down the scope of potential competences. We then cross-referenced this list with the 21 competences identified through a survey with >300 industry partners in the EuroTeQ universities' ecosystem[2].

This exploration into the expected competencies of our students shifts the focus of inclusive teaching. It moves beyond merely creating an inclusive learning environment to addressing the question of which inclusive competencies will increase students' employability.

Finally, we selected 17 competences, that we identified as broad enough to allow individual interpretation for teachers across our alliance, academic disciplines, and individual differences.

2.3 Characters

The last part of *All Inclusive* invites a well-known character into the game, who people can attribute certain characteristics to. We were inspired by the third person perspective dialogue workshop introduced by Hermsen, Dommelen and Espinosa (2023) at the SEFI 2023 conference in TU Dublin. We activate Hermsen, Dommelen and Espinosa's proposed introduction of a third person perspective in unfolding behavioural insights and inviting reflection. In the context of our game: *All Inclusive* this is related to how different behavioural strategies and competencies will produce different outcomes in turning diversity to a resource in various educational settings.

3 Workshop Setup

The room was prepared with tables spread out to allow 4-5 participants at each table. Participants arrived and placed themselves accordingly. One game was prepared at each table.

[2] https://euroteq.eurotech-universities.eu/docuwiki/wp4/

3.1 All Inclusive, the game

The session commenced with the selection of a “game master” at each table. The participants were given five minutes to go over the rules of the game and then 15-20 minutes to play the game. The facilitators were available for questions and clarifications throughout the game.

The game design and rules are as follows:

Setup: Participants arrange the dilemma, competence, and character cards into three separate piles, face down. The gamemaster reveals the top card from the dilemma pile, then shuffle the competence cards and deal 3 to each player.

Dilemma Discussion: Gamemaster reads the dilemma card out loud. Players discuss the dilemma, acknowledging that players may interpret it differently.

Competence Reveal: Each player selects one competence card and discuss its’ relevance in addressing the dilemma.

Character Perspective 1: Gamemaster reveals a character card. Players discuss how the character might approach the dilemma.

Character Perspective 2: Gamemaster reveals another character card. Explore how this new character might approach the dilemma in a different way than the previous character.

Reflection and Takeaways: Each player shares their insights from the discussion, focusing on how they would engage with similar dilemmas in the future.

4 BUILDING A ROADMAP

The second part of the workshop commenced with a presentation of the rationale and motivation for creating the game and an overview of the theoretical underpinnings. We invited the participants to think-pair-share and explore the classroom diversity dilemmas and inclusive approaches that emerged during their playing of the game.

During facilitated small group discussion, we raised the perspective from the individual level to the institutional and debated initiatives that increase the diversity potential. In plenum we outlined a roadmap on inclusive practices and ideas at universities.

4.1 Workshop – insights and outcomes

The participants at the workshop ranged from PhD students, engineering teachers to teacher support staff. We experienced a small cohort that engaged with the game's dilemmas, skills, and characters, and contributed to operationalising inclusive practices in engineering education.

They saw relevance in own teacher (training) practice, and took games home, to continue the dialogues elsewhere.

4.2 Road Map

Fig.1 Compilation of ideas developed during the workshop

The road map was drawn up in a matrix, allowing participants to reflect on the student, teacher and organisational level, both in terms of practices (what do we already do) and ideas (what would we like to do). For the sake of creating an overview, we split up some post its to allow one point/post it, condensed others for clarity, and finally grouped the inputs into common categories (see fig. 1). The aggregated matrix showed many interesting trends, overlaps and discrepancies between what institutions do/want to do. The matrix invites a range of possibilities for analysis, for the purpose of this paper, we will limit ourselves to present the results, which show clear differences on responsibility and focus between the student, teacher and organisational level.

It was evident that the suggestions for practices and ideas related to the student were focussed on the expectations and potential for the individual to act.

The student perspective was primarily focused on communities, social events and entry barriers to these. There was a clear emphasis on students being respectful and developing openminded and inviting attitudes. On the other hand, there was a lack of focus on academic belonging and how students can contribute to/hinder processes of becoming legitimate members of the academic society.

This last part was, however, evident on the teacher level, where the focus was less on the teacher as an individual and more on the teaching context and the teaching practice itself.

On both a practice and an idea level, the focus on the teacher was related to the role as communicator and facilitator in developing a reflective practice based on knowing and understanding issues that hinders participation and reducing barriers to that. There was a clear focus on the teaching role as also mediating the students feeling of psychological safety to invite the students to engage and participate.

The tools to do so are facilitating open and anonymous communication channels, inviting and listening to feedback and selecting inclusive study materials.

Lastly, and as could be expected, the suggestions made for the organisation were on an overarching perspective as related to the structural conditions the organisation offers, and can offer, to provide an inclusive environment.

In this section it was particularly clear that what some organisations offer as practice are still predominantly ideas at other institutions. Overarching these there was a clear focus on the responsibility to create structural changes and conditions that support both students and teachers in developing a broad perspective on inclusive practices, including training opportunities, developing clear codes of conduct, and robust it-infrastructure. Other points made invited the organisations to acknowledge that real inclusive practices also involve implementing intentional strategies in hiring both academic and administrative staff as well as student uptake to help foster a more diverse range of role models.

5 SIGNIFICANCE TO ENGINEERING EDUCATION

Inclusion was a recurring theme throughout the SEFI conference. It is indeed a multifaceted concept. The roadmap we present here remains open to additional practices and ideas necessary for building inclusive learning environments. This and other workshops show that there is no single path to creating inclusive universities, and the journey is paved with dilemmas that require ongoing conversations.

REFERENCES

Ahmad, A. S., Sabat, I., Trump-Steele, R., King E. “Evidence-Based Strategies for Improving Diversity and Inclusion in Undergraduate Research Labs.” *Frontiers in Psychology* 10 (2019). https://doi.org/10.3389/fpsyg.2019.01305

Awang-Hashim, R., Kaur, A., and Valdez, N. P. "Strategizing Inclusivity in Teaching Diverse Learners in Higher Education." *Malaysian Journal of Learning and Instruction* 16, no. 1 (2019): 105-128. https://doi.org/10.32890/mjli2019.16.1.5

Ceo-Difrancesco, D., Kochlefl, M. K., Walker, J. "Fostering Inclusive Teaching: A Systemic Approach to Develop Faculty Competencies." *Journal of Higher Education Theory and Practice* 19, no. 1 (2019): 31-43.

Engelbrecht, P.. “Teacher education for inclusion, international perspectives.” *European Journal of Special Needs Education*, 28 no. 2, (2013) 115–118. https://doi-org.proxy.findit.cvt.dk/10.1080/08856257.2013.778110

European Commission, Directorate-General for Education, Youth, Sport and Culture, Key competences for lifelong learning, Publications Office, 2019. https://data.europa.eu/doi/10.2766/569540

Hermsen, P., Van Dommelen, S., & Hueso Espinosa, P.. Reflection On Your Personal Perspective Through Other Perspectives. A Step In Dealing With Wicked Problems. European Society for Engineering Education (SEFI). (2023) https://doi.org/10.21427/GFTG-HQ42

“Ideate the EuroTeQ Professionals” EuroTeQ. Access date: 05.04.2024 https://euroteq.eurotech-universities.eu/docuwiki/wp4/

Kruse, S. D., Rakha, S., & Calderone, S.. ”Developing cultural competency in higher education: an agenda for practice.” *Teaching in Higher Education*, 23, no. 6, (2018) 733–750. https://doi-org.proxy.findit.cvt.dk/10.1080/13562517.2017.1414790

Molbaek, M. “Inclusive teaching strategies – dimensions and agendas.” *International Journal of Inclusive Education*, 22 no. 10, 2018 1048–1061. https://doi-org.proxy.findit.cvt.dk/10.1080/13603116.2017.1414578

Rattleff, P., & Sass, D. S. "Teach as You Preach: Teacher Training For STEM-Educators At DTU." European Society for Engineering Education (SEFI) (2023). https://doi.org/10.21427/6BZA-7C58.

REFINING A TAXONOMY AND LEXICON FOR CONTINUING ENGINEERING EDUCATION

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1 MOTIVATION AND LEARNING OUTCOMES

1.1 Motivation

An effective and current Continuing Engineering Education (CEE) ecosystem is vital to support the millions of practising engineers globally. CEE is considered as education of an engineer, technologist or technician after their initial educational phase (Uhomoibhi & Ross 2019). However, previous work has identified (Gomez Puente et al. 2023) the need for a shared lexicon around practices in CEE to allow better knowledge sharing that would enable a faster and more effective diffusion and adoption of concepts.

A taxonomy offers such a shared lexicon is a "*hierarchical classification system that makes categorising or finding terms within text easier*" (Pack 2002) and one that involves a clear vocabulary. Previously there was no taxonomy aligned specifically to CEE, which led to a creation of an initial taxonomy for CEE (Caratozzolo et al. 2024) to align CEE concepts and their implementation. Methodologically, this initial taxonomy was developed from an inductive analysis of eight case studies (Gomez Puente 2023), then refined and combined with a scoping review of literature (Caratozzolo et al. 2024, 2025). Such a methodology aligns with an empirical (a posteriori approach) to taxonomy development (Bailey 1994) and allows sequential inductive and deductive consideration of the emerging terms and their structure. In line with the approach of Finelli et al (2015), then this taxonomy benefits from an iterative refinement, particularly from experts within the field, and this workshop is intended to contribute a further stage of refinement from a broader sample

The workshop reviewed this initial taxonomy with the SEFI CEE expert community to validate and to refine further.

1.2 Learning Outcomes

The workshop brought together a range of experts (from universities, and professional and accrediting bodies), to review and refine the taxonomy for CEE.

At the end of this workshop, participants had:

1. Contributed their perspectives on what terms are important when considering CEE;
2. Gained an understanding of the existing CEE taxonomy;
3. Supported the authors to evaluate the coverage and validity of the CEE taxonomy, based on participant's own experiences and perspectives;
4. Identified areas to enhance the CEE taxonomy and enabled an iterated version to be developed (will be completed after the workshop through further ongoing engagement).

2 BACKGROUND AND RATIONALE

Engineers have influenced society, communities and the economies for centuries, with this impact historically being seen as broadly positive. However, we are increasingly aware of the (unintended) consequences of engineering practice on society and the world, as we better understand local, national and international interconnectedness. In essence, engineers need to be able to deal with “wicked” problems and fully recognise the more holistic impact of their practice (from an ethical, inclusivity, sustainability, human-centred and community perspectives). Moreover, they need to ensure society benefits from an appropriate fusion of technology and people (aspirations, skills, and their communities), e.g., as per Industry 5.0 (Huang et al. 2022).

In addressing these challenges, we need to find educational and training approaches for engineers throughout their educational and practice preparation and working lives. Considering the number of practising engineers and scientists globally, e.g. seven to 25 million in USA (NSB 2019); 17.2 million in EU (Eurostats 2019), then the need for an effective ecosystem around Continuing Engineering Education (CEE) is vital for engineers, society and industry.

For this ecosystem, we need to facilitate faster exchange of approaches to respond to the rapidly-changing skills demands and ways to deliver this education and training.

The current CEE taxonomy (Caratozzolo et al, 2024) has a limitation of being based on a small sample of perspectives from university academics, along with a corresponding review of literature for terms.

This workshop, with the range of roles and backgrounds involved in CEE, allowed a review of the taxonomy to ensure it has broader validity and utility as a tool to enable sharing of practices and approaches.

3 WORKSHOP DESIGN

The workshop was attended by a range of experts – from academic institutions from different countries (Europe, North America, and Australia) and from Professional and Accreditation Bodies. The overall goal of the workshop was to engage the workshop participants to help refine the current version of the CEE Taxonomy, with the intention that it better reflects a range of stakeholders in CEE.

The 60-minute workshop was organised in three main parts:

1. Participants individually noted what terms and concepts around CEE were important to them, and in their context and then clustered these through small group work;
2. The current taxonomy was introduced;
3. Participants worked to add their terms to the existing taxonomy to identify overlap with existing concepts, as well as to highlight new ones.

4 WORKSHOP FINDINGS

4.1 Participants’ terms and clustering

There were two separate groups that noted down their own terms and then in group-work clustered these together. Figure 1 gives an example of the grouping by one of groups with a similar approach taken by the other group.

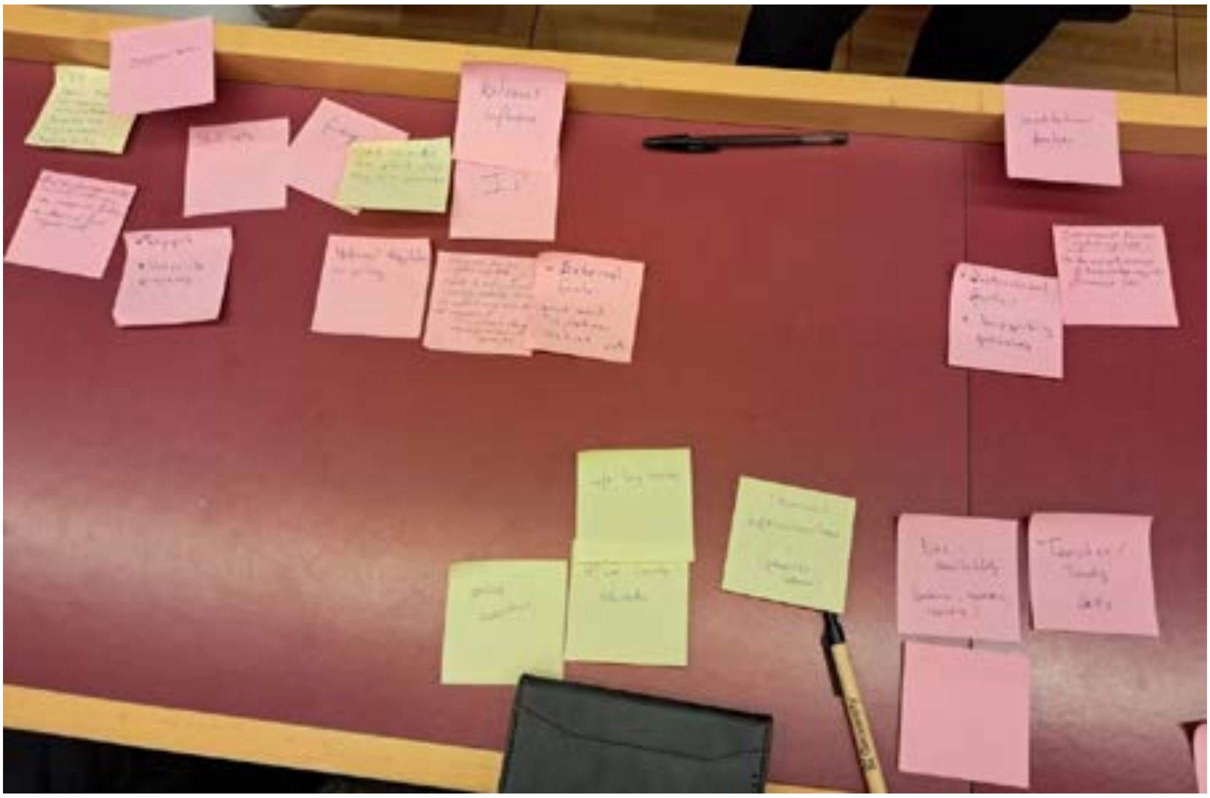

Figure 1: clustering of terms relevant to CEE from one of the groups.

Regarding the group discussions, group 1 output indicates institutional factors such as supporting policies, and recognizes institutional factors influencing permanent CEE. Some general points of attention are for instance, time availability; teachers' skills development; lifelong learning approaches; online/hybrid education, and alike. With regards to external factors, some elements mentioned are IP; government regulations, funding and budget possibilities; possibilities for the companies to pay for CEE offerings; national regulations within the EU; (pre-)defined set of skills; and, CEE organization differences, e.g. education vs. industry.

Group 2 indicated external factors, such as government policies, as well as institutional policies including how CEE was resourced, as well as recognising that CEE needed to be organised differently by universities. Importantly, they brought out the different types of learning, not just formal learning but also informal. Additionally, they detailed that the IT infrastructure for CEE is important. The important point of who teaches CEE, what motivates them to teach and remuneration for this work was detailed.

4.2 Update to the taxonomy

The current taxonomy was presented (version 2.1) (Caratazollo et al. 2025). In the open discussions around the taxonomy, then a number of enhancements were identified.

Key additional points that were not covered within the current taxonomy included:

- Intellectual Property;
- Consideration of IT/technical infrastructure to achieve this;
- Continuing Professional Development (CPD) as a term was missing and important;

- Digital badging (recognition of successfully engaging in and completing CEE courses);

Refinements of language suggested included:

- Referring to learning and not teaching (to reflect that CEE is not only taught, and that learning is the desired outcome);

Clarity was sought around the differences between hybrid and blended learning, and so links to recognised definitions will need to be included in the associated definitions for terms within the taxonomy.

Additionally, further terms/configurations were highlighted, such as

- "Diplomat" (course with greater than 106 hours of learning) and nano-credentials;
- Whether workplace learning should differentiate between 'Off-the-job' and 'on-the-job' training.

To validate the current taxonomy (version 2.1), then participants were asked to place their CEE terms (post-it notes) physically on a printed-out version of the taxonomy. This process saw strong overlay with terms; Figure 2 below gives a snap-shot of this overlay.

5 CONCLUSION AND NEXT STEPS

In conclusion, we perceived the acknowledgment of the participants to have a taxonomy that compiles a set of elements crucial to map CEE practices, organizational approaches and regulations. Furthermore, the taxonomy was recognized as a suitable method for further analysis of CEE practices.

Next steps will be to refine the taxonomy, and to engage further participants to ensure that the taxonomy is valid, useful and reflects international perspectives. Thereafter, clear definitions (lexicon) will be developed.

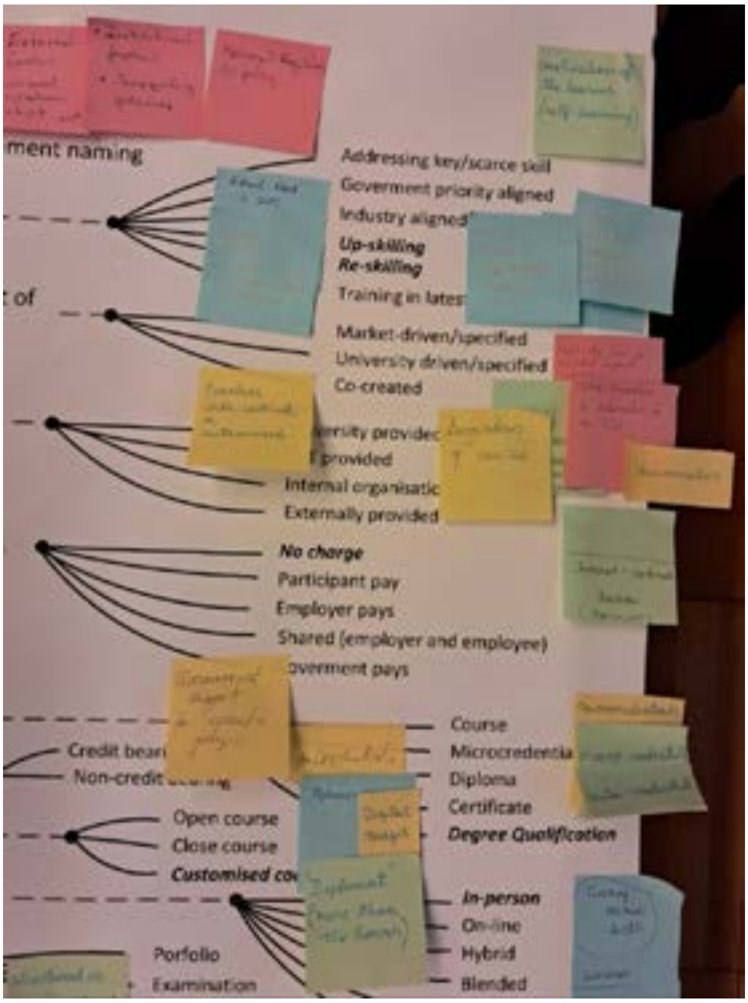

Figure 2: photo of overlay of participant Post-It notes on current taxonomy

REFERENCES

Bailey, Kenneth D. *Typologies and taxonomies: An introduction to classification techniques*. No. 102. Sage, 1994.

Caratazzolo, Patricia, Christopher J.M. Smith, Sonia, Gomez Puente, Matias Urenda Moris, Bente Nørgaard, Hans-Ulrich Heiß, Katriina Schrey-Niemenmaa and Rigas Hadzilacos, “A Novel Taxonomy for Continuing Engineering Education” in 19th World Conference of *International Association of Continuing Engineering Education*, Comillas, Spain.

Caratazzolo, Patricia, Christopher J.M. Smith, Sonia, Gomez Puente, Matias Urenda Moris, Bente Nørgaard, Hans-Ulrich Heiß, and Jose Daniel Azofeifa. 2025. “A novel taxonomy for Facilitating In-Depth Comparison of Continuing Engineering Education Practices” *Frontiers in Education (in review).*

Eurostats. 2018. “Number of scientists and engineers up 4% in 2018.” Accessed 20th March 2024. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20190830-1.

Finelli, Cynthia J., Maura Borrego, and Golnoosh Rasoulifar. 2015. “Development of a Taxonomy of Keywords for Engineering Education Research.” *IEEE Transactions on Education* 58 (4): 219–41. https://doi.org/10.1002/jee.20101.

Gomez Puente, Sonia M., Christopher Smith, Matias URENDA Moris, Bente Norgaard, Hans-Ulrich HEISS, Patricia Caratozzolo, Katriina Schrey, H.-R. Myllymäki, and Rigas Hadzilacos. 2023. “Towards Building A Framework For Continuing Engineering Education In Higher Education Institutions: A Comparative Study.” In *SEFI 2023 - 51st Annual Conference of the European Society for Engineering Education: Engineering Education for Sustainability*, 2085–93. Dublin, Ireland. https://doi.org/10.21427/P43B-6Z03

Huang, Sihan, Baicun Wang, Xingyu Li, Pai Zheng, Dimitris Mourtzis, and Lihui Wang. "Industry 5.0 and Society 5.0—Comparison, complementation and co-evolution." *Journal of manufacturing systems* 64 (2022): 424-428.

NSB. 2019. “Science and Engineering Labour Force.” Accessed 20th March 2024. https://ncses.nsf.gov/pubs/nsb20198/.

Pack, Thomas. "Taxonomy's Role in Content Management." *EContent* 25, no. 3 (2002): 26-31.

Uhomoibhi, J., & Ross, M. 2019. “The Five Stage Framework for Life Long Learning in Engineering Education and Practice”. In INSPIRE XXIV, Twenty-Fourth International Conference on Software Process Improvement Research, Education and Training: Global Connectivity and Learning Across the Nations.

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SKILLS-BASED WORKSHOP FOR EDUCATORS NAVIGATING A VOLATILE, UNCERTAIN, COMPLEX AND AMBIGUOUS WORLD USING RECENTLY CO-CREATED TOOLS

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ABSTRACT

Ensuring that teaching practice is fit for the 21st century is of pressing importance because it is the means by which we prepare all future practitioners and professionals to respond to challenges of unprecedented complexity whilst acting sustainably, ethically and equitably. However, change is complex, uncomfortable, frustrating but importantly, worth the investment - to teach better and to make positive and long-lasting improvements within our educational system. While many

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excellent resources on sustainability education exist, there aren't many that explicitly guide engineering educators to integrate these into their teaching, or indeed that are intended to upskill engineering academics to be able to deliver this teaching. Recently, three projects have addressed this challenge are the Reimagined Degree Map by Engineers Without Borders UK (sponsored by the Royal Academy of Engineering), the Sustainability Toolkit by the UK's Engineering Professors' Council (sponsored by Siemens and the Royal Academy of Engineering), and the Engineering for One Planet Framework of essential sustainability learning outcomes and three companion teaching guides, co-created by hundreds of engineering education stakeholders (sponsored The Lemelson Foundation). Through reflection and a hands-on approach, this workshop will focus on what is needed to build the capacity and confidence of engineering educators to integrate global responsibility into their teaching, and make long-lasting change to their education practice.

1 OUTLINE OF THE WORKSHOP

1.1 Motivation and learning outcomes

In a Volatile, Uncertain, Complex and Ambiguous (VUCA) world (Rouvrais et al. 2018), navigating the complexities of educating the next generation is no easy feat, especially when educators can feel burdened with the pressures of accreditation, the need to embed transferable skills alongside technical curricula, the realities of space and resource constraints, not to mention their own scholarship and promotion agenda. Add these realities to the effects that Covid-19, AI, political conflict, and climate change have brought to education and the situation seems particularly stressful for those working in higher education. Indeed, reimagining engineering degrees is a huge task that involves questioning fundamental questions like 'what,' 'how' and 'why' we teach, and coupling that questioning with emerging understanding about how to engineer with deeper consideration of the broader impacts of engineering on people and the planet.

Educators must be supported in addressing these challenges, and this includes the support they require to build their own knowledge and skills in what are often new areas. Workshop presenters have worked with hundreds of engineering faculty, gathering feedback about their interests, priorities and needs for preparing students in today's context. This process has informed the co-creation of several teaching tools and curricular planning tools and has also revealed other gaps educators would like addressed. Among these are opportunities to develop their confidence, capabilities and commitment in teaching social and environmental sustainability/responsibility (in terms of both content and pedagogy), assessment of student learning, and assessment of their own teaching competence. With all this in mind, this workshop has three aims:

1. Engage with participants to critically reflect on the challenges, gaps and opportunities for preparing future engineers to be globally responsible and well-versed in sustainability.
2. Enable participants to identify what support is available to help them with "what" to teach but also on the "why" and "how" of educating globally responsible engineers. Presenters will showcase a suite of useful tools that participants can use (and the story of how they were co-created) to effectively

integrate social and environmental sustainability/responsibility into engineering education.
3. Identify what evolving teaching means for the roles educators play, and the competencies and capabilities required.

Following the workshop, participants will be able to:

1. Reflect on their own levels of competency in education for global responsibility, remaining needs or gaps, and identify resources that can support their development;
2. Access new tools, each containing multiple resources, (Reimagined Degree Map, Sustainability Toolkit, Engineering for One Planet) for supporting educators to develop their own knowledge and skills in order to integrate sustainability into engineering education and explain the relevance of these tools to their module/programme;
3. Consider the practical changes they can make to their institution's degrees, deeply consider what they need to invest in to support their team to adopt them and adapt to the changes.
4. Introduce these tools to their colleagues and advocate for their use.

1.2 Background and rationale

Society relies on engineering companies and professionals to build nearly everything around us and to address the urgent social and environmental challenges we face, including the transition to net zero and beyond. Yet coverage of sustainability, inclusion and ethics across engineering degrees remains insubstantial and inconsistent. Engineering education is key to shaping the next generation of engineers not only as technological experts but also as responsible citizens, equipping them to use their unique problem-solving capability to play a crucial role in stewarding humanity's future. Their impact is immense: in the UK alone, 250,000 engineers are expected to graduate from its universities before 2030, and these engineers will help shape the world we live in for at least 40-50 years (Engineers Without Borders UK, 2024).

The need for engineers to embrace global responsibility has long been recognised (Kamp, 2020) and now comes through as a central message of a new initiative called "Engineers 2030" catalysed by the Royal Academy of Engineering (2024). It emphasises the need for engineers to continuously develop their skills and approaches due to digitalisation, rapidly evolving complex technologies and the sustainability crisis. However, recent studies reveal a deeply concerning skills gap whether it is the capability to deliver on industry sustainability strategies (Institution of Engineering and Technology, 2021), decarbonisation and meeting net-zero targets, or a lack of exposure to the United Nations Sustainable Development Goals (SDGs) in higher education (Siemens, 2023), which has alarming repercussions for the workforce. Add to this the sense that "engineering degrees are not 'fit for purpose'", a sentiment that has emanated from both industry and professional bodies in recent years (see e.g. Flaig, 2022) and it is clear that change is urgently required in engineering higher education.

Decisions taken by people at every level of universities shape the content of a degree and the resultant student experience. Successful improvement in teaching often hinges on the emotional and cultural journey taken by an institution to create change (Goldberg and Somerville, 2023). Empowering people to act at all levels is key, as is developing shared direction and strong ambition across a department or faculty. This workshop is all about clarifying how to navigate making changes and equipping educators to act–from learning about new concepts and technologies, to discovering different pedagogies, to changing activities, projects and assessments, to making shifts at the strategic level that require adjusting outcomes and degree content.

During SEFI 2023, the Engineering Professors Council, Engineers Without Borders UK, and Engineering for One Planet shared three new resources through an introductory and reflective workshop - to catalyse educators who are enthusiastic about bringing sustainability into engineering education but lack the tools or practices they need to do so effectively. Read the report to learn more. https://www.sefi.be/2023/10/31/tools-for-sustainability-in-engineering-education/. Thanks to input from stakeholders in sessions like that one, the resources are now fully developed and shareable.

They are:

- The Reimagined Degree Map project undertaken by Engineers Without Borders UK (developed in collaboration with the Royal Academy of Engineering and endorsed by the Engineering Council, the Institution of Mechanical Engineers and the Institution of Materials, Minerals, and Mining);
- The Sustainability Toolkit project undertaken by the UK's Engineering Professors' Council (sponsored by Siemens and the Royal Academy of Engineering);
- The Engineering for One Planet (EOP) Framework of key social and environmental sustainability learning outcomes co-created by hundreds of engineering education stakeholders and used by hundreds of faculty (sponsored by The Lemelson Foundation), mapped to ABET and AHEP4 standards, and companion teaching guides.

Based on existing frameworks for teaching sustainability topics (e.g., Wiek et al., 2011) and extensive input from educators, students and practitioners in the engineering system, these tools simplify the process of curricular change. Some of these tools have already been vetted and used to modify or introduce hundreds of courses. Nevertheless, very little research and knowledge exists about the key competencies engineering educators need to develop in order to effectively teach and assess such content.

This workshop therefore will focus on what is needed to build the capacity of engineering educators to integrate global responsibility into their teaching. With participant reflection and input, we will aim to articulate key educator competencies needed to successfully teach and assess the skills of globally responsible and sustainability-minded future engineers. Through a hands-on approach, we will showcase how these available resources can be used to bolster what they know, what they can do, and how they can act to make the changes needed in engineering education.

2 STRUCTURE OF THE WORKSHOP

2.1 Audience

This session is relevant to engineering educators of all disciplines and backgrounds in higher education, as well as administrators and programme leaders responsible for accreditation and/or curriculum development.

2.2 Session Outline

This 60-minute interactive workshop will deepen attendees' understanding of *why* sustainability, ethics and inclusion must be embedded in engineering education, and *how* they could be implemented in their own educational contexts.

1. (15 minutes) First, the workshop will introduce the Knowledge, Skills, and Attitudes (KSA) framework that has been used to describe sustainability competence, such as in the European Commission's GreenComp Framework (2022). Through a reflective exercise and small group discussion, we will consider how these might be applied to engineering educators in the context of their work.
2. (10 minutes) Second, the participants will engage in a large-group discussion on how educator development of these KSAs might facilitate the ability for engineering programmes to change to meet 21st century needs. In this portion of the workshop, we will also identify barriers to both competency development and change-making within universities.
3. (30 minutes) Third, participants will have the opportunity to engage and explore interventions and practical steps they can make in their own institution, department, and modules with the support of the Reimagined Degree Map, Sustainability Toolkit, and Engineering for One Planet's "Tools for Teaching and Learning" resources.
4. (10 minutes) Finally, participants will be guided to reflect on existing good practice, where gaps remain in implementation and opportunities for collaborating through adopting these resources for driving change within engineering curricula.

3 RESULTS AND IMPACT

The intention was that the workshop initiated a broader conversation about the continuous professional development of educator competencies and commitment to teaching global responsibility. While some promising initial work has been done in this area (e.g. Corres et al., 2020; Kondur et al., 2020), clearly more needs to be done to support this, especially within engineering teaching.

One way to start this process is to ask educators to reflect on their own competencies. So, after introducing the Global Responsibility Competency Compass (a resource by Engineers Without Borders UK which articulates 12 essential competencies that align with the four principles of global responsibility: Responsible, Purposeful, Inclusive, and Regenerative. See www.ewb-uk.org/global-responsibility-competency-compass), we used Menti (polling software) to ask participants to rate themselves on the competencies they personally felt most and least confident about. Participants reported being most comfortable with two Skills competencies: Building

Resilience, and Facilitation, and with the Knowledge competency of Diversity, Equity, and Social Justice. They reported being least comfortable with the Mindset competency of Technology Stewardship and the Knowledge competency of Life-Centred Design.

We then used Padlet (collaboration software) to survey participants on which knowledge, skills, and mindsets engineering educators needed to have and develop to become confident and competent in teaching global responsible practice to students. In response to the question “What should engineering educators KNOW?”, replies included:

- How to effectively and seamlessly incorporate sustainability topics into their courses;
- That ‘correct’ solutions don’t exist;
- How students identify with engineering prior to enrolment;
- What the impact of introducing sustainability topics is to an engineering course;
- Emerging teaching methods;
- Broader non-technical content;
- How to incorporate aspects of humanities and social sciences into technical modules;
- How to develop reflection and awareness in ourselves and our students.

In response to the question “What should engineering educators be able to DO?”, replies included:

- Ask questions to generate clarity over time;
- Analyse and communicate data;
- Use statistical models and prognoses;
- Apply critical thinking;
- Address sustainability issues according to discipline.

In response to the question “How do engineering educators need to BE?”, replies included:

- Sensitized to social dynamics and complexity;
- Nimble and open to change;
- Curious, humble and open-minded.

Participants then worked in groups to explore the various resources available to them to support this competency development and educational practice: The Engineering for One Planet Framework, the Sustainability Toolkit, and the Reimagined Degree Map. 95% of attendees had not previously encountered these resources, and they left the session with ideas about how they could be used in their own teaching contexts.

Finally, because another outcome for the workshop was to discuss opportunities for establishing an international community of practice dedicated to using, promoting, and further developing these resources, we shared lessons learned to spur larger institutional change and asked participants to suggest ways that we could help each other. “Collaboration” was the theme of the responses, with “dialogue,” “share practices”, “communicate,” “listen,” and “cooperate” among the words used.

The more we understand why the world needs globally responsible engineers, why degrees need to evolve to meet this demand, why our pedagogies need to be active and contextual and therefore our assessments need to be authentic, the more likely we as educators are to feel connected to a culture of continuous improvement, and to feel motivated to make these changes within our departments or faculties. This leads not only to purposeful and future-proof engineering graduates, but also to educators with a stronger sense of meaning and purpose.

REFERENCES

Corres, Andrea, Marco Rieckmann, Anna Espasa, and Isabel Ruiz-Mallén. "Educator Competences in Sustainability Education: A Systematic Review of Frameworks" *Sustainability* 12, no. 23 (November 2020): 9858. https://doi.org/10.3390/su12239858

European Commission Joint Research Centre (2022). “GreenComp: The European sustainability competence framework”. https://publications.jrc.ec.europa.eu/repository/handle/ JRC128040. Accessed 12 June 2024.

Engineers Without Borders UK (2024) “Reimagined Degree Map”. https://www.ewb-uk.org/reimagined-degree-map/. Accessed 12 June 2024.

Flaig, J. (2022). “Learning curve: Are engineering degrees fit for purpose? Institution of Mechanical Engineers”. https://www.imeche.org/news/news-article/learning-curve-are-engineering-degrees-fit-for-purpose

Goldberg, David and Mark Somerville. A Field Manual for a Whole New Education: Rebooting Education for Human Connection and Insight in a Digital World. (ThreeJoy Associates, 2023).

Kamp, Aldert. Navigating the Landscape of Higher Engineering Education: Coping with Decades of Accelerating Change Ahead. (4TU Centre for Engineering Education, TUDelft, 2020).

Kondur, Oksana, Halyna Mykhailyshyn, Nataliia Ridei, and Oksana Katsero. “Formation of Competences of Future Educators for Requirements Education for Sustainable Development.” *Journal of Vasyl Stefanyk Precarpathian National University* 7, no. 1 (April 2020): 7–14.

Institution of Engineering and Technology (2021) “93% of industry without skills to meet 2050 climate targets”. https://www.theiet.org/media/press- releases/press-releases-2021/press-releases-2021-january-march/2-february-2021- 93-of-industry-without-skills-to-meet-2050-climate-targets. Accessed 4 October 2023.

Rouvrais, Siegfried; Gaultier Le Bris, Sophie; Stewart, Matthew. "Engineering Students Ready for a VUCA World? A Design based Research on Decisionship".

Proceedings of the 14th International CDIO Conference, KIT, Kanazawa, Japan. (July 2018): 872–881.

Royal Academy of Engineering (2024). “Engineers 2030: redefining the engineer of the 21st century Future skills needs – a review of the literature”. https://raeng.org.uk/media/mk4kpnpu/raeng-future-engineering-skills-lit-review-final.pdf. Accessed 19 March 2024.

Siemens (2023). “Skills for sustainability. The Student Voice”. https://resources.sw.siemens.com/en-US/analyst-report-the-student-voice-report-for-the-skills-for-sustainability-survey. Accessed 4 October 2023.

The Lemelson Foundation. The Engineering for One Planet Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022). Cynthia Anderson and Cindy Cooper (Eds). (The Lemelson Foundation, Portland, Oregon, USA, 2022), 28.

Wiek, A., Withycombe, L. & Redman, C.L. Key competencies in sustainability: a reference framework for academic program development. *Sustainability Science,* no. 6 (May 2011): 203–218, https://doi.org/10.1007/s11625-011-0132-6

Lifelong learning as an engineering educator: A hands-on co-creation exercise to enhance engineering students' lifelong learning competencies

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Conference Key Areas: *Continuing education and life-long learning in engineering, Engineering skills, professional skills, and transversal skills*
Keywords: *lifelong learning competencies, educational practices, assessment, personal development process*

ABSTRACT

Teaching staff in engineering education often recognize the importance of Lifelong Learning (LLL) competencies but may feel ill-prepared to support students in developing these essential competencies. The TRAINengPDP project, an Erasmus+ initiative, addresses this challenge by focusing on preparing students for LLL through a Personal Development Process (PDP). This final workshop of the project aims to facilitate the co-creation of practical intervention designs. Drawing from a survey capturing perceptions of LLL competencies within engineering practice, alongside a scoping review of successful interventions in higher education, the workshop provides a comprehensive toolkit. This toolkit includes a training scheme for lecturers and the ENG-IST tool, designed to assist educators in selecting and implementing appropriate interventions, which can be tailored to their specific context. Participants engage in activities aimed at assessing the applicability of PDP interventions, designing interventions to develop specific LLL outcomes, and proposing assessments to evaluate achievement of these outcomes. Through active participation in the workshop, engineering educators can bridge the gap between recognizing the importance of LLL competencies and effectively integrating them into their teaching practice. By co-creating practical intervention designs, educators not only enhance their capacity to foster LLL competencies in students but also strengthen their own proficiency in lifelong learning practices. This workshop offers a valuable opportunity for engineering educators to acquire the tools and strategies needed to cultivate resilient, adaptable learners capable of thriving in a dynamic professional landscape. During the workshop 5 intervention designs were co-created.

1 MOTIVATION AND LEARNING OUTCOMES

Teaching staff often acknowledge the importance of Lifelong Learning (LLL) competencies but they do not necessarily feel adequately prepared to support students' personal development towards obtaining these important skills. TRAINengPDP is an Erasmus+ project which aims to prepare students for a life full of learning through a personal development process (PDP).

As part of the project a toolkit will be developed, including a training scheme for lecturers, the ENG-IST tool to support lecturers when selecting and implementing the appropriate intervention for their context, case studies of the project including the lessons learned from the pilots, and designs for possible interventions. In this final workshop of the TRAINengPDP project, the focus will be on co-creation of practical intervention designs. Participants of the workshop will be able to:

1. Assess the applicability of PDP interventions for achieving specific LLL learning outcomes.
2. Design a PDP intervention which enables development of specific LLL outcomes.
3. Propose an assessment to evaluate achievement of specific LLL learning outcomes.

By the end of the workshop participants will have a design draft of how to use a PDP intervention in their teaching practice.

2 BACKGROUND AND RATIONALE

Last year, the project team organized a survey to capture engineering students' and lecturers' perceptions about lifelong learning (LLL) competencies required in engineering practice (Beagon et al., 2023). Lifelong Learning (LLL) is considered to be a container concept, consisting of a variety of competencies. In their systematic review, Cruz et al. (2019) list the most frequently used criteria for lifelong learning competencies in engineering: self-reflection, willingness, motivation and curiosity to learn, self-monitoring, locating and scrutinizing information, and creating a learning plan. The results of the survey indicate that both students and lecturers consider all of the different competencies are either important or very important. Additionally, the results show that students and lecturers perceive that these lifelong learning competencies, are only taught to a limited extent and evaluated even less (Authors 2023). This in in line with another outcome of the project, namely the analysis of engineering study programmes to map out the extent to which LLL competencies are currently included. Findings indicated that there are very few learning outcomes which explicitly address LLL competencies.

The project team undertook a scoping review to identify which types of interventions have already been successfully implemented in higher education more generally (Beagon et al., 2022). We used these findings and the contextual aspects of how they were implemented to create the ENG-IST tool to be appropriate to the engineering classroom. The ENG-IST tool is a flowchart which identifies the most appropriate intervention for a particular context, and the educator's aims, based on different criteria and preconditions. In this workshop the participants will use the ENG-IST tool to develop an intervention design.

Participant engagement

0-10 minutes: Short introduction to the workshop, used concepts and definition, and introductory explanation of currently developed material.

10-20 minutes: Each group gets a learning outcome and individually choose two interventions that they believe they can use to achieve the learning outcome by using the ENG-IST tool. (LO1)

20-30 minutes: Use the intervention sheet to work out the intervention individually (LO1 & LO2)

30-35 minutes: Share with a pair (LO2)

35-45 minutes: Based on the selected teaching methods or tools, participants will individually work on including assessment and finalize their design. (LO3)

45-50 minutes: Share with group (LO2 & LO3)

50-60 minutes: Wrap-up by shortly, each group provides one example they worked out with some feedback and evaluate the usefulness of the intervention sheets. Each participant takes away an intervention design (LO1, LO2 & LO3).

Summary after the workshop & takeaway message

The different designs of the participants were collected and summarized after the workshop. The outputs will be included as a possible design in the toolkit. The five different designs are added in Appendix A.

Significance for engineering educators

Although teaching staff acknowledge the importance of LLL competencies, they are not considered the primary teaching goals (Nesterova, 2019) nor do they feel adequately prepared to support students in developing a LLL attitude nor the PDP itself. By engaging in this workshop, educators will gain access to a comprehensive toolkit developed through the TRAINengPDP, specifically designed to aid in the selection and implementation of PDP and LLL interventions. Through the co-creation of practical intervention designs, educators will not only enhance their ability to foster LLL competencies in their students but also strengthen their own proficiency in LLL.

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Appendix A

Case 1

a. Learning objective: The student can manage projects effectively, including the ability to plan, execute, and oversee tasks while considering resource constraints.

b. Context: Introductory course for new doctoral students, where students use the writing of their first journal article as a learning project. Hence the project has a tangible goal and the project is concrete and useful but not too big. Related to the project students need to define their timeline, end-users, milestones, roles and responsibilities, communication etc.

c. Teaching interventions to support the learning objective: Active student engagement. In class activities. Student-centered methods, Knowledge transfer sessions (e.g. upon tools, frameworks, external factors etc.), Mentoring (story-telling & peer support for intrinsic motivation), Reflective journal (peer evaluation, "advisory board" similar to real projects)

d. Assessment practices and criteria to support the learning objective: Criteria: ability to lead, reaching goals, own strategy building, ability to update plan, people committed, sticking to the budget. Practices: Feedback from project partners (co-authors. advisor/supervisor)

Case 2:

a. Learning objective: The student can solve problems, can respect deadlines, be flexible, and shows perseverance

b. Context / target group: 1st year undergraduate students

c. Teaching interventions to support the learning objective: E-portfolio

PDP-phase	Related activities
Identify	Students follow workshops in order to find out more about skills in professional context. Students set goals for themselves.
Prepare	Students prepare their portfolio. They make a plan for the semester, including deadlines.
Act	Updating the portfolio during semester. Collecting examples, reflecting on tasks and planning.
Monitor	Intermediate peer and/or mentor meetings to discuss progress and receive feedback.
Reflect	Conclude with a short reflection on the goals and the planning.

d. Assessment practices to support the learning objective:

Pass / Fail based on:

1. Participation in the workshop
2. Final portfolio (evaluation complemented by meeting with mentor

CASE 3:

Learning objective: The student can think critically and rationally about the role and responsibilities of engineers in their work organization and in society.

Context: not specified

Teaching interventions to support the learning objective**:** stimulate students to observe the world/news to see what engineers have been doing this day or week, and how that impacts the world

Assessment practices to support the learning objective**:** Reflective essay applying the approach of A.D. de Groot: Write about what you learned about the world: 1) What surprised you about the world; 2) what you learned about yourself; and 3) what surprised you about yourself - conveying an explicit and implicit message to continue to do this all your professional life

CASE 4:

Learning objective: The student can improve their professional competencies throughout the internship/module.

Context: International 1st year cohort of master's students; professional competencies understood to consist of e.g. self-regulation, reflective practice, value creation, working in teams, international/cultural skills, listening & communication, anticipatory thinking

Teaching interventions to support the learning objective: Reflective journal, in which students answer weekly following three questions

1. Most satisfying experience this week?
2. Most challenging experience this week?
3. What made you curious and want to learn more?

At the end of semester students deliver a copy of their journal including a final statement/conclusion

Assessment practices to support the learning objective: Journal contributes to the final assessment of students

CASE 5:

Learning objective: The student can integrate and apply knowledge from different engineering disciplines to address multidisciplinary challenges.

Context: Smart cities master, 1st year course on optimization methods, linear programming and network

Teaching interventions to support the learning objective:

PDP-phase	**Related activities**
Identify	1. Quick overview of the methods students need to comprehend (leaving space for others they may want to use and/or develop) 2. Look into city reality for problems that students find useful to solve
Prepare	Define the problem carefully with different steps to be accomplished (teacher support/input with materials to read/research)
Act	
Monitor & Reflect	Regular presentations evaluated by the teacher providing formative feedback about execution and constraints. Students incorporate the feedback to improve the tasks.

Assessment practices to support the learning objective: Students present the project with report and oral presentation

REFERENCES

Beagon, U., Byrne, A., Depaor, C., Van den Broeck, L., Dujardin, R., Craps, S., Naukkarinen, J.. "Lifelong Learning competencies in Engineering Programmes – Heat Map Report." Available on the TRAINengPDP project website (2022).

Cruz, M. L., Saunders-Smits, G. N., & Groen, P. "Evaluation of competency methods in engineering education: a systematic review." *European Journal of Engineering Education* 45,5 (2019): 729-757.

Beagon, U., Byrne, A., Depaor, C., Van den Broeck, L., Dujardin, R., Craps, S., Naukkarinen, J.. Help Them Grow – The ENG-IST Tool - Supporting Students' Personal Development Process To Stimulate Lifelong Learning. Paper presented at *European Society for Engineering Education (SEFI), Dublin, September 2023*.DOI: 10.21427/7V8Q-YQ07

Nesterova, O. (2019). "Lifelong learning competence development of mining students and academic integrity: Case study of language courses". *Mining of Mineral Deposits*, *13*,1 (2019): 80–85. https://doi.org/10.33271/mining13.01.080

Workshop: Teach Students how to Study Successfully - What science tells you as a lecturer about effective learning and studying

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Conference Key Areas: *Teaching technical knowledge in and across engineering disciplines, Continuing education and life-long learning in engineering, Engineering skills, professional skills, and transversal skills, Curriculum development and emerging curriculum models in engineering and Building the capacity and strengthening the educational competences of engineering educators*
Keywords: *Evidence Informed (meta-)Cognitive Study Strategies*

ABSTRACT

The workshop "Teach Students How to Study Successfully" utilizes contemporary cognitive psychology to improve teaching effectiveness in engineering education. Addressing the gap in students' study skills, this workshop integrates evidence-based strategies to promote deep learning and motivation. Participants will explore historical and modern learning theories, challenge common learning myths, and apply Cognitive Load Theory to optimize teaching practices. Through hands-on exercises, interactive min-sessions, and group discussions, educators will experience and implement effective study strategies such as spaced repetition, retrieval practice, and self-explanation. The workshop aims to provide educators with tools to develop self-regulated learners, promote resilience, and create supportive learning environments.

Key takeaways include the importance of understanding cognitive, metacognitive, and behavioural aspects of learning, the necessity of practical application of these strategies, and the value of continuous reflection and adaptation of teaching methods. The workshop emphasizes collaboration among educators to share

insights and create a community of practice. By redesigning their educational practices based on workshop insights, participants will enhance their teaching methodologies, ultimately improving students' learning outcomes. This approach aligns with SEFI's mission to advance engineering education across Europe.

Participants will receive a comprehensive guide of effective study strategies, access to the original publication, and assignments to reflect and integrate these strategies into their teaching. The goal is to empower educators with confidence and tools to transform their methodologies, thus encouraging deeper learning and improved academic performance among students.

1 INTRODUCTION

Unfortunately students entering ours universities do not always have the right study skills. They might use study strategies that feel good, but are not that effective at all. One of my students* rephrased this by saying: “How to score straight A’s in the least amount of time!” Of course I don’t like the idea of only focusing on grades, neither did he: “No by really engaging and emerging yourself in learning, you do not only achieve deeper learning but your motivation increases as well!”.

This student was really touched by the workshop How to Study Successfully, a quite similar workshop I’ve given over 25 times now – So much so, that he dove into even more literature about studying and learning. That is something I hope to achieve with some participants as well.

I am pleased to present a workshop proposal entitled "Teach Students how to Study Successfully”. I aim to leveraging scientific insights for enhanced teaching efficacy. This workshop aims to illuminate the intersection of time-honored educational practices with the rich, empirical insights of contemporary cognitive psychology.

Drawing inspiration from luminaries such as Leonardo da Vinci and the foundational research of B.F. Skinner, the workshop will explore beyond traditional reward systems to the sophisticated processes that shape human cognition and learning. The workshop will dissect the nuances of visual stimuli in memory retention, challenging educators to reconsider the very fabric of teaching methodology.

Grounded in evidence-based strategies and historical pedagogy, including Guy Whipple's seminal "How to Study Effectively," the workshop aims to redefine the educational narrative. The workshop intends to foster an environment in which educators are equipped to cultivate self-directed learners and instil effective study habits as second nature.

This workshop will not only provide a platform for academic exchange but also serve as a catalyst for educational transformation within the engineering community. The workshop is based on the publication “Leer studenten studeren met succes” (Hoof 2021).

I look forward to the opportunity to contribute to SEFI's mission of enhancing engineering education across Europe.

Figure 1: The original publication Leer studenten studeren met succes. (Thomas More-hogeschool 2021)

Teach Students how to Study Successfully!

2 INTENDED LEARNING OUTCOMES

The publication "*Leer studenten studeren met succes*" (Hoof 2021) is very condensed and touches upon many cognitive, meta-cognitive and behavioral aspects of learning and studying:

1. **Understand the Evolution and Psychology of Learning:** Participants will be able to articulate how historical views on learning have evolved over time, including misconceptions and advancements in cognitive science.
2. **Comprehend Modern Learning Theories:** Participants will comprehend behaviorism and its implications for learning and recognize the shift towards cognitive theories that emphasize the roles of visual stimuli and memory processes.
3. **Define and Distinguish between Learning and Studying:** Participants will distinguish between innate learning processes and the deliberate practice of studying, understanding the cognitive activities that contribute to effective learning outside the classroom environment.
4. **Recognize and Challenge Learning Myths:** Participants will be able to identify and challenge common myths about learning, such as learning styles and multitasking, and understand their implications for teaching practices.
5. **Apply Cognitive Load Theory:** Participants will understand the principles of cognitive load theory and be able to apply this understanding to reduce unnecessary cognitive load in learners.
6. **Implement Metacognitive Strategies:** Participants will apply metacognitive strategies that help learners plan, monitor, and evaluate their understanding and progress.
7. **Develop and Encourage Effective Study Habits:** Participants will foster strong, motivating study habits based on evidence-based strategies, such as spaced repetition, retrieval practice, and self-explanation.
8. **Utilize Knowledge of the Brain and Memory:** Participants will gain knowledge of how the brain processes information and how memory works, applying this to enhance teaching and learning methodologies.
9. **Facilitate Self-Regulated Learning:** Participants will foster self-regulated learning in students, enabling them to become autonomous learners capable of setting goals, self-assessment, and adapting study approaches.
10. **Promote Metacognition in Learning:** Participants will understand the importance of metacognitive knowledge in their own learning process, using it to plan, monitor, and assess their study methods.
11. **Create a Supportive Learning Environment:** Participants will learn to construct a learning environment that minimizes distractions and maximizes engagement to aid the learning process.

12. **Develop Resilience and Adaptability in Learning:** Participants will be able to encourage students to embrace challenges and to develop resilience, understanding that struggle and difficulty are natural and necessary aspects of effective learning.

13. **Design Brain Friendly Learning Experiences:** Participants will be able, integrating all of the above, to redesign their educational practices into more effective and efficient active learning activities that use maximizes the students' brain potential.

3 RELEVANCE FOR AUDIENCE AND ENGINEERING EDUCATION IN GENERAL

Teaching lecturers about study strategies is essential for engineering education because of the unique challenges this field presents to students. Engineering courses often involve complex theoretical concepts in topics such as thermodynamics, or statics, or circuit analysis coupled with practical applications that require a deep understanding and retention of knowledge. Students frequently encounter multidisciplinary subjects that span mathematics, physics, materials science, and more, making the ability to integrate knowledge from various domains critical.

3.1 Common Study Problems Faced by Students:

1. **Conceptual Understanding:** Students often memorize procedures without understanding the underlying principles, leading to difficulties when problems require adaptive thinking.
2. **Integration of Disciplines:** Engineering programs often require knowledge of multiple disciplines, and students may struggle to see the connections between them.
3. **Time Management:** The volume and complexity of material can overwhelm students, making effective time management and study planning critical.
4. **Application of Theory to Practice:** Students may find it challenging to apply abstract theoretical knowledge to practical, hands-on problems.
5. **Overreliance on Rote Learning:** Engineering students may resort to rote learning, which is less effective for long-term retention and understanding, particularly in complex problem-solving.

Becoming aware of the problems students might have is often the first step to start helping them. Of course studying effectively is something they must do themselves, but implicitly and explicitly showing them what might work best for them, is something a lecturer can do.

3.2 Importance of Teaching Study Strategies to Lecturers:

1. **Enhanced Learning Outcomes:** When lecturers understand effective study strategies, they can design courses that promote better comprehension, retention, and application of complex engineering concepts.
2. **Cognitive Load Management:** Engineering students often face high cognitive loads due to the density of information. Lecturers can help manage

this by presenting information in ways that align with cognitive load theory, making learning more efficient.

3. **Problem-Solving Skills:** Engineering is a problem-solving discipline. Lecturers equipped with study strategies can teach students how to approach problems systematically, fostering critical thinking skills.
4. **Adaptability:** Engineering fields evolve rapidly with technology. Understanding study strategies enables lecturers to equip students with the skills to learn independently and stay updated with emerging trends.
5. **Practical Application:** Engineering requires the translation of theoretical knowledge into practical solutions. Lecturers can use study strategies to bridge this gap, emphasizing learning activities that simulate real-world engineering challenges.

Becoming aware of what impact lecturers can have on the learning and studying of students is often liberating, and feels enabling. Yes, you can make a difference! When faculty members join forces and align courses with the cognitive, meta-cognitive and behavioral principals in mind this impact will be even bigger. Students will increasingly get better at applying the study strategies.

They might surprise you with their deeper learning capabilities and the level of learning outcomes that become achievable.

4 ACTIVATING THE PARTICIPANTS

A workshop about Studying Effectively must contain effective study strategies. I'll do one better! Most of the study strategies will be experienced by the participants during the workshop! Therefor the workshop will be a mix of different activating activities in which participants will be asked to combine their own insights with the insights from the workshop to improve their teaching practice:

- **Interactive Sessions**: Participants will be actively encouraged to share insights from their experiences in teaching and learning. These sessions will be shaped by participant contributions, fostering a collaborative learning environment.
- **Hands-on Exercises**: Engaging, hands-on exercises will provide participants with a firsthand understanding of how the brain processes and retains information. Practical tasks will allow participants to experience effective study strategies and observe their impacts on learning.
- **Group Discussions**: Small discussion rounds will focus on challenging and bold statements about learning. These discussions are designed to provoke critical thinking and reassessment of existing beliefs and teaching practices.
- **Direct Instruction Bursts**: Concise, direct instruction sessions will cover theoretical foundations and current research on cognitive processes, metacognition, and the impact of learning behaviors. These bursts of learning will provide the scaffolding necessary for participants to understand the why behind the practices being discussed.
- **Educational Practice Assignments**: Assignments will prompt participants to reflect critically on their own teaching methods and consider

practical ways to modify them in favor of more effective study strategies. Participants will use the Wave model of blended learning to design the learning process of their students using the effective study strategies adjusted to their educational needs and setting.

A hand-out will facilitate rapidly shifting from one activity to another. An active learning space would best suit this workshop.

5 TAKE HOME MESSAGE

The take-home message of the workshop emphasizes the vital role that educators play in shaping not just the knowledge but also the learning skills of their students. It underlines the necessity of a strategic approach to teaching that goes beyond the dissemination of content to encourage life learning learning through evidence-based study strategies. The key points for participants to carry forward would include:

1. **Effective Study Strategies Matter:** A deep understanding of cognitive, metacognitive, and behavioral aspects of learning is crucial for enhancing the efficacy of study practices in engineering education.
2. **Practical Application is Key:** The theoretical knowledge of learning strategies gains true value when applied in practice. Participants are urged to actively incorporate these strategies into their teaching.
3. **Adaptation and Personalization:** While there is a shared foundation of effective strategies, the most impactful implementation will vary based on individual teaching styles and student needs.
4. **Continuous Reflection and Improvement:** The process of integrating these strategies requires ongoing reflection and willingness to adapt one's teaching practices for continual improvement.
5. **Collaboration and Sharing:** Educators are encouraged to share their experiences and insights with their peers, fostering a community of practice that supports mutual growth.

Participants will be provided with:

1. **A Comprehensive Document:** A detailed guide of effective study strategies will serve as a reference to support the integration of these methods into educational practices. This 10 pager describes the study strategies:
    - What is it?
    - Examples
    - When to use and for which goal
    - How to apply
    - Pitfalls
2. **Access to Original Research:** A link to the original publication (in Dutch for now but English might be there over the summer) will be made available for those who wish to delve deeper into the research behind the strategies discussed.
3. **Impactful Assignments:** The final assignment, which involves redesigning their educational practice, serves as an indirect measure of the workshop's impact and the participants' readiness to implement new strategies.
4. **Collective Reflection:** Reflecting together on the ease of incorporating these strategies into their teaching will culminate in a shared understanding of the most effective ways to implement these strategies in educational practice.

Figure 2: Cards with the study strategies. (Expertisecentrum Onderwijs en Leren (ExCEL) 2022)

The overarching goal is to leave educators with not only a toolkit of strategies but also the confidence to transform their teaching methodologies and, by extension, enhance their students' learning outcomes.

6 RESULTS

The "Teach Students How to Study Successfully" workshop yielded significant positive outcomes among the participating educators. The attendees were highly engaged throughout the sessions, actively contributing to discussions, exercises, and collaborative activities designed to immerse them in effective learning strategies.

Active Engagement and Participation

All participants demonstrated a high level of engagement during the workshop. They enthusiastically took part in interactive sessions and hands-on exercises that simulated cognitive processes related to learning and memory retention. This active participation fostered a collaborative environment where educators felt comfortable sharing insights and challenging existing beliefs about teaching and learning.

One participant encapsulated the collective sentiment by stating, "Of course we don't want students to reinvent the bicycle, but in order to understand the topic, students should reinvent the bicycle." This remark highlighted a shared recognition of the importance of encouraging students to actively engage with lesson content to deepen their understanding.

Enhanced Understanding of Cognitive Processes

Participants developed a robust understanding of how the brain functions in the context of learning. Through direct instruction bursts and practical exercises, they explored concepts such as cognitive load theory, metacognition, and the mechanics of memory. This enhanced understanding enabled them to critically assess and refine their teaching methodologies.

Integration of Effective Learning Strategies

A key outcome of the workshop was the successful integration of evidence-based learning strategies into participants' teaching practices. Utilizing the comprehensive guide provided, educators redesigned lesson plans for their courses, incorporating strategies such as:

- **Spaced Repetition:** Scheduling content reviews at increasing intervals to enhance long-term retention.
- **Retrieval Practice:** Encouraging students to recall information without prompts to strengthen memory pathways.
- **Self-Explanation:** Prompting students to explain concepts in their own words to reinforce understanding.

By applying these strategies, participants aimed to foster stronger, more effective study habits among their students.

Revamped Lesson Plans and Educational Practices

Participants employed the Wave model of blended learning to redesign their lesson plans, ensuring that the new approaches were tailored to their specific educational settings and student needs. The revamped plans featured:

- **Application of Cognitive Load Theory:** Adjustments were made to instructional materials to reduce extraneous cognitive load, making content more accessible without oversimplifying complex engineering concepts.
- **Metacognitive Skill Development:** Activities were incorporated to help students plan, monitor, and evaluate their own learning processes, promoting autonomy and self-regulated learning.
- **Supportive Learning Environments:** Changes were made to classroom setups and teaching approaches to minimize distractions and enhance student engagement.

Feedback and Reflection

Participants provided positive feedback on the workshop's impact, noting an increased confidence in their ability to apply cognitive and metacognitive strategies in their teaching. They appreciated the practical nature of the workshop and the immediate applicability of the strategies discussed. As one participant stated: “You have teached as you preached (.. about effective learning strategies).”

Educators also engaged in collective reflection on the ease and challenges of incorporating these strategies into their teaching practices. This reflection facilitated a shared understanding of best practices and potential pitfalls, reinforcing the workshop's collaborative spirit.

Impact on Teaching Methodologies

As an indirect measure of the workshop's effectiveness, the participants' readiness to implement new strategies was evident in their redesigned lesson plans and commitment to applying what they learned. The immediate integration of effective study strategies into their courses suggests a meaningful transformation in teaching methodologies that is likely to enhance student learning outcomes.

REFERENCES

Expertisecentrum Onderwijs en Leren (ExCEL). *X - Expertisecentrum Onderwijs en Leren (ExCEL).* 26 11 2022. https://twitter.com/ExCELThomasMore/status/1596436160280072193 (geopend 06 24, 2024).

Hoof, T., Surma, T., & Kirschner, P. A. *Leer studenten studeren met succes.* Antwerpen: Thomas More-hogeschool, 2021.

Thomas More-hogeschool. *(Leer studenten) Studeren met succes.* 2021. https://thomasmore.be/nl/onderwijs-en-leren/leer-studenten-studeren-met-succes (accessed 06 24, 2024).

INNOVATING RESPONSIBILITY: FOSTERING CREATIVE COMPETENCES FOR SUSTAINABLE ENGINEERING SOLUTIONS

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Conference Key Areas: *Diversity, equity and inclusion in our universities and in our teaching, Building the capacity and strengthening the educational competences of engineering educators*
Keywords: *creativity, innovation, diversity, responsibility, competences*

1 MOTIVATION AND LEARNING OUTCOMES

In an increasingly technology-driven and complex world, STEM jobs are crucial for fostering innovation with a focus on social and environmental responsibility. However, the engineering sector is currently facing a shortage of qualified professionals. Therefore, it is crucial to adequately prepare young individuals for careers in engineering to ensure a sustainable future. To address the lack of skilled professionals, education plays a vital role in developing relevant skills that drive innovative and creative solutions (Cropley 2015; Felder 1988). Beyond intellectual capabilities, research highlights the impact of self-efficacy – the belief in one's ability to surmount challenges – on students' motivation, interest, and success in both academic and vocational pursuits. Evidence suggests (Wimmer 2023) that individuals with a strong sense of their own competence tend to be more resilient in completing tasks and solving problems. Within STEM disciplines, creativity is widely acknowledged as a fundamental element in addressing modern demographic, technological, and societal challenges. Consequently, creativity is an essential attribute for aspiring engineers and a key determinant for career success.

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In Germany, there is a significant underrepresentation of women in STEM fields, especially in engineering. Gender stereotypes and conflicts act as barriers that discourage women from pursuing careers in these fields (Jeanrenaud and Wimmer 2023).

Incorporating creative methods into teaching offers a potential avenue to reverse this trend by making STEM subjects more appealing to female students. This strategy allows for unbiased discovery of their skills and competences, by actively breaking down stereotypes. Engaging with STEM topics through inventive and enjoyable methods fosters a personal curiosity towards these subjects, altering the perception of them as merely theoretical and uninteresting. Interactive, hands-on activities, problem-solving tasks, and inquiry-driven learning engage learners' intuitive, sensory, and playful thinking, nurturing their creativity and encouraging discovery and experimentation. Therefore, integrating creative elements into STEM education can inspire students to cultivate a personal connection and a genuine interest in these fields. Evidence indicates that incorporating creativity-promoting elements in engineering education can enhance students' confidence, intrinsic motivation and engagement in this field through the experience of self-efficacy (Henriksen 2014, 2014; Conradty and Franz X. Bogner 2018; Bedewy and Lavicza 2023). Ultimately, fostering creativity in engineering students can facilitate their integration into the workforce and equip future engineers with an essential interdisciplinary skill, crucial for solving complex challenges (Nordstrom and Korpelainen 2011) in a technologically advanced, multifaceted and changing world (Ciolacu et al. 2023; Qadir 2023).

Hence, the workshop aims to explore and elaborate different perspectives on creativity. Subsequently, we will consider how these concepts can be integrated into teaching methods and curricula for engineering education and research in the future, anticipating the future direction of engineering education.

Therefore, this workshop aims to explore strategies that can stimulate creativity and how these can be applied in engineering education. Firstly, to direct education towards a more diverse and inclusive engineering workforce (Abra 1994; Landes, Steiner, and Utz 2022). Secondly, by exploring how creative methods in education can encourage engineering graduates by experiencing their emerging competence to create innovative solutions that are also socially and environmentally conscious. Through this exploration, participants share their experiences and best practices within engineering disciplines. The workshop offers a practical experience in applying a creative teaching method, so the participants will be equipped with knowledge and a practical experience for cultivating creativity within engineering disciplines as well as a networking opportunity.

2 BACKGROUND AND RATIONALE

2.1 Why Creativity is Important for Engineering Education

In our technology-driven and sustainability-focused world, engineers need to be creative thinkers. Creativity is a key role for successful engineering and is fundamental to problem-solving (Felder 1988). It involves thinking in an analytical, critical and creative way incorporating multidisciplinary knowledge (Kirillov, Leontyeva, and Moiseenko 2015). Furthermore, in response to the challenges posed by the pandemic and the disruptions of Industry 4.0, engineering and higher education institutions must undergo a paradigm shift. This requires a greater emphasis on innovation and collaboration, with a focus on prioritising skills development and effectively integrating technology (Ciolacu et al. 2023). The importance of fostering creativity in engineering education is highlighted by its vital role in today's professional environment. Curiosity and creativity are essential for academic success and practical problem-solving, as they promote personal development and increase student engagement. Maintaining a well-rounded learning experience is important, as educators are central to cultivating these essential skills that prepare students for future challenges and opportunities (Pusca and Northwood 2018). Creativity promoting elements can contribute educating individuals who are capable of innovating rather than simply duplicating. This will enable them to respond effectively to the dynamic demands of our permanent changing world (Kirillov, Leontyeva, and Moiseenko 2015).

However, it is curious that despite the potential benefits there is not yet a stronger link between creativity and engineering education, resulting in a lack of emphasis on creativity in engineering education (Stouffer and Russell 2004). There is therefore a need to address the integration of creativity into engineering curricula (Cropley 2015 ; Qadir 2023).

2.2 Teaching Creativity for Engineers

Recognising the central role of creativity in problem-solving, it is crucial to integrate it into engineering curricula. As a result, various teaching tools, methodologies and learning environments as well as didactics have been developed and widely discussed in the field of engineering education. (e. g. Badran 2007; Tiza et al. 2023; Cropley 2015) Like Nordstrom and Korpelainen (2011) have highlighted, unconventional teaching tools in science education are fostering not only the learning process, but also creativity and problem-solving.

As one example, we have successfully been deploying association exercises (Santamarina 2003) in engineering education for more than seven years, especially for business engineering master students at Technical University of Munich, not only to highlight the importance of creativity for innovation, but also to provide means of fostering individual and organisational creativity by providing conducive environments.

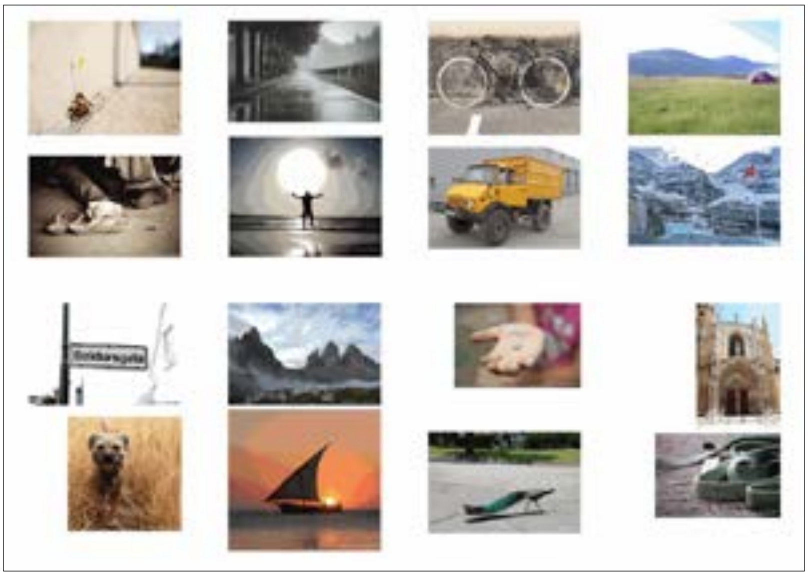

Fig. 1. Some examples used in the exercise “forced<>fit”.

Figure 1 shows some examples of images used in this type of exercise. They were collected from the online photographic platform Flickr[2] in 2024 and are all licensed under Creative Commons license (CC). Their respective authors are marked within the pictures by their Flickr handles.

The exercise called “forced<>fit” was particularly designed to help overcome mental blocks and system standards as well as to stimulate creativity. The exercise consists of mumbling groups (Waldherr et al. 2021) who are given a photograph printed in full colour on a sheet of paper. The first task is to freely collect as many associative strings as possible for the chosen picture, similar to Santamarina (2003), and then discuss it with one to two participants for a short amount of time. Afterwards, their results and insights are shared with the class. The exercise has proven to be easily applicable and yet powerful enough to help participants with problem-solving tasks and to experience the benefits of networking with knowledgeable individuals in our experimental setting by fostering creativity.

3 Workshop Design

The workshop’s target audience consisted of educators, researchers, and engineering students attending the annual SEFI conference 2024 in Lausanne, Switzerland. It was divided into three phases: onboarding and activation (1), creative co-creation of creativity (2) and summarising the results (3). These are illustrated in figure 2 hereafter. Within the timeframe of 60 minutes, the project-based group work (Melguizo-Garín et al. 2022) took place and longed to produce valuable results on the workshop’s topic.

[2] https://www.flickr.com/ [22 03 2024]

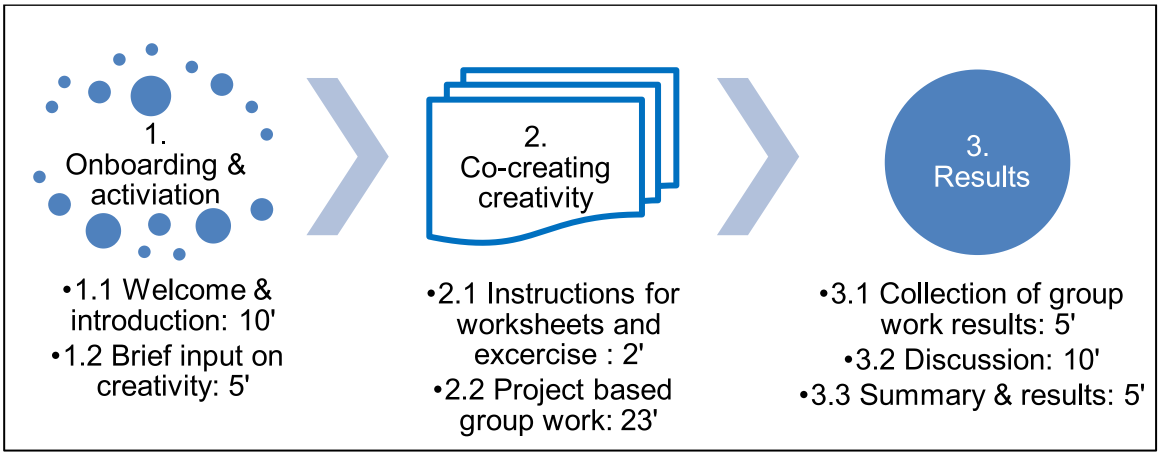

Fig. 2. Workshop Design in Three Phases

While the first phase (Onboarding & activation) was dominated by the starting phase, the short introductions of the workshop attendees was skipped due to the large number of attendees (25) (1.1, Welcome & introduction). Therefore, the framework of the workshop, its goals and working modes were briefly presented to set up the following process. A brisk introduction to the topic of creativity was given by the trainers (1.2) to have had everyone on the same page. The initial phase lasted approximately ten minutes. It was crucial to establish a productive and welcoming atmosphere for the workshop and to ensure a similar level of knowledge among participants.

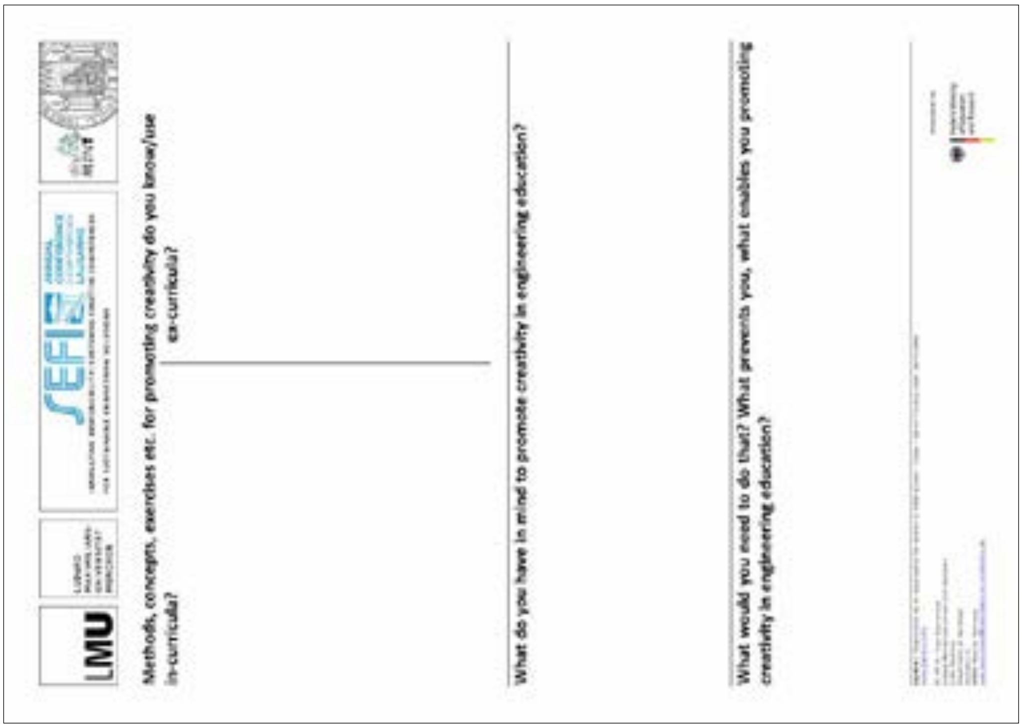

Fig. 3. Worksheet

The second and main phase of the workshop consisted of work in small groups of three to four people, dynamically allocated depending on the number of participants. If attendance had been particularly low, the workshop might also have been conducted with one larger group only. However, these groups were tasked with discussing and exchanging their perspectives from their corresponding background on creativity in engineering education and the profession. The worksheet (figure 3) was prepared to foster and steer this project-based group work as well as to document their efforts at the same time. The group work was introduced by using an exercise to foster creative thinking, such as the example “forced<>fit” shown above. This phase was taking place for about 25 minutes.

In the third phase, which lasted for 20 minutes and focused on the exchange of creativity concepts and teaching methods, respectively, the findings of each small group were collected and summarised in front of the entire workshop audience. Each group willing to do so briefly presented their specific findings (3.1), which then were collectively discussed by the larger workshop group (3.2). This discussion was moderated and documented by the workshop trainers. Finally, a summary of the findings was briefly presented for further discussion (3.3). To conclude the workshop, the results were summarised and put up for discussion (3.3). These results are hereby published in the revised workshop paper that is the final workshop report.

4 RESULTS

The workshop aimed to provide a platform to discuss creativity in engineering and engineering education from a theoretical as well as practical perspective. This helped to develop new methods and strategies to promote creativity in teaching practices within engineering programmes, thereby enhancing students' ability to think creatively and innovatively.

Some workshop participants seemed to struggle with the ambiguity of creativity, as the trainers avoided giving a clear definition, while others embraced the approach of leaving room for interpretation and henceforth allowing them to reflect more freely on creativity in the context of engineering education. The presentation of the “forced<>fit” exercise was deemed quite successful by the trainers and the audience, even though one participant questioned its link to creativity, suggesting that it might help more with concentration instead. However, research has shown that letting your mind wander and engage with other unrelated tasks, as the exercise demands, can be a crucial source of inspiration and may enhance creative problem-solving (Baird et al. 2012) by promoting divergent thinking, which is also true in natural sciences (Gable et al. 2019).

Hence, the implementation of the exercise was successful overall in the workshop. The project-based group work after that was perceived as very fruitful and insightful by the participants and trainers alike. However, more time to systematise findings and group sharing would have been beneficial. A methodology such as the World Café (Celments et al. 2024) could be helpful if the workshop had fewer time constraints.

The main findings from 16 worksheets volunteerly handed to the trainers revealed manifold approaches to teaching within engineering sub-disciplines, highlighting the impact of curricular constraints. As engineering education might leave little room nor time for extra-curricular content, despite its proven importance (Fakhretdinova et al. 2021), methods to promote creativity tend to align with and enhance existing learning goals already implemented in the curriculum, such as challenge-based learning, prototyping or design thinking. Essential methods sought include fostering self-efficacy and team collaboration. However, the main factors hindering these approaches are time constraints, lack of open-mindedness and difficulties in assessing creativity, despite some existing research in this area (Halpern 2012).

The workshop aimed to provide valuable insights into and exchange on the conceptual framework of creativity in engineering education and its impact on STEM fields, using the example of engineering, which was achieved. In addition, the workshop aimed to engage collaboration and knowledge sharing among educators and researchers, which also took place. The goal was to gain a deeper understanding of how creativity is perceived within STEM disciplines, here, especially engineering, and its implications for educational practices and career paths. The results thereafter help researchers deepen their understanding of engineers' education and career choices (Jeanrenaud and Wimmer 2023).

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REFERENCES

Abra, J. 1994. “Collaboration in Creative Work: An Initiative for Investigation.” *Creativity Research Journal* 7 (1): 1–20. https://doi.org/10.1080/10400419409534505.

Badran, I. 2007. “Enhancing Creativity and Innovation in Engineering Education.” *European Journal of Engineering Education* 32 (5): 573–85. https://doi.org/10.1080/03043790701433061.

Baird, B.,J. Smallwood, M. D. Mrazek, J. W. Y. Kam, M. S. Franklin, and J. W. Schooler. 2012. “Inspired by Distraction: Mind Wandering Facilitates Creative Incubation.” Psychological science 23 (10): 1117–22. https://doi.org/10.1177/0956797612446024.

Bedewy, S. E., and Z. Lavicza. 2023. “STEAM + X - Extending the Transdisciplinary of STEAM-Based Educational Approaches: A Theoretical Contribution.” *Thinking Skills and Creativity* 48:101299. https://doi.org/10.1016/j.tsc.2023.101299.

Ciolacu, M. I., B. Mihailescu, T. Rachbauer, C. Hansen, C. G. Amza, and P. Svasta. 2023. “Fostering Engineering Education 4.0 Paradigm Facing the Pandemic and VUCA World.” *Procedia Computer Science* 217:177–86. https://doi.org/10.1016/j.procs.2022.12.213.

Clements, A. J. , A. Sharples, and J. Bishop. 2024. “The World Café Method for Engaging Groups in Conversation: Practical Considerations and an Agenda for Critical Evaluation.” bpsopo 3 (1): 6–18. https://doi.org/10.53841/bpsopo.2024.3.1.6.

Conradty, C., and F. X. Bogner. 2018. “From STEM to STEAM: How to Monitor Creativity.” *Creativity Research Journal* 30 (3): 233–40. https://doi.org/10.1080/10400419.2018.1488195.

Conradty, C., and F. X. Bogner. 2020. “STEAM Teaching Professional Development Works: Effects on Students’ Creativity and Motivation.” *Smart Learn. Environ.* 7 (1). https://doi.org/10.1186/s40561-020-00132-9.

Conradty, C., S. A. Sotiriou, and F. X. Bogner. 2020. “How Creativity in STEAM Modules Intervenes with Self-Efficacy and Motivation.” *Education Sciences* 10 (3): 70. https://doi.org/10.3390/educsci10030070.

Cropley, D. H. 2015. “Promoting Creativity and Innovation in Engineering Education.” *Psychology of Aesthetics, Creativity, and the Arts* 9 (2): 161–71. https://doi.org/10.1037/aca0000008.

Emami, M., S. Rezaei, N. Valaei, and J. Gardener. 2023. “Creativity Mindset as the Organizational Capability: The Role of Creativity-Relevant Processes, Domain-Relevant Skills and Intrinsic Task Motivation.” *APJBA* 15 (1): 139–60. https://doi.org/10.1108/APJBA-12-2020-0437.

Fakhretdinova, G. N., Petr Osipov, and L. P. Dulalaeva. 2021. “Extracurricular Activities as an Important Tool in Developing Soft Skills.” In Educating Engineers for Future Industrial Revolutions. Vol. 1329, edited by Michael E. Auer and Tiia Rüütmann, 480–87. Advances in Intelligent Systems and Computing. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-68201-9_47.

Felder, R. M. 1988. “Creativity in Engineering Education.” *Chemical Engineering Education (CEE)* 22 (3): 120–25.

Gable, S. L., E. A. Hopper, and J. W. Schooler. 2019. “When the Muses Strike: Creative Ideas of Physicists and Writers Routinely Occur During Mind Wandering.” Psychological science 30 (3): 396–404. https://doi.org/10.1177/0956797618820626.

Halpern, Diane F. 2012. “Creativity in College Classrooms.” In Nurturing Creativity in the Classroom, edited by Ronald A. Beghetto and James C. Kaufman, 380–93: Cambridge University Press. https://doi.org/ 10.1017/CBO9780511781629.019.

Henriksen, D. 2014. “Full STEAM Ahead: Creativity in Excellent STEM Teaching Practices.” *steam* 1 (2): 1–9. https://doi.org/10.5642/steam.20140102.15.

Jeanrenaud, Y., and A.-K. Wimmer. 2023. “Digitalisation as an Opportunity for Women in STEM: Researching the Nexus of School, University and Labour Market.” *European Society for Engineering Education (SEFI)*, 2211–21. https://doi.org/10.21427/Z323-BX67.

Kirillov, N. P., E. G. Leontyeva, and Y. A. Moiseenko. 2015. “Creativity in Engineering Education.” *Procedia - Social and Behavioral Sciences* 166:360–63. https://doi.org/10.1016/j.sbspro.2014.12.537.

Landes, M. E. Steiner, and T. Utz. 2022. “Kreativität Und Innovation in Organisationen.”.

Melguizo-Garín, A., I. Ruiz-Rodríguez, M. A. Pláez-Fernández, J. Salas-Rodríguez, and E. R. Serrano-Ibáñez. 2022. “Relationship Between Group Work Competencies and Satisfaction with Project-Based Learning Among University Students.” *Frontiers in psychology* 13:811864. https://doi.org/10.3389/fpsyg.2022.811864.

Nordstrom, K., and P. Korpelainen. 2011. “Creativity and Inspiration for Problem Solving in Engineering Education.” *Teaching in Higher Education* 16 (4): 439–50. https://doi.org/10.1080/13562517.2011.560379.

Pusca, D., and D. Northwood. 2018. “Curiosity, Creativity and Engineering Education.” *Global Journal of Engineering Education 20* (3). http://www.wiete.com.au/journals/GJEE/Publish/vol20no3/01-Pusca-D.pdf. Accessed April 07, 2024.

Qadir, J. 2023. “Engineering Education in the Era of ChatGPT: Promise and Pitfalls of Generative AI for Education.” In *2023 IEEE Global Engineering Education Conference (EDUCON)*, 1–9: IEEE.

Santamarina, J. C. 2003. “Creativity and Engineering: Education Strategies.” In IEEI. *International Conference on Engineering Education in Honor of James T.P. Yao*, 99–107.

Stouffer, B., and J. Russell. 2004. “Making the Strange Familiar: Creativity and the Future of Engineering Education.” In *Proceedings*, edited by ASEE: ASEE Conferences.

Tiza, D. R. H., E. E. Herrera, J. P. T. Lipa, E. C. Checa, C. J. L. Mamani, F. A. Limo, E. W. P. Paricahua, K. P. Paricahua, and H. Quispe Berrios. 2023. “Promoting Creativity and Innovation Through Agile Engineering in Design Education: Comparative Analysis in Latin America.” *Operational Research in Engineering Sciences: Theory and Applications (ORESTA)* 6 (1): 410–31. https://doi.org/10.31181/oresta/0601135.

Waldherr, F., C. Walter, J. Wendorff, and M. Kipp. 2021. “Murmelgruppe oder Buzz Group.” In *didaktisch und praktisch: Methoden und Medien für die Präsenz- und Onlinelehre*, edited by Franz Waldherr, and C. Walter. 3. überarbeitete und erweiterte Auflage 2021, 50–52. Freiburg: Schäffer-Poeschel Verlag.

Wimmer, A.-K. 2023. “Can Students’ Self-Efficacy Beliefs Explain Academic Motivation and Career Intentions?” *European Society for Engineering Education (SEFI)*, 1471–78. https://doi.org/10.21427/694C-DC64.

SEFI ANNUAL CONFERENCE 2-5 SEPTEMBER 2024 LAUSANNE

Enacting Our Values - Steps Towards a More Sustainable and Inclusive SEFI Community

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Conference Key Areas: *Diversity, equity and inclusion in our universities and in our teaching; Building the capacity and strengthening the educational competences of engineering educators.*
Keywords: *sustainable communities; diversity, equity & inclusion; inclusive communities; inclusive conferences*

ABSTRACT

Our mission of educating responsible engineers requires a diverse and inclusive community where sustainability is a shared commitment. This workshop engaged

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participants in considering what it means to be a sustainable community and how this interacts with Sustainable Development Goals related to addressing inequity of access and experience. Specifically, we considered the barriers that people face to both being a part of the SEFI community and participating in SEFI events, and the potential impacts of these barriers on the sustainability of the community, and thus the future of engineering education. Based on a 2023 SEFI@Work event and survey data collected from SEFI members, this workshop engaged participants in reviewing initiatives, identifying priorities, and establishing recommendations for inclusion at SEFI events. We encouraged people from across the SEFI community, both those that see their concerns reflected in current inclusion activities and those who do not, to attend this workshop.

1 BACKGROUND & RATIONALE

To ensure a socially and environmentally sustainable future, it is imperative that our educational institutions focus on educating responsible engineers. However, developing such professionals requires the work of a community - dedicated engineering educators who leverage curricula and pedagogical strategies intentionally crafted by engineering education researchers. This approach underscores the importance of responsibility not only among the engineers but also within the ranks of educators and researchers who guide their development. Initiatives to make engineering education more inclusive must include both pedagogical aspects (de Lima, Isaac, and Kovacs 2024; 2023; Isaac, Kotluk, and Tormey 2023) and academic aspects (Dixon 2024; Chugh and Joseph 2024). By establishing a community where sustainability is a shared commitment across all these groups, we can more effectively address the challenges of today and pave the way for a resilient tomorrow.

Sustainability as a value also extends to the community, i.e. the SEFI community. What, therefore, does it mean to be a sustainable community? Going back to the 17 Sustainable Development Goals, we see that addressing inequity of access and experience is an integral part of the sustainable development agenda. The SDGs explicitly address inclusivity and equitability in educational experiences (goal 4), equal experiences across genders (goal 5), reducing inequities based on geographical locations (goal 10), and promoting inclusive and accountable institutions (goal 16) (United Nations [UN] 2015). Additionally, “Sustainability” along with “Inclusivity” and “Supporting and respecting diversity, equality and different cultures”, are three of the core SEFI values (SEFI, n.d.). This therefore requires us to consider the barriers that people might face to both being a part of the SEFI community and participating in SEFI events, and the potential impacts of these barriers on the sustainability of the community.

Making the SEFI community more inclusive, and therefore more sustainable, will have multiple desirable effects for both the community in particular, but also for engineering education in general. Increasing coherence with our professed values of sustainability and inclusion will allow us to widen our community and further enrich the education we are providing our engineering students. Integrating diverse perspectives and expertise, that might have been traditionally excluded and ignored, will ensure that our students are better equipped to build sustainable solutions and societies (Lucena and Schneider 2008; The United Nations Educational, Scientific and Cultural Organization [UNESCO] 2021). Additionally, this will allow formerly excluded community members to get access to the resources and recognition they deserve so as to improve engineering education across the globe.

An important aspect of building the SEFI community is participation in SEFI events such as SEFI conferences. Attending such events is beneficial both for community building but also for individual career development (de Leon and McQuillin 2020; Oester et al. 2017). Multiple studies have however shown that access to these events is not equitable (Biggs, Hawley, and Biernat 2018; Débarre, Rode, and Ugelvig 2018; King et al. 2018; Rushworth et al. 2021; Shishkova et al. 2017). As a community it is therefore critical that we identify and address these barriers to ensure that the knowledge we produce and the policies we implement are inclusive and representative of diverse voices (Abernethy et al. 2020). Involved in this work is the identification of potential barriers and subsequently defining key steps towards mitigating issues which run counter to social justice and equity.

2 MOTIVATION & WORKSHOP OBJECTIVES

This workshop built upon a previous SEFI@Work event (SEFI 2023), as well as data from a survey based on barriers to submitting and participating in SEFI conferences. It was intended to facilitate further conversation about what we can do individually and collectively to ensure sustainability in terms of evolution and renewal of the SEFI community and the resultant discourse. Although several initiatives have been introduced for the first time at SEFI 2024, work is required for them to become integral, regular parts of the annual conference, as well as other SEFI activities. We used the workshop to increase visibility and support and help refine future initiatives.

This workshop welcomed all members of the SEFI community, especially those who are interested in fostering a sustainable SEFI community, focusing on making it more inclusive, equitable, and welcoming of a diversity of members.

During this workshop, participants:

- Exchanged perspectives and reviewed survey data from the SEFI community on barriers they encountered to participating.
- Proposed strategies for mitigating and reducing barriers to participating in the SEFI community, including initiatives at SEFI 2024.
- Drafted a proposal of inclusion measures for future SEFI events (what is essential? What is nice to have?)

3 OUTCOMES OF THE WORKSHOP

This workshop engaged participants in constructive discussions about how SEFI could be more inclusive. Data from a survey completed by SEFI members between December 2023 and January 2024 was presented to support collaborative discussion. Participants were divided into two groups with each considering either barriers to feeling included in the SEFI community or barriers to participating in the SEFI conference (Table 1). Having shared the barriers identified with the wider group, each group suggested possible actions which could be implemented to address these barriers. Finally, participants were each given the opportunity to vote for 3 votes for initiatives that should definitely be implemented, and 3 votes for ‘nice to have’ initiatives. The proposed initiatives and results of the voting are presented in Table 2.

Table 1: List of barriers to ‘participating in SEFI events’ and ‘Feeling part of the SEFI community’, as identified by workshop participants.

Barriers to participating in SEFI events (e.g. conference, SIG events)	**Barriers to feeling part of the SEFI community**
High registration fees (lack of institutional membership and need to pay for individual membership)	Do not look like the rest of the community
Timing / schedule of the conference	Tensions between “engineering” and “education”
Lack of knowledge about SEFI	Different scientific traditions and having to apologise for identity (“I'm not an engineer but…”)
Being new the community	Perceived lack of confidence and competence in unfamiliar research methods and quality aspects.
Lack of knowledge about how Special Interest Groups (SIGs) work	Perceived status hierarchy between practitioners and researchers which also results in ambiguity and misalignment in relevant audiences for work.
Language (non-native English speakers)	Not knowing anyone else at the conference
Lack of knowledge about the sessions / scope and thus the value of attending	Lack of community outside the SEFI conference (during the year)
Childcare commitments	
Health issues	

Table 2: Actions proposed by workshop participants to mitigate some of the barriers listed in Table 1, along with the frequency of votes accorded to each initiative.

No.	**Initiatives that …**	**Should implemented at**	**Would be nice to**

		SEFI 2025 + future events	implement if possible
1	Asking for participants to provide keywords that reflect their teaching and research interests during registration. These keywords can then be added to the badges / app and will help people make connections based on shared or new interests.	5	2
2	Code of conduct with consequences	5	2
3	Prepare an informative welcome video “SEFI for new members” which introduces the aims and workings of SEFI including SIGs	5	1
4	Set strategic goal to hold SEFI conference in less expensive location in 4 years -> start now to identify potential locations and build capacity	4	2
5	Do more activities between annual conferences to build community and connections	3	3
6	Create “Faces of SEFI” profiles of community members throughout the year to highlight diversity of the community	2	6
7	Initiate research activities focused on uncovering the hidden curriculum at SEFI (research)	2	4
8	Reduce costs by co-hosting between an institution in less expensive city and an institution with a strong team and/or organising experience	2	1
9	Produce a SEFI glossary - what is a SIG, who ‘can be a member’ and how to get involved	1	2
10	Introduce more semi-structured/’icebreaker’ activities (like bingo activity during the newcomers’ lunch) to help build connections	1	2

11	Recommend SIG chairs start their meetings with an introduction to the SIG activities (avoiding jargon)	1	
12	Hold non-SIG SEFI community events		2
13	Creation of a ‘diagnostic online quiz that helps people identify with which SIG their interests are aligned and how to get involved		

Additional items that were not included in the voting activity

- Communicate being mindful that newcomers are in the room
- Promote benefits of SEFI for different target groups (value proposition)
- Different ways of working with engineering education (working across the differences)
- Provide a searchable database for people

From Table 2 it is clear that initiatives 1-3 were the most popular and are all considered to involve relatively low commitment. We would therefore suggest that these be the focus of efforts within the short term. In the case of initiative 2, “**Code of conduct with consequences**”, there was discussion around what would constitute a suitable and appropriate consequence and how this would be enforced, something which would involve discussion with the SEFI Board. Initiative 3 “**Informative welcome video**” (and initiative 9, “**SEFI glossary**”) would involve prior work into understanding the types of content that would be useful to newcomers but are relatively low commitment with potential for significant benefits.

Although popular, initiative 4 “**less expensive location**” (and initiative 8 “**co-hosting the conference**”) involve the support of the SEFI Board at a strategic level and may be more suitable as considerations in the long term. Initiative 5 “**activities between annual conferences**” (which received 6 votes in total) involves understanding the types of events that would be helpful in community building as well as higher levels of commitment, for example support from the wider SEFI community such as SIGs. This initiative should thus be investigated further but should not be considered as the primary area of focus.

Initiative 6 “**Faces of SEFI**” involves relatively low, but regular levels of commitment and, given the total votes (6), it is worth investigating the possible routes to achieving this. Initiative 7 “**uncovering the hidden curriculum at SEFI**” involves high levels of commitment and given the relatively low number of votes, may be considered at some point in future. Initiatives 10 “**more semi-structured activities**” and 12 “**non-SIG SEFI community events**” are fairly low commitment and may be pursued, assuming the availability of willing volunteers. Initiative 11 “**start SIG meetings with an introduction to the SIG activities**” is low commitment and therefore, despite the low number of votes, is worth pursuing. Finally, initiative 13 “**diagnostic online quiz**” received no votes, perhaps because of its aspirational nature.

4 CONCLUSION

The output from the group activity and feedback of participants was used to identify barriers that people might face to both participating in SEFI events and feeling a part of the SEFI community. Together, we also generated recommendations for future SEFI events and conferences to improve inclusion. Participants also had an opportunity to develop networks with those who are interested in supporting DEI, build their professional networks and learn from the diverse perspectives of their fellow participants.

REFERENCES

Abernethy, Erin F., Ivan Arismendi, Anna G. Boegehold, Checo Colón-Gaud, Matthew R. Cover, Erin I. Larson, Eric K. Moody, et al. 2020. 'Diverse, Equitable, and Inclusive Scientific Societies: Progress and Opportunities in the Society for Freshwater Science'. *Freshwater Science* 39 (3): 363–76. https://doi.org/10.1086/709129.

Biggs, Jacklyn, Patricia H. Hawley, and Monica Biernat. 2018. 'The Academic Conference as a Chilly Climate for Women: Effects of Gender Representation on Experiences of Sexism, Coping Responses, and Career Intentions'. *Sex Roles* 78 (5): 394–408. https://doi.org/10.1007/s11199-017-0800-9.

Chugh, Mayank, and Tiffany Joseph. 2024. 'Citizenship Privilege Harms Science'. *Nature* 628 (8008): 499–501. https://doi.org/10.1038/d41586-024-01080-x.

de Leon, Fernanda Leite Lopez, and Ben McQuillin. 2020. 'The Role of Conferences on the Pathway to Academic Impact: Evidence from a Natural Experiment'. *Journal of Human Resources* 55 (1): 164–93. https://doi.org/10.3368/jhr.55.1.1116-8387R.

de Lima, Joelyn, Siara Isaac, and Helena Kovacs. 2023. 'Inclusive Engineering Classrooms: Student Teaching Assistants' Perspectives'. In *Engineering Education for Sustainability*, edited by Ger Reilly, Mike Murphy, Balàzs Nagy, and Hannu-Matti Järvinen, 336–46. Dublin. https://doi.org/10.21427/Z015-7602.

de Lima, Joelyn, Siara Isaac, and Helena Kovacs. 2024. 'Teaching Assistants' Contributions to Creating Inclusive and Equitable Learning Spaces in Engineering'. *European Journal of Engineering Education*. https://doi.org/10.1080/03043797.2024.2346332.

Débarre, F., N. O. Rode, and L. V. Ugelvig. 2018. 'Gender Equity at Scientific Events'. *Evolution Letters* 2 (3): 148–58. https://doi.org/10.1002/evl3.49.

Dixon, Emily. 2024. 'How Men Get Away with Dodging "Academic Housework"'. Times Higher Education (THE). 23 April 2024. https://www.timeshighereducation.com/news/how-men-get-away-dodging-academic-housework.

European Society for Engineering Education [SEFI], dir. 2023. *SEFI@Work: Increasing Inclusion at SEFI Conferences*. https://www.youtube.com/watch?v=ROYBrqMSVu8.

European Society for Engineering Education [SEFI], dir. 2023. n.d. 'SEFI Values'. Accessed 19 April 2024. https://www.sefi.be/about/.

Isaac, Siara, Nihat Kotluk, and Roland Tormey. 2023. 'Educating Engineering Students to Address Bias and Discrimination Within Their Project Teams'. *Science and Engineering Ethics* 29 (1): 6. https://doi.org/10.1007/s11948-022-00426-w.

King, Leonora, Lucy MacKenzie, Marc Tadaki, Sara Cannon, Kiely McFarlane, David Reid, and Michele Koppes. 2018. 'Diversity in Geoscience: Participation, Behaviour, and the Division of Scientific Labour at a Canadian Geoscience Conference'. *FACETS* 3 (1): 415–40. https://doi.org/10.1139/facets-2017-0111.

Lucena, J., and J. Schneider. 2008. 'Engineers, Development, and Engineering Education: From National to Sustainable Community Development'. *European Journal of Engineering Education* 33 (3): 247–57. https://doi.org/10.1080/03043790802088368.

Oester, Samantha, John A. Cigliano, Edward J. Hind-Ozan, and E. Christien Michael Parsons. 2017. 'Why Conferences Matter—An Illustration from the International Marine Conservation Congress'. *Frontiers in Marine Science* 4. https://doi.org/10.3389/fmars.2017.00257.

Rushworth, Catherine A., Regina S. Baucom, Benjamin K. Blackman, Maurine Neiman, Maria E. Orive, Arun Sethuraman, Jessica Ware, and Daniel R. Matute. 2021. 'Who Are We Now? A Demographic Assessment of Three Evolution Societies'. *Evolution* 75 (2): 208–18. https://doi.org/10.1111/evo.14168.

Shishkova, Evgenia, Nicholas W. Kwiecien, Alexander S. Hebert, Michael S. Westphall, Jessica E. Prenni, and Joshua J. Coon. 2017. 'Gender Diversity in a STEM Subfield – Analysis of a Large Scientific Society and Its Annual Conferences'. *Journal of the American Society for Mass Spectrometry* 28 (12): 2523–31. https://doi.org/10.1007/s13361-017-1803-z.

The United Nations Educational, Scientific and Cultural Organization [UNESCO]. 2021. *Engineering for Sustainable Development*. https://unesdoc.unesco.org/ark:/48223/pf0000375644.locale=en.

United Nations [UN]. 2015. 'Transforming Our World: The 2030 Agenda for Sustainable Development'. https://sdgs.un.org/2030agenda.

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TRANSVERSAL SKILLS THAT PROMOTE SUSTAINABILITY - AN EXPERIENTIAL ACTIVITY FOR ENGINEERING STUDENTS

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Keywords: Transversal skills, sustainability, experiential learning, systems thinking, negotiation

ABSTRACT

This workshop addresses two major preoccupations in engineering education: the need to integrate sustainability and transversal skill development. In addition to knowledge about sustainability, engineering students require skills for effectively integrating these concepts into their work to both perceive opportunities and to convince others to adopt more sustainable approaches. It is these skills that are the focus of this workshop. Participants will experience an interactive activity with tangibles, designed for engineering students, that targets the development of 3 transversal skills relevant to sustainability: systems thinking, perspective taking and negotiation. This activity employs a three-facet framework for teaching transversal skills: knowing (strategies and models to implement the skill), experiencing (opportunities to apply the skills and encounter relevant difficulties) and learning by experience (meta-cognitive/emotional reflection to promote transfer). Workshop activities provide structured opportunities to consider how to create learning experiences that embody the evidence-informed criteria of providing relevant information on implementing the targeted skills, supporting low-stakes

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experimentation, delivering timely feedback and encouraging transfer into future contexts. This workshop provides engineering educators with both a specific activity (https://doi.org/10.5281/zenodo.10731771) and a general framework (https://doi.org/10.5281/zenodo.13328581) for designing activities to teach transversal skills. Engineering students consistently express interest in developing their transversal skills and in sustainability. By exploiting their dual motivations, this workshop offers a practical way to equip students with skills fundamental for responsible engineers.

1 BACKGROUND AND RATIONALE

This workshop simultaneously addressed two major priorities in engineering education: the urgency to integrate sustainability (Lozano et al. 2013; Wilson 2019) and the need for transversal skill development (Kolmos and Holgaard 2019). In addition to knowledge about sustainability, engineering students require skills for effectively integrating these concepts into their work to both perceive opportunities and to convince others to adopt more sustainable approaches. It is these skills that were the focus of this workshop. Based on a practical framework for designing learning activities that teach transversal skills (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024; Isaac, Petringa, et al. 2023), this workshop provided engineering educators a way to enhance transversal skills particularly focusing on the skills of systems thinking, perspective taking, and negotiation for their potential to assist students to promote sustainability (Isaac and de Lima 2024a).

How engineers frame problems has implications for the solutions envisaged, specifically by identifying which characteristics, boundaries, issues and approaches that are deemed relevant to be included. When engineers do not see sustainability as integral to engineering, it is rarely included in their problem solving (Isaac, Kothiyal, et al. 2023). While sustainability is not itself a skill, educating responsible engineers requires that students are equipped with transversal skills that promote sustainability in the products and processes they design.

Students are interested and ready to develop their transversal skills (Passow and Passow 2017; de Lima, Isaac, and Dehler Zufferey 2024a; 2024b) and are specifically interested in skills to support sustainability (Isaac, de Lima, Jalali, Rossi, Tormey, et al. 2024). While there is growing consensus that transversal skills must be explicitly taught (Picard et al. 2022; Isaac, Petringa, et al. 2023), engineering education is plagued by a persistent misconception that students will be able to develop their skills without specific pedagogical interventions (Isaac, Petringa, et al. 2023). We have identified the following three transversal skills as particularly relevant to develop engineering students' ability to integrate sustainability:

- **Systems thinking** is fundamental to a comprehensive understanding of complex phenomena (Senge 1990), such as the intersection of technological, environmental, societal and economic issues. Students often lack this skill (Huang et al. 2015), particularly as related to sustainability (Hiller Connell, Remington, and Armstrong 2012). This results in students being inadequately prepared to contextualise their problem solving in sufficiently broad and interconnected ways.

- Thoroughly **exploring different perspectives** and constraints improves the quality of solutions (Cross 2006) and creates scope to include elements from diverse stakeholders in how problems are formulated. It is pertinent to provide support for engineering students to develop this skill because while they have difficulty incorporating multiple stakeholder perspectives (Björklund 2013; Scott 2008; Zoltowski, Oakes, and Cardella 2012), their perspective taking skills have been found to be moderately correlated with their ethical reasoning (Hess et al. 2019).
- Establishing a common set of objectives or priorities among the different experts and stakeholders in a project is a major asset for decision making. **Negotiating skills** are therefore useful for all engineers to ensure that their concerns are perceived and valued by colleagues; the importance of negotiation skills is amplified for engineers who seek to promote sustainability (Svanström, Lozano-García, and Rowe 2008). Engineering student teams were found to obtain better outcomes when they received explicit training on negotiation skills (Jin, Geslin, and Lu 2007).

This workshop introduced engineering educators experientially and conceptually to a 3-facet framework for teaching transversal skills: ***knowing*** (strategies and models to implement the skill), ***experiencing*** (opportunities to apply the skills and encounter relevant difficulties) and ***learning by experience*** (meta-cognitive/emotional reflection to promote transfer) (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024). Workshop activities provided structured opportunities for engineering educators to consider how to create learning experiences for developing transversal skills that provide relevant information on implementing the target skills, support low-stakes experimentation, deliver timely feedback and support transfer into future contexts.

The activity at the centre of this workshop used the selection of materials for a wind turbine to engage participants in a contextualised optimisation of sustainability through principled negotiation between multiple stakeholder perspectives. The learning outcomes for the workshop addressed the three transversal skills mentioned above: perspective taking, systems thinking, and negotiation (Isaac and de Lima 2024a). Participants first assumed one of 4 engineering roles to identify specific sustainability priorities based on their responsibilities and expertise of these functions (mechanical engineer, geological engineer, production manager, and project coordinator). Next, using a physical prototype of a wind turbine to increase the visibility of the outcome, they negotiated from the perspective of their assigned roles to optimise the choice of material for the wind turbine. This activity has been consistently well received when facilitated for Bachelor and Masters students, as well as faculty, at several European institutions.

In the second part, participants used the framework (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024) to analyse the experiential activity and identify how students' transversal skills development was supported. The facilitation guide for the activity (https://doi.org/10.5281/zenodo.10731771) and worksheets for creating activities to teach transversal skills (https://doi.org/10.5281/zenodo.10992806) are available as open-source resources.

2 WORKSHOP LEARNING OBJECTIVES

This 60-minute workshop engaged participants in

- Applying skills of perspective taking, systems thinking, and negotiation to promote sustainability in collaborative engineering projects.
- Characterising experiential learning situations effective for teaching transversal skills to engineering students.
- Analysing how to integrate better support for students to develop their transversal skills in engineering courses.

This workshop was designed for engineering educators and pedagogical advisors interested in developing teaching activities for transversal skill development. Prior knowledge of transversal skills, sustainability or teaching experience was not required.

3 WORKSHOP DESIGN

The first part of this workshop was an experiential activity that teaches three transversal skills valuable for promoting sustainability: perspective taking, systems thinking, and negotiation. In the second part, participants analysed the activities of part one to identify pedagogical interventions relevant to the 3 facets of the framework for teaching transversal skills.

Table 1. Activity schedule for the 60-minute workshop

Duration	Activity	Mode	Material
Part One			
5 min	Welcome, learning objectives	Whole group	• Slides
5 min	Warm up: Models of sustainability	Small groups	• LEGO blocks
5 min	Presentation: How perspective taking, systems thinking, and negotiation skills support strong sustainability approaches	Whole group	• Slides
25 min	Wind turbine activity a. Determine priorities in role groups b. Negotiate materials for wind turbine prototype in mixed groups	Small groups in a jigsaw rotation	• LEGO prototypes of wind turbines • Roles handout Interdisciplinary team decision handout
5 min	Individual reflection + group debrief	Individual	• Slides
Part Two			

5 min	Presentation: 3-part framework for teaching transversal skills	Whole group	• Slides
10 min	Meta Activity: applying the framework to present workshop + chapter walk through	Small groups	• Activity outline (per Chapter)
5 min	Conclusion	Whole group	• Access to resources to duplicate / adapt the workshop
			•

4 OUTCOMES OF WORKSHOP

This workshop was based on an activity created by the 3T PLAY team that is designed to help teach skills that promote sustainability (Isaac and de Lima 2024a). The design of the activity, and the workshop, explicitly incorporates the three aspects of the 3T PLAY Trident framework (Isaac, de Lima, Jalali, Rossi, Schmid, et al. 2024). Additional activities that target other transversal skills have also been developed by the team (3T PLAY 2024). Additionally, educators can design activities that target transversal skills of their choice using a self-guided self-paced guide based on the framework (Isaac and de Lima 2024b). All these open-access resources are available online: https://zenodo.org/communities/3tplay/records

REFERENCES

3T PLAY, ed. 2024. *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10392281.

Björklund, Tua A. 2013. 'Initial Mental Representations of Design Problems: Differences between Experts and Novices'. *Design Studies* 34 (2): 135–60. https://doi.org/10.1016/j.destud.2012.08.005.

Cross, Nigel. 2006. *Designerly Ways of Knowing*. London: Springer-Verlag. https://doi.org/10.1007/1-84628-301-9.

de Lima, Joelyn, Siara Isaac, and Jessica Dehler Zufferey. 2024a. 'Distinctly Human - Students' Perception of Transversal Skills in Engineering Curriculum'. In *Proceedings of the 20th International CDIO Conference*.

de Lima, Joelyn, Siara Isaac, and Jessica Dehler Zufferey. 2024b. 'Transversal Skills Priorities and Curricular Support as Experienced by Engineering Students on Their Path to Becoming Responsible Engineers'. In *Proceedings of the 52nd Annual SEFI Conference*.

Hess, Justin L., Jonathan Beever, Carla B. Zoltowski, Lorraine Kisselburgh, and Andrew O. Brightman. 2019. 'Enhancing Engineering Students' Ethical Reasoning:

Situating Reflexive Principlism within the SIRA Framework'. *Journal of Engineering Education* 108 (1): 82–102. https://doi.org/10.1002/jee.20249.

Hiller Connell, Kim Y., Sonya M. Remington, and Cosette M. Armstrong. 2012. 'Assessing Systems Thinking Skills in Two Undergraduate Sustainability Courses: A Comparison of Teaching Strategies'. *Journal of Sustainability Education* 3. https://krex.k-state.edu/handle/2097/13783.

Huang, Shaobo, Karim Heinz Muci-Kuchler, Mark D. Bedillion, Marius D. Ellingsen, and Cassandra M. Degen. 2015. 'Systems Thinking Skills of Undergraduate Engineering Students'. In *2015 IEEE Frontiers in Education Conference (FIE)*, 1–5. https://doi.org/10.1109/FIE.2015.7344341.

Isaac, Siara, and Joelyn de Lima. 2024a. 'Chapter 4: How to Support Students to Develop Skills That Promote Sustainability'. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10731771.

Isaac, Siara, and Joelyn de Lima. 2024b. 'Chapter 8: How Teachers Can Use the 3T PLAY Trident Framework to Design Activities That Develop Transversal Skills'. In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.10992806.

Isaac, Siara, Joelyn de Lima, Yousef Jalali, Valentina Rossi, Samuel Schmid, Roland Tormey, and Jessica Dehler Zufferey. 2024. 'Chapter 1: How to Develop Engineering Students' Transversal Skills.' In *Teaching Transversal Skills for Engineering Students: A Playbook of Practical Activities with Tangibles*, edited by 3T PLAY. Lausanne, Switzerland: Center for Learning Sciences, EPFL. https://doi.org/10.5281/zenodo.13328581.

Isaac, Siara, Joelyn de Lima, Yousef Jalali, Valentina Rossi, Roland Tormey, and Jessica Dehler Zufferey. 2024. 'Exploring Engineering Students' Perception of Sustainability and Ethics in Their Curriculum Across Disciplines'. In *2024 IEEE Global Engineering Education Conference (EDUCON)*, 01–05. https://doi.org/10.1109/EDUCON60312.2024.10578603.

Isaac, Siara, Aditi Kothiyal, Pierluca Borsò-Tan, and Bryan Alexander Ford. 2023. 'Sustainability and Ethicality Are Peripheral to Students' Software Design'. *International Journal of Engineering Education*.

Isaac, Siara, Natascia Petringa, Yousef Jalali, Roland Tormey, and Jessica Dehler Zufferey. 2023. 'Are Engineering Teachers Ready to Leverage the Power of Play to Teach Transversal Skills?' In *Proceedings of the SEFI 2023 Conference*. https://doi.org/10.21427/QP3D-B914.

Jin, Y., M. Geslin, and S. C. -Y. Lu. 2007. 'Impact of Argumentative Negotiation on Collaborative Engineering'. *CIRP Annals* 56 (1): 181–84. https://doi.org/10.1016/j.cirp.2007.05.043.

Kolmos, Anette, and Jette Egelund Holgaard. 2019. 'Employability in Engineering Education: Are Engineering Students Ready for Work?' In *The Engineering-Business Nexus: Symbiosis, Tension and Co-Evolution*, edited by Steen Hyldgaard Christensen, Bernard Delahousse, Christelle Didier, Martin Meganck, and Mike

Murphy, 499–520. Philosophy of Engineering and Technology. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-99636-3_22.

Lozano, Rodrigo, Rebeka Lukman, Francisco J. Lozano, Donald Huisingh, and Wim Lambrechts. 2013. 'Declarations for Sustainability in Higher Education: Becoming Better Leaders, through Addressing the University System'. *Journal of Cleaner Production*, Environmental Management for Sustainable Universities (EMSU) 2010, 48 (June): 10–19. https://doi.org/10.1016/j.jclepro.2011.10.006.

Passow, Honor J., and Christian H. Passow. 2017. 'What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review'. *Journal of Engineering Education* 106 (3): 475–526. https://doi.org/10.1002/jee.20171.

Picard, Cyril, Cécile Hardebolle, Roland Tormey, and Jürg Schiffmann. 2022. 'Which Professional Skills Do Students Learn in Engineering Team-Based Projects?' *European Journal of Engineering Education* 47 (2): 314–32. https://doi.org/10.1080/03043797.2021.1920890.

Scott, J. Blake. 2008. 'The Practice of Usability: Teaching User Engagement Through Service-Learning'. *Technical Communication Quarterly* 17 (4): 381–412. https://doi.org/10.1080/10572250802324929.

Senge, Peter. 1990. *The Fifth Discipline: The Art and Practice of Learning*. New York: Doubleday.

Svanström, Magdalena, Francisco J. Lozano-García, and Debra Rowe. 2008. 'Learning Outcomes for Sustainable Development in Higher Education'. *International Journal of Sustainability in Higher Education* 9 (3): 339–51. https://doi.org/10.1108/14676370810885925.

Wilson, Denise. 2019. 'Exploring the Intersection between Engineering and Sustainability Education'. *Sustainability* 11 (11): 3134. https://doi.org/10.3390/su11113134.

Zoltowski, Carla B., William C. Oakes, and Monica E. Cardella. 2012. 'Students' Ways of Experiencing Human-Centered Design'. *Journal of Engineering Education* 101 (1): 28–59. https://doi.org/10.1002/j.2168-9830.2012.tb00040.x.

SEFI Annual Conference 2-5 September 2024 Lausanne

AI and ICT Integration in Mathematics Engineering Education: Enhancing Learning and Teaching

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ABSTRACT

Artificial Intelligence (AI) in mathematics education has been gaining momentum, with various applications promising to transform teaching and learning processes. The pros and cons of incorporating AI in mathematics education can be analysed through multiple lenses, including pedagogy, accessibility, personalization, and data security. while AI offers promising opportunities to enhance mathematics education through personalized learning, engagement, and accessibility, it also presents challenges related to data privacy, equity, reliance on technology, and implementation. Balancing these pros and cons requires careful consideration and a thoughtful approach to ensure that AI's integration into mathematics education maximizes benefits while mitigating potential drawbacks. A questionnaire followed by a debate was promoted with participants at the SEFI Mathematics Special Interest Group workshop held in Lausanne at the SEFI annual conference.

In this paper, we will present the results of the referred questionnaire and debate involving 20 teachers from 14 countries at the SEFI'2024 conference. This questionnaire delved into teachers' perspectives on utilising AI and ICT Integration in Mathematics Engineering Education with the purpose of enhancing learning and teaching.

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1 MOTIVATION AND LEARNING OUTCOMES

With this workshop, the authors intend to discuss and survey how its participants are using Artificial Intelligence software, platforms, ICT, and their achievements in terms of consolidated knowledge, together with teaching challenges that may be anticipated.

Attendees will be invited to answer some specific questions regarding AI assistance platforms, and software possible to use while teaching and/or learning Mathematics and perform an evaluation of how their perception of the knowledge is acquired by their students. The emergence of ChatGPT and how its usage may be an ally to students' knowledge tutoring, but also as a fountain of misunderstanding concepts and incorrect application will also be discussed.

After collecting the above information, a discussion/reflection period between the attendees will be promoted to generate conclusions that are fruitful and may be accomplished by Mathematics teachers when returning to their universities. A not necessarily equal but similar way of teaching and learning mathematics across Europe is crucial for fostering educational mobility and enhancing students' mathematical competence. By aligning pedagogical methods, curricula, and learning outcomes, students can benefit from a harmonized educational experience that transcends borders. Collaboration, consistent academic standards, and a strengthened European identity are the fruits of such endeavours. Embracing this shared vision of mathematics education will prepare students to tackle the challenges of a globalized world and contribute to the development of a highly skilled and interconnected workforce.

2 BACKGROUND RATIONALE AND RELEVANCE

Mathematics education plays a critical role in developing analytical thinking, problem-solving skills, and logical reasoning abilities among students. With the fast advancements in technology, the integration of Information and Communication Technology (ICT) has opened up new possibilities for teaching and learning mathematics. In the past 3 to 4 years, the emergence of ChatGPT usage by students worldwide generated mixed feelings inside the teaching community. In the field of engineering education, the use of different tools and pedagogic methodologies has gained significant attention due to their potential to enhance mathematical understanding and application within an engineering context. This workshop delves into the state of the art in teaching mathematics, emphasizing the integration of AI techniques in engineering education and their evaluation by the workshop attendees.

It is recognised by the academy that Mathematics and Physics serve as foundation disciplines for engineering courses, and it is also stated by the teachers' community that a solid mathematical background is crucial for students to succeed in their engineering education and future careers. Traditionally, mathematics was taught using traditional pedagogical methods such as lectures, textbooks, and pen-and-paper exercises. However, the integration of AI and ICT tools significantly enhanced the teaching and learning experience. Interactive simulations, computer algebra systems, graphing calculators, educational software, and online resources offer dynamic and engaging platforms for exploring mathematical concepts. By integrating ICT/AI in Mathematics Education the learning experience is enhanced since these tools provide: interactive and engaging experiences for students helping with simulations, visualization, and multimedia content which promotes understanding of abstract concepts; personalized learning and differentiation since AI-powered adaptative learning platforms allow personalized learning experiences tailored to individual student needs. Adaptive software and online platforms can provide targeted instruction, immediate feedback, and adaptive challenges, catering to students' unique learning styles and paces; immediate feedback to students on their answers and progress, allowing them to identify and correct mistakes in real-time. This feedback loop promotes active learning, encourages experimentation, and reinforces learning behaviours (feedback within courses with many students is always a hard process difficult to be successfully achieved); collaborative learning since AI/ICT tools enable collaborative learning experiences, facilitating communication and collaboration among students. Virtual platforms and online forums create opportunities for students to discuss, solve problems, and share mathematical insights, fostering a collaborative and supportive learning environment.

In Engineering Education, integrating ICT tools and AI in mathematics instruction has become increasingly prevalent and necessary. Engineering-specific software packages, computational tools, and programming languages provide students with practical applications of mathematics in engineering contexts. Using virtual laboratories, simulation software, and data analysis tools helps students connect mathematical concepts to real-world engineering problems. Nevertheless, AI models have limitations, especially in areas where comprehension may be less accurate and reliable since it relies on patterns and context learned to generate answers. It is time for teachers to embrace the challenge and anticipate pedagogical and teaching methodologies that may cope with all the good provided by AI but also give students competencies that allow true knowledge to be acquired.

3 SIGNIFICANCE FOR ENGINEERING EDUCATION, ENHANCEMENT OF KNOWLEDGE AND DIALOGUE, AND ATTRACTIVENESS OF THE WORKSHOP TOPIC

It seems widely accepted that the integration of AI/ICT in mathematics education, particularly in the field of engineering education, has transformed traditional teaching and learning approaches. By leveraging the power of technology, educators can enhance students' understanding, engagement, and application of mathematics. As technology continues to advance, embracing ICT integration in mathematics education becomes imperative to prepare students for the challenges and opportunities of the engineering profession.

In an increasingly interconnected world, fostering education mobility has become essential for preparing students to thrive in a globalized society. Within the realm of mathematics education, promoting not necessarily equal but similar teaching and learning approaches across Europe holds great importance. Harmonizing mathematical education methods and fostering mobility among students, emphasizing the advantages of a shared pedagogical framework in promoting educational excellence and enhancing students' mathematical competence is a preoccupation of some teachers. Europe is a diverse continent with a multitude of educational systems and approaches to teaching mathematics. While each country has its unique cultural and educational context, fostering a more similar framework of mathematics education can bridge the divide between different systems. This ensures that students, regardless of their geographic location, have access to high-quality mathematics education and can seamlessly transition between educational systems. Promoting a similar approach to teaching and learning mathematics across Europe facilitates educational mobility for students. When mathematical concepts and pedagogical methods align, students can transfer their knowledge and skills more easily when moving between countries or participating in international exchange programs. This mobility opens doors for students to experience different educational systems, gain diverse perspectives, and develop adaptability skills. A shared understanding and implementation of mathematics education methods can contribute to the establishment of consistent academic standards across Europe. By aligning curricula, learning outcomes, and assessment practices, educational institutions can ensure that students receive a comparable level of mathematical education, regardless of their location. This consistency fosters transparency and helps students and employers recognize and evaluate mathematical competence uniformly.

Promoting similar teaching and learning approaches in mathematics encourages collaboration and knowledge exchange among educators across Europe. When educators share best practices, pedagogical strategies, and innovative approaches to teaching mathematics, it enriches the professional development of teachers and contributes to the continuous improvement of mathematics education. This collaboration can occur through teacher training programs, conferences, online platforms, and professional networks. By embracing a shared pedagogical framework, Europe can foster a sense of unity and belonging among its diverse nations. This shared educational experience helps create a cohesive community, where students can learn from one another, appreciate cultural diversity, and develop a deeper understanding of their European counterparts.

4 WORKSHOP DESIGN

The following bullet points summarize the content of the workshop and its design:

- A 10-minute activity showing the most common AI and ICT tools used by Mathematics teachers
- A 10-minute activity of individual reflection and questionnaire answers
- A 30-minute discussion/reflection among all attendees
- A 10-minute wrap-up and conclusions document construction to take away

5 RESULTS AND CONCLUSIONS

Twenty individuals from 14 countries, Fig. 1, attended the workshop and answered the proposed questionnaire.

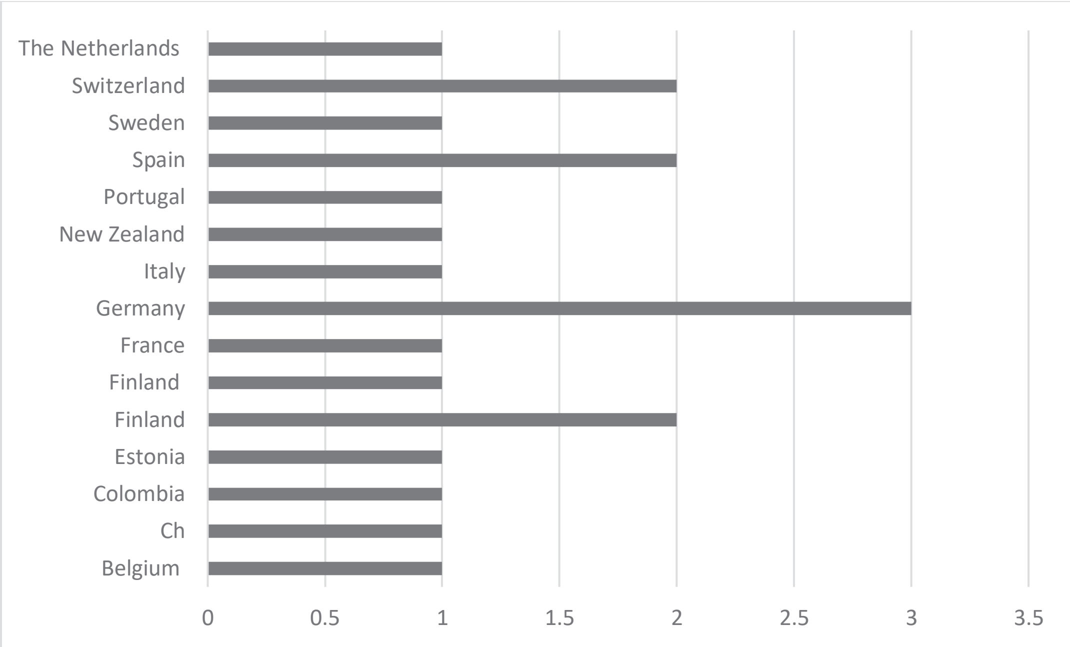

Fig. 1. Attendees' origin country

The gender distribution was balanced between individuals, as shown in the pie chart below, which allows us to analyse possible different perspectives.

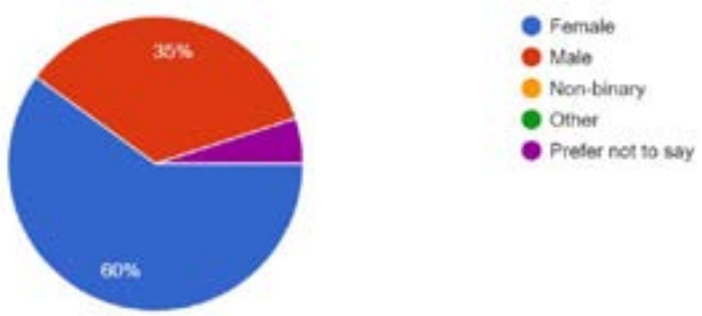

Fig. 2. Attendees gender.

The years of teaching experience among workshop attendees were also considered an important variable that could potentially influence the subjects being discussed. As evident from the histogram in Fig. 3, representing attendees' years of teaching experience, the sample includes individuals from all experience levels.

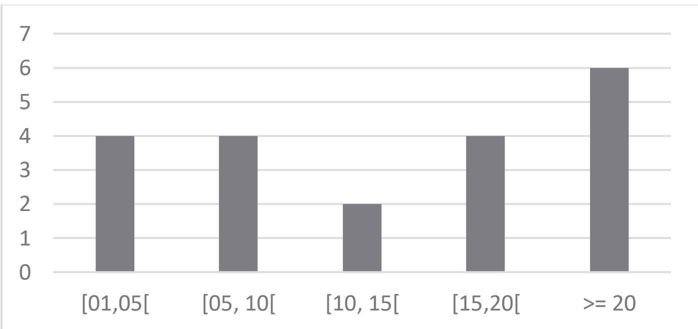

Fig. 3. Attendees teaching experience years.

From a list of possible Mathematics curricular units, which may have different strategic pedagogical approaches, attendees were asked to choose which ones did they teach. At Fig. 4 we may observe their answers:

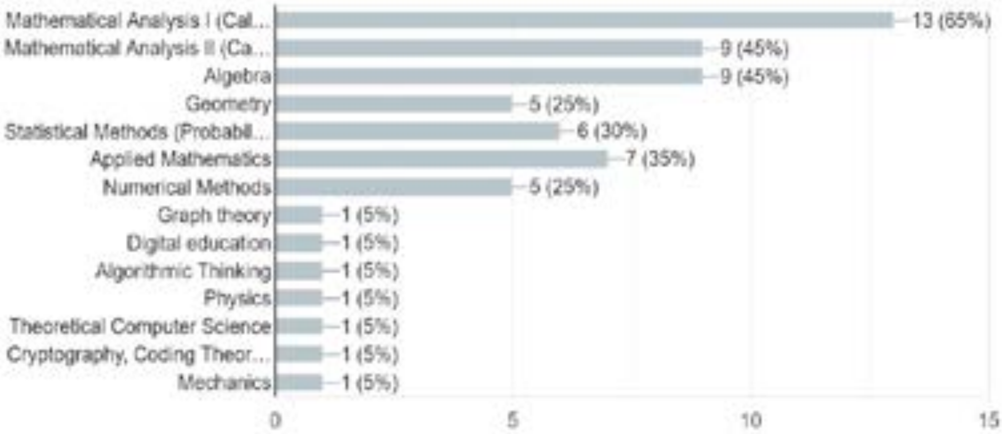

Fig. 4. Attendees' curricular units taught.

Regarding different pedagogical strategies, Fig. 5, we observed that all attendees use at least one pedagogical strategy besides standard education model (expository using only blackboard).

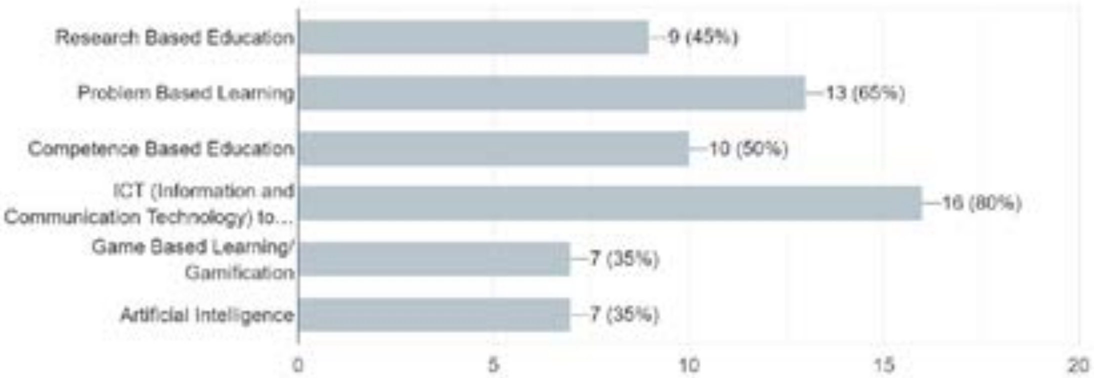

Fig. 5. Attendees' pedagogical strategies

When asked about the frequency with which the above-mentioned pedagogical methods were applied, we may observe, Fig. 6, that their applicability is higher than half the number of classes taught within a semester (1-Rarely and 5-Within almost all classes).

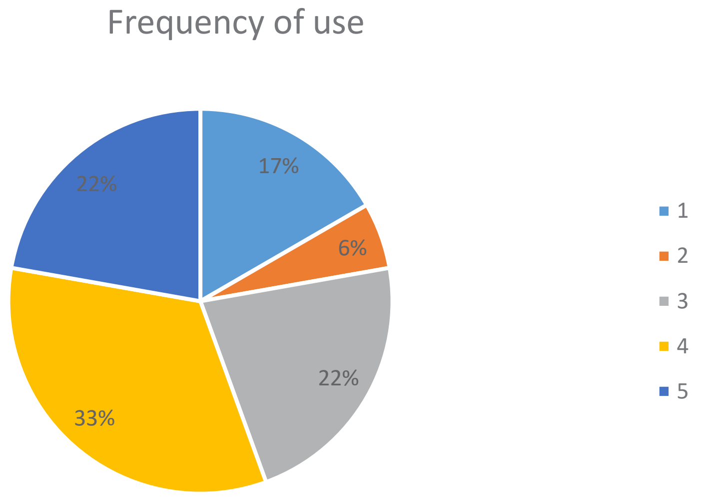

Fig. 6. Attendees' different pedagogical strategies usage

When trying to apply these strategies difficulties arise and the pointed main ones that attendees face when overcoming traditional pencil and paper Mathematics classes were, Fig. 7, the time to teach all contents needed and the difficulty of adapting curricula followed by financial conditions and insufficient ICT conditions available.

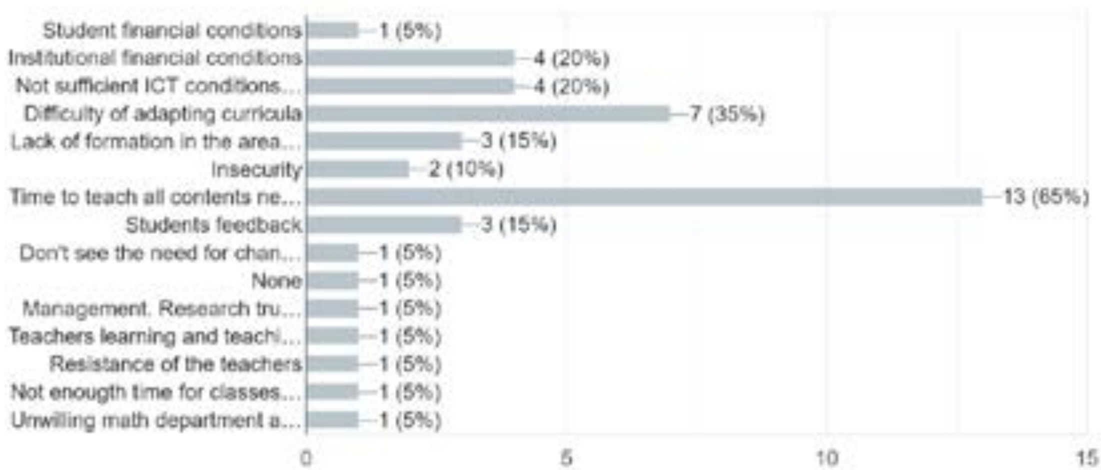

Fig. 7. Attendees' main difficulties regarding the applicability of different strategies

In future endeavours, fostering synergies between those responsible for engineering curriculum development and mathematics teachers should be regarded as an important theme.

The purpose of ICT tools usage inside classes are, for the present attendees, Fig. 8:

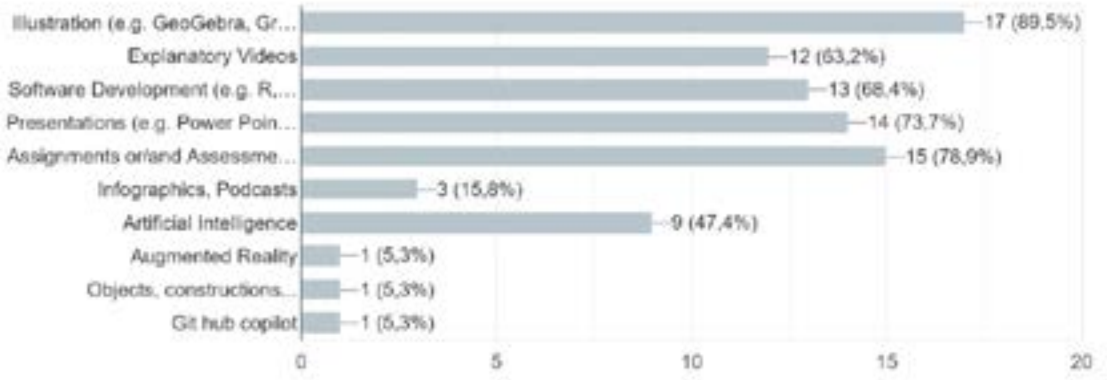

Fig. 8. Attendees ICT tools usage purpose

Regarding AI tools and the question “Which of the following AI tools do you use while teaching?” we observe, Fig. 9, that Wolfram Alpha and ChatGPT are the most used, followed by MATLAB and Python.

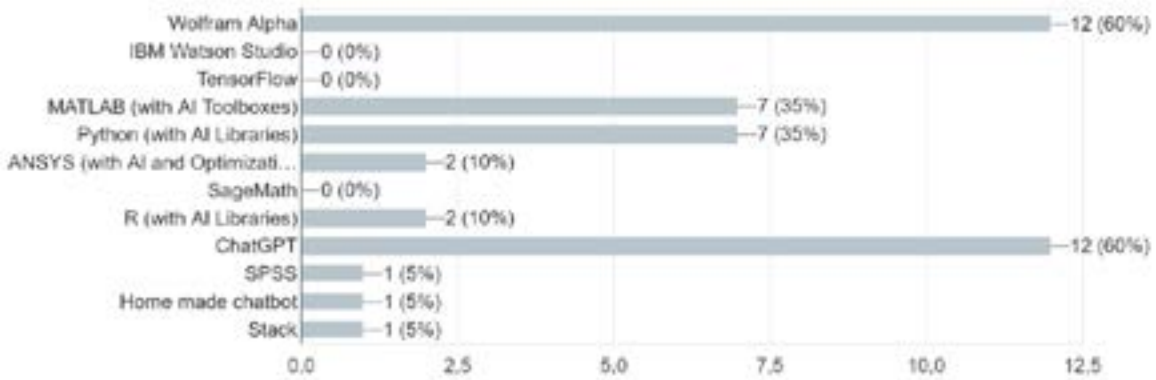

Fig. 9. Attendees AI tools usage

At workshop participants' curricular units’ classes, students may use some AI tools. The ones allowed are shown in Fig. 10:

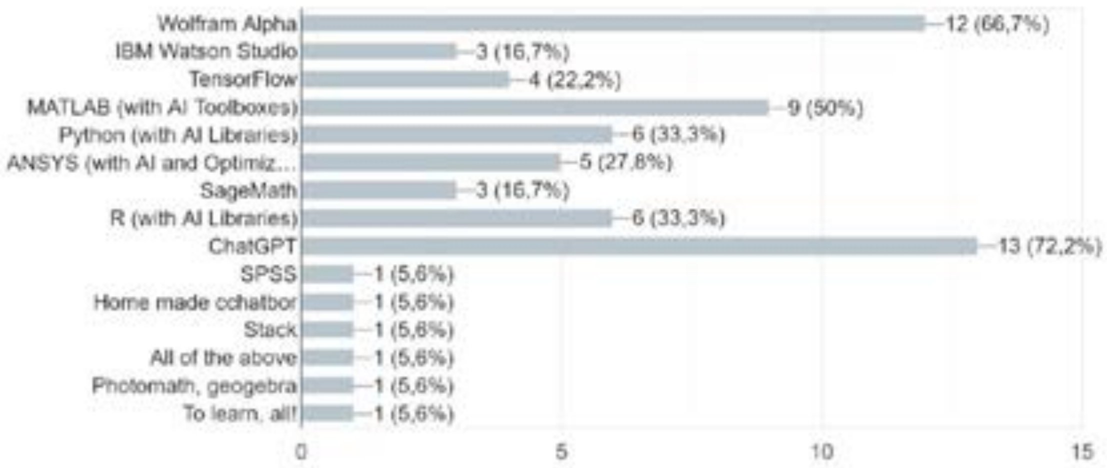

Fig. 10. AI tools used by participants students.

When asked about the main concerns while participants' usage of ChatGPT, the answers were:

- Hallucination
- Security
- Privacy/errors in content generated
- none
- Inequities in access and cost. Otherwise, a great helper in work, especially in programming and scripting.
- Added workload because of mathematical errors
- Lack of knowledge about tool and their limitations
- The varying results. Sometimes the results and proofs for example mathematical induction or optimization problems of two variables are different if you ask ChatGPT to produce the solution consecutively.
- Not the same definitions I use
- Cannot realise errors if you don't have previous knowledge
- Uncertainty in results
- Ethic

As for students' usage of ChatGPT participants concerns are:

- Wrong use
- Students are (usually) not able to detect the mistakes it states very confidently. Lack of critical attitude. Some students to see it as a quick win tool. Are they learning?
- Security
- Errors and privacy
- Students do not notice when AI is wrong
- Correctness of the answers and capacity of students to recognize errors
- Overreliance and not learning
- Incorrect answers, misleading explanations. Use for academic misconduct instead of learning methods
- Correctness of the answers provided by ChatGPT, students' ability to formulate good questions, no graphical supports
- No critical thinking on their own
- The likewise above
- Do not reflect the answers
- Same, students lack knowledge, they agree with all IA says
- Cheating
- The student's ability to be critical about texts and solutions provided; Ethics; Losing their ability to think and rationale by themselves

Participants expressed concerns regarding using AI tools other than ChatGPT, citing issues such as their perceived opacity ('black box'), potential for deskilling, similarity to one another, or a lack of competence in effectively utilizing them. For students, the use of AI tools different from ChatGPT presents the following concerns:

- Black box
- Deskilling
- I have no control over the answers and the feedback they provide them, and I don't know if the answers are aligned with what was done in the classroom.
- Overreliance and not learning.
- We've been dealing with overreliance on Wolfram Alpha and Symbolab since before COVID.
- The same
- Similar

- Lack of competence

Students' feedback, Fig. 11, regarding the use of the AI/ICT tools is encouraging as expected.

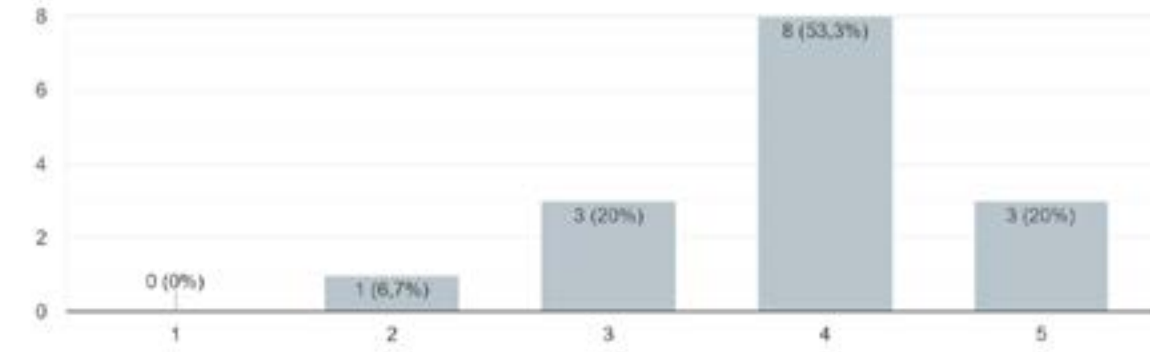

Fig. 11. Attendees' students feedback

At the conclusion of the semester, attendees' perception of students' apprehending mathematical concepts is moderate. This suggests that nearly all students grasp the concepts to some extent, although they may not achieve expertise. However, the concepts can be considered as having been apprehended by the students.

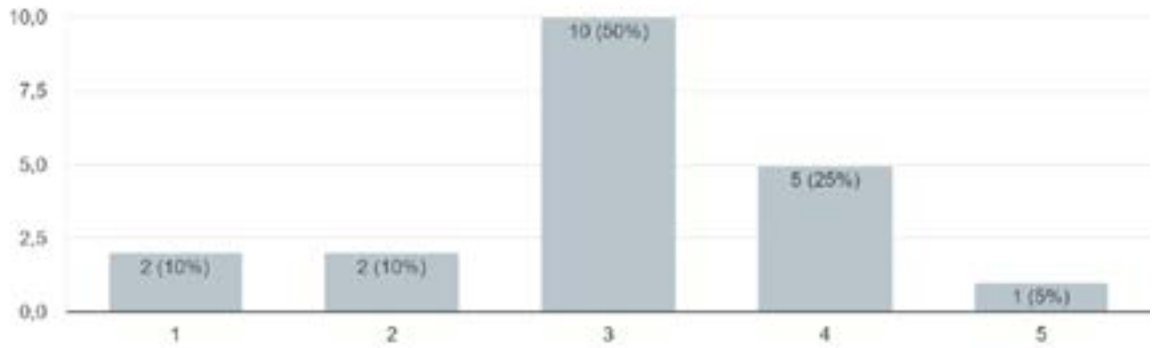

Fig. 12. Attendees' student's concepts apprehension (1 – Not apprehend;5 – Experts)

Nevertheless, apprehending the concepts is not a synonym of rigorous application and the attendees' perception regarding the rigour with which the Mathematical concepts were grasped reflects it, Fig. 13.

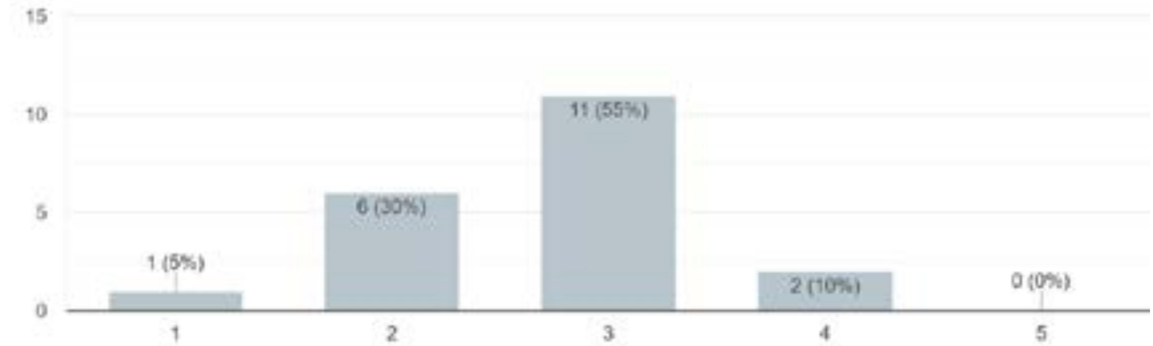

Fig. 13. Attendees' student's concepts rigour (1 – Not rigorous; 5 – Absolutely rigorous)

Authors were also interested in understanding which Mathematical competences were most valued by the attendees. The answer to that question reveals that to the attendees present at this workshop the most valued competences are the ability to be critical about the solution obtained and also the ability to apply the acquired knowledge to a different situation as we may observe on Fig. 14 a) b):

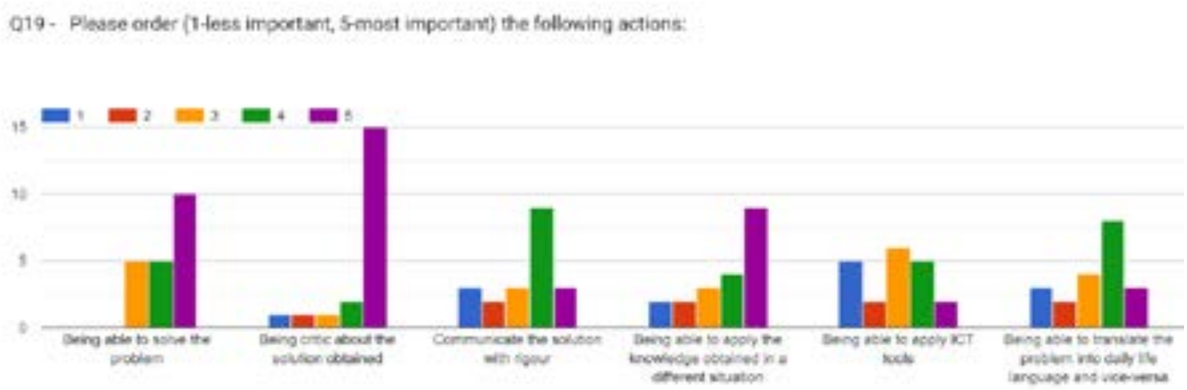

Fig. 14 a). Attendees' competencies ordering

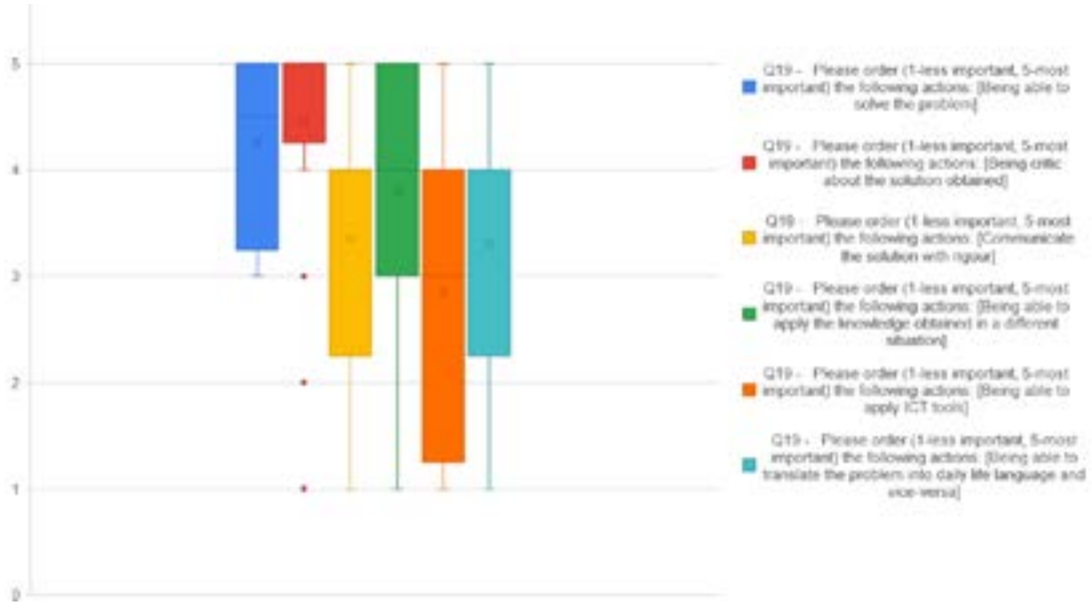

Fig. 14 b). Attendees' competencies ordering boxplot comparison.

At the end of the questionnaire authors asked attendees to share some fruitful educational experience in terms of pedagogy, ICT tools used, assessment procedures, AI, etc., and the inputs received were the following:

- Students use it whether we like it or not, we have to give them some guidance
- Students use ChatGPT for a curve sketching question and correct it (if any mistakes are detected).
- Solving problems with any ICT tool
- Forums allow to an increase grades of weaker students
- A PBL (problem-based learning) class about coding.
- Critiquing ChatGPT solutions make for good exercises in critical thinking, and students find this challenging - even the latest releases still make mistakes and carry the errors through!
- Discussion with students

6 ACKNOWLEDGMENTS

The authors extend sincere gratitude to the audience of the Mathematics Special Interest Group workshop for their keen interest and active participation.

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REFERENCES

Kurilovas, E., & Kubilinskiene, S. 2020. "Lithuanian Case Study on Evaluating Suitability, Acceptance and Use of IT Tools by Students–An Example of Applying Technology Enhanced Learning Research Methods in Higher Education." Computers in Human Behavior 107: 106274.

Oliveira, G., Grenha Teixeira, J., Torres, A., & Morais, C. 2021. "An Exploratory Study on the Emergency Remote Education Experience of Higher Education Students and Teachers During the COVID-19 Pandemic." British Journal of Educational Technology 52 (4): 1357-1376.

Sánchez-Ruiz, Luis M., Santiago Moll-López, Adolfo Nuñez-Pérez, José Antonio Moraño-Fernández, and Erika Vega-Fleitas. 2023. "ChatGPT Challenges Blended Learning Methodologies in Engineering Education: A Case Study in Mathematics" Applied Sciences 13, no. 10: 6039. https://doi.org/10.3390/app13106039

Santos, J., Figueiredo, A. S., & Vieira, M. 2019. "Innovative Pedagogical Practices in Higher Education: An Integrative Literature Review." Nurse Education Today 72: 12-17.

Ryan, M. 2013. "The Pedagogical Balancing Act: Teaching Reflection in Higher Education." Teaching in Higher Education 18 (2): 144-155.

SEFI SIG Workshop: Eager to further develop the field of engineering ethics education?

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Motivation

At the 2021 Annual SEFI Conference, the SEFI Ethics SIG proposed the idea of a Handbook developed by the community and launched an invitation to contribute during the workshop which asked participants whether they are “Eager to contribute to an Engineering Ethics Education Handbook?” (Børsen et al, 2021). The workshop attracted many participants interested to become co-authors, who during an active brainstorming section suggested other potential contributors and key themes that made their way in the handbook as co-authors and as chapters or sections. Three years later, this project is becoming a reality and *The Routledge International Handbook of Engineering Ethics Education* (Chance, Børsen et al, 2024) is soon to be launched, featuring 108 authors who collaborated in the development of 36 chapters “mapping” the field of engineering ethics education.

This project would not have been possible without the support of the community, and we want to celebrate with you and think together about next steps for continuing this project, alongside other interested engineering ethics teachers and researchers, as part of a rapidly growing community. The 2024 SIG workshop took stock of key advancements in the field of teaching the ethics and philosophy of technology, while looking ahead by making a series of recommendations for the next decade.

In the same collaborative spirit that was at the core of the development of *The Routledge International Handbook of Engineering Ethics Education*, we invited workshop participants to think alongside the editors what’s next: while celebrating the launch, to continue seeing the Handbook as an evolving project. This editorial project is a project that is continuously shaped by the European and non-European members of the engineering ethics education community, and responsive to emerging issues in ethics and the philosophy and technology as well as to recent calls for broadening the cultural inclusivity and the use of non-Western ethical frameworks.

Let’s think together of the next decade of engineering ethics education and how we, as a community, can contribute to the development of the field!

1 Theoretical background

Writing a handbook implies “mapping” the fundamental information needed by those teaching or researching in a field. This is a challenging task when the field is still maturing. This handbook grew from the idea that we could ‘collaboratively write’ engineering ethics education, and in doing so, striving to ‘decolonize’ the discourses that have traditionally dominated engineering ethics education and offer geographically and culturally diverse perspective on this field.

While we are indeed using the “mapping” metaphor, we do so conscious that it refers to past colonial practices, and as such we have encouraged authors to reflect on their positionality and be part of multi-cultural and geographical inclusive chapter teams. Mapping also refers to attempts to shift one’s perspective as to visualize a field from above, and to the continuous and unending task of striving to provide a representation of the reality we experience as teachers, researchers or citizens, that also continuously changes in response to current developments, pressing societal needs and to our own spiritual awakening. As technology and educational science are changing, what we know about engineering ethics education is changing, too. And so, any attempt to map the space of engineering ethics education will only ever represent a snapshot of that territory at a given moment in time. This process requires continuous effort from us, the cartographers of this field, across cultures and geographical borders.

2 Workshop structure

The workshop began with a short presentation of the forthcoming Routledge Handbook of Engineering Ethics Education by the editorial team. This includes details of the organisation of the Handbook, its origins as a SIG Ethics community project and the collaborative process behind its development, as well as insights on its significance for the engineering ethics education community.

This presentation was followed by an active session, where participants worked in groups on a theme related to a section in the handbook (foundations of engineering ethics education, ethics issues specific to the different engineering fields, dialogue with other disciplines, teaching methods, assessment, accreditation). The participants discussed what are for them the key challenges and developments noticed in connection to each theme. Based on these, each group proposed recommendations for developing the field or highlighted emerging areas of interest. An example of a new working topic proposed is care ethics.

The session concluded with a discussion of the next steps needed to continue the handbook initiative in a participatory manner, as to include not only those who contributed but also those who did not have the chance to be authors in the volume. Potential options include a post-workshop publication and identifying a thematic focus for the next SEFI Ethics Spring School.

3 Key takeaways

At the end of the session, the participants left with:

(a) An enhanced awareness of recent trends and developments in the field of engineering ethics education, including of a new resource that they may use in their teaching and research (i.e. the forthcoming Routledge Handbook of Engineering Ethics Education)
(b) The opportunity to be further involved in processes of the SEFI SIG Ethics community meant to expand or complement the forthcoming Routledge Handbook of Engineering Ethics Education

4 Significance for engineering education

Engineering ethics education is a maturing field that is rapidly expanding. A major driver is represented by current expectations related to the societal responsibility of engineers and the need for engineering education to prepare its graduates for the complex sociotechnical challenges they will face.

The SIG Ethics workshop strives to bring together novices and experienced engineering ethics teachers and researchers alike to empower them to take personal action in further building the engineering ethics education community. Are you *eager* to contribute to further develop engineering ethics education and join us?

References

Børsen, Tom; Bombaerts, Gunter; Chance, Shannon; Lennerfors, Thomas; Martin, Diana; Tormey, Roland. (2021). Eager to contribute to an Engineering Ethics Education Handbook? 2021 SEFI Annual Conference.

Chance, S., Børsen, T., Martin, D., Tormey, R., Lennerfors, T. T., & Bombaerts, G. (Forthcoming 2024). *The Routledge International Handbook of Engineering Ethics Education*. Routledge Taylor & Francis Group.

CURRICULUM DEVELOPMENT AND EMERGING CURRICULUM MODELS IN ENGINEERING

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***Conference Key Areas**: Curriculum development and emerging curriculum models in engineering*
***Keywords**: Curriculum development, Curriculum Design.*

ABSTRACT

The past decade or two have seen a renewed emphasis on curriculum design and the advent of a new set of approaches to help ensure the development of a programme structure which supports student progression. In this workshop, members of the Curriculum Development special interest group (SIG) worked with colleagues from a wide range of institutions to consider how to approach the design of a holistic and integrated curricula. We introduced common curriculum models and gave an example of a curriculum design methodology to help attendees consider how they might apply a holistic curriculum design process in their own institutional context.

1 MOTIVATION & LEARNING OUTCOMES

Curriculum development is the systematic process that defines and delivers what will be taught, who will be taught, and how they will be taught within an educational programme. It involves the planned, purposeful, progressive, and holistic process to create positive improvements in an education system so that our graduates are best prepared to maximise their future. As such it draws together threads of core content, engineering and transferable skills and pedagogic approaches to create an amalgamated set of learning experiences to meet the intended programme-level outcomes.

To achieve this, a number of curriculum frameworks have been developed. Some notable examples include the Connected Curriculum (Fung 2017) which aims to provide an outline of how relationships to connect students with research, the public, the workplace and each other across disciplines, can be formed within the design of a curriculum. Within engineering, many examples of curriculum revisions follow models such as CDIO, Conceiving — Designing — Implementing — Operating (Crawley et al., 2014) which provide a framework for a curriculum that features aspects of design-build-test based project-work and an integration of skills development. It promotes a curriculum organised around mutually supporting courses, but with the CDIO activities highly interwoven in what we would term, an integrated curriculum. An integrated curriculum suggests that the learning that students undertake is delivered across traditional subject areas, with the learning experiences designed to be mutually reinforcing and staged in a manner that allows for increases in depth and complexity. As a concept it has been popular in schools, and in higher education there have been a number of notable programmes from the late 90's onwards (see Froyd and Ohland, 2005). In this workshop we used the ABC curriculum design process as developed by Young and Perović (2016).

When considering the design of a curriculum it is common to consider the curriculum as having four elements as defined by Bernstein (2000). Firstly, there is the planned curriculum. This is the curriculum that is designed, developed and ultimately validated through bureaucratic university processes. It is ultimately driven by the local or national approvals process – however, this would deny the central value and artistry in such planning. The complex requirement to balance often conflicting interests while recognising legacy and context, mean that this is a challenging task. In recent years, learning design tools have been developed to support practitioners in ensuring that all the inherent and sometimes conflicting concerns can be captured and incorporated. Examples include ABC (Young and Perović 2016), ICEBERG (Weller, van Ameijde, and Cross 2018), or Carpe Diem (Armellini, Salmon & Hawkridge 2009).

Secondly, there is the delivered curriculum, the manifestation of the designed curriculum when put into practice. In an ideal world, this will be simply the practical realisation of the planned curriculum, however, it is often more complex. For example, it is common that different staff will have engaged in the process as the curriculum moves from design to delivery, leading to modification and adaptions when the planning curriculum is actually delivered.

Thirdly, there is the received or perceived curriculum, terms which acknowledge that the curriculum received by students may differ from that proposed or delivered by staff. Finally, and perhaps most crucially, but most often ignored during the design stages, is the hidden curriculum. This is the curriculum that is not formally specified, but that is often acutely felt by the students as it often embodies the processes and cultures of the university or department.

Central to many of these approaches is the concept of a curriculum that builds and develops as student progress through it. This is often referred to as a spiral curriculum (Harden and Stamper 1999). It provides students with an opportunity to iteration and revisit important elements of learning such as key skills throughout the curriculum. This concept is based off the work of Bruner (1960) and has proved popular as it encourages reinforcement and integration of knowledge through a process where new learning is built on previous learning.

2 WHY IS THE SESSION RELEVANT AND ATTRACTIVE FOR THE AUDIENCE?

Although all universities have a curriculum, it is often difficult, even for those within the organisation, to see exactly how it was originally designed. This may be because the design has been in place for some time, because it has been driven by outside forces such as accreditation or national regulation, or, because it has grown and developed somewhat organically, with modules evolving and the whole rarely being considered. It should also be recognised that what influence an individual can have over the curriculum may well depend on the structures within the university and/or nationally. In some jurisdictions, especially those with credit-hour systems, it is hard to fully prescribe the content and timings of the elements that the students will meet. In others, there is far more opportunity to structure the learning activities to build threads and progressions within the curriculum.

This workshop presented an approach to curriculum design, drawing on the context of participants institutions and a range of widely used models to enable a high-level design of a holistic and integrated curriculum to be produced.

3 WORKSHOP PLAN:

The workshop began with a short presentation of the key approaches to curriculum design. Participants will be asked to consider their key curriculum objectives in the context of their own educational mission. We then introduced a reduced version of the ABC (Young and Perović 2016) framework for curriculum design and allowed participants to undertake this exercise in small groups to identify approaches to structure a curriculum that will lead to the to their curriculum objectives. The session concluded with a feedback session to capture the major insights of the facilitators and participants of going through this process.

A group of facilitators with experience in curriculum development were present to support the 50 participants in attendance. Although this workshop was ideally suited to those with curriculum leadership responsibilities, it was clear that it was of value to all those who are interested or aspire to consider the design of the programmes beyond the module level.

4 Output of the Workshop:

The ABC activity is usually undertaken in a workshop of at least 90 minutes, and so only a reduced version was possible in the confines of this workshop. However, it is hoped that the key strategies of this approach were apparent. Participants were asked to first identify a programme level learning outcome that they wished to see in their graduating students and articulate this in one sentence. From this they should collaboratively identify the key skills that students should be developing as they progress through their programme if they are to meet this learning outcome. Finally, supported by the ABC learning designer categories (Acquisition, Collaboration, Discussion, Investigation, Practice, Production), groups should consider what activities students should engage in to develop these skills.

A range of topics were considered by the groups including:

- Curricular Community Engagement
- Developing an understanding of sustainable principles in engineering
- Students should be able to work together and collaborate
- Ability to solve complex problems
- Be able to critically evaluate ones' own results and actions and those of others
- Ability to apply systems thinking principles to address complex problems
- Evaluate consequences of the outcomes of a project
- Online collaboration in active learning
- Develop engineers with a systems perspective
- Reflectively design an energy engineering project.

Although not all groups achieved the full set of tasks, many fruitful conversations were had and in the workshop demonstrated the need for holistic curriculum design across multiple years to achieve programme level learning outcomes.

5 Resources:

- ABC Learning Design - https://abc-ld.org/
- Online Learning Designer - https://www.ucl.ac.uk/learning-designer/
- The Conversational Framework - https://www.futurelearn.com/courses/blended-and-online-learning-design

REFERENCES

Armellini, A., Salmon, G., & Hawkridge, D. The Carpe Diem journey: Designing for learning transformation. In T. Mayes, D. Morrison, H. Mellar & Bullen, Peter and Oliver, Martin (Eds.), Transforming higher education through technology-enhanced learning. York: The Higher Education Academy (2009) 135-148

Bruner, J.S. The Process of Education (Cambridge M A, Harvard University Press). 1960

Crawley, E. F., J. Malmqvist, S. Östlund, D. R. Brodeur, K. Edström. "The CDIO approach." Rethinking Engineering Education: The CDIO Approach (2014): 11-45.

Froyd, J. E., and M. W. Ohland. "Integrated engineering curricula." Journal of Engineering Education 94(1) (2005): 147-164.

Fung, D. (2017). Connected Curriculum for Higher Education. UCL Press. https://doi.org/10.2307/j.ctt1qnw8nf

Harden R.M. and N. Stamper “What is a spiral curriculum?”, Medical Teacher, 21:2, (1999) 141-143

Weller, M., J. van Ameijde, and S. Cross. "Learning design for student retention." Journal of Perspectives in Applied Academic Practice 6, no. 2 (2018).

Young, C. and N. Perović, “Rapid and Creative Course Design: As Easy as ABC?” Procedia – Social and Behavioral Sciences, 228, (2016) 390-395

Staff Capacity Building for Educating Socially Responsible Engineers: Considerations Related to Culture and Emotion

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***Conference Key Areas**: Building the capacity and strengthening the educational competences of engineering educators; Educating the whole engineer: teaching through and for knowing, thinking, feeling and doing*
***Keywords**: Capacity building, culture, emotion*

1 MOTIVATION AND OUTCOMES

1.1 Motivation

This workshop was organised by the Capacity Building SIG: an international and interdisciplinary group of educators and researchers interested in a broad understanding of capacity building, such as teacher pedagogical training and PhD student and researcher development. The aim of this workshop was to explore the intersection between capacity building and the conference theme of educating socially responsible engineers.

Educating socially responsible engineers requires moving beyond developing students' technical knowledge and skills to also fostering their personal and social responsibility [1]. The literature variously uses terms such as “21st century skills" [2], "professional competencies", but also "empathy" [3][4], "inner development goals" [5], and "educating the whole engineer" [6]. Redirecting engineering education in these areas can be challenging for educators who have not received any training for teaching other than the technical aspects of engineering. Therefore, capacity building is particularly important for educating socially responsible engineers.

With this motivation, there were three parts to the session: brief introduction to the workshop goals and terminology, rotating pair conversation, and panel discussion. After establishing common language and situating the workshop aim, the second part provided participants with the opportunity to self-select into three topical groups that explored how we approach teaching material at the intersection of technical skills and skills for responsible citizenship, and the responsibilities and pressures that this places on the educator. Through these pair conversations, participants developed reflective questions that they posed to the panellists in the third part of the workshop. There was no background knowledge or capacity building experience required for participants.

1.2 Outcomes

The aim of the workshop was to provide a safe space for exploring staff capacity building related to educating socially responsible engineers. The session was designed to achieve the following outcomes:

- Develop a better understanding of how we, individually and collectively, approach capacity building for educating socially responsible engineers
- Develop awareness of diverse ways in which emotion and culture influence our approaches to capacity building for educating socially responsible engineers
- Share concrete ideas of how we can improve capacity building practise in this context
- Build a community of educators and researchers who, from diverse disciplinary and practice-based vantage points, share an interest in strengthening capacity building for educating socially responsible engineers.

2 BACKGROUND AND RATIONALE

2.1 Positionality

As the SEFI SIG for Capacity Building, we lean on previous research (outlined above) that points to the importance of teaching not only technical knowledge and skills, but to also engaging students in the social, emotional, and professional aspects of being and becoming socially responsible engineers. Changing engineering education in this way requires transforming assumptions, practices, and structures, both individually and collectively. Exchanging experiences, ideas, dreams, and concerns is an important first step for fostering a community of research and practice of capacity builders who, over time, can support momentum for transformative change in engineering education.

2.2 Capacity Building

Capacity building is defined as the process of developing and strengthening the skills, instincts, abilities, processes, and resources that organisations and communities need to survive, adapt, and thrive in a fast-changing world [7]. Within SEFI, this is translated into the aim to empower the process of developing and strengthening the competencies that trainers (faculty, staff, student teachers, and researchers) in engineering higher education need to support and impact their students.

3 WORKSHOP DESIGN

The workshop was organised in three parts to facilitate conversation and engagement between the participants, facilitators, and panellists.

Part 1 of the workshop introduced the participants to the topic of the workshop, outlining the aims; our definitions of capacity building, socially responsible engineers, emotional responsibility, and cultural context; what is already known in literature about the intersection between these concepts and how it plays out in engineering education practice.

Part 2 of the workshop provided participants with the opportunity to self-select into three topical groups: (1) capacity building to educate socially responsible engineers, (2) the emotional load or labour of teaching the social and professional aspects of becoming socially responsible engineers, and (3) the relevance of cultural context in teaching social responsibility. Within each group, participants engaged in brief, rotating one-on-one conversations. In these conversations, participants were encouraged to share their thoughts and emotions related to their chosen topic and to share and/or co-develop reflection questions that could guide further exploration of the topic, both individually and collectively. Focusing on reflection questions allowed us to take into account that specific tools or methods for capacity building are context dependent. Thus, our aim was not to simply share best practices that may or may not be relevant to different cultural and disciplinary backgrounds but rather generate reflective dialogue that participants could use to develop good practices for their own specific context.

Part 3 of the workshop consisted of a panel discussion in which participants posed the reflective questions they developed during Part 2 to panellists who have expertise in each of the three topic areas. The aim of this part was to consolidate understanding, bring different perspectives to the forefront, and learn from experts, enabling participants to leave with new knowledge, contacts, and plans for the future.

4 WORKSHOP RESULTS

Participants recorded questions and reflections on Padlet to guide the panel discussion and provide a community resource. Three primary themes emerged in the panel discussion. (1) Defining social responsibility in a globalised context and reconciling different world views: One takeaway was that social responsibility takes on different meanings in various contexts, and our goal as educators should not be convergence. We can celebrate differing world views and learn from them through inter- and transdisciplinarity. (2) Choosing 'safe' topics for the classroom: The group reflected that cultural and political factors can make it challenging for educators to know which topics are safe to bring into classroom conversation. Creating group norms around respect and openness can support the classroom environment, but some level of discomfort can be expected and should be acknowledged. It is important for educators to consider how much discomfort is reasonable and whose discomfort is generally tolerated in engineering education – both of which are affected by privilege. (3) Supporting staff: A final theme centred on support staff need for educating socially responsible engineers. Considerations include how comfortable staff are in pushing the boundaries of students' learning and making a conscience effort to show such teaching has a purpose on which students should reflect.

5 SIGNIFICANCE

The contemporary practice of engineering involves the consideration and negotiation of varied perspectives and interests in achieving sustainable economic, social, and environmental outcomes. Therefore, it is critical that engineering educators have the capacity -- which consists of a combination of knowledge, pedagogical skills, and understanding of global context and emotional aspects of teaching and learning -- to prepare their graduates to practice engineering in a socially responsible manner. This workshop modelled and explained transferrable approaches to engaging teaching staff and students in contextually appropriate capacity building activities.

REFERENCES

UNESCO, "Pathways to 2050 and beyond: findings from a public consultation on the futures of higher education." United Nations Educational, Paris, Nov. 2021.

D. Sangwan, K. S. Sangwan, and P. Raj, "21st century competencies in engineering education: initiation, evolution, current, and now whither to," SEFI 50th Annual conference of The European Society for Engineering Education, 2022, doi: 10.5821/conference-9788412322262.1409.

Bairaktarova, D., & Plumlee, D. (2022). Creating Space for Empathy: Perspectives on Challenges of Teaching Design Thinking to Future Engineers. International Journal of Engineering Education, 38(2), 512–524.

Walther, J., Brewer, M. A., Sochacka, N. W., & Miller, S. E. (2020). Empathy and engineering formation. Journal of Engineering Education, 109(1), 11–33. https://doi.org/10.1002/jee.20301

Inner Development Goals (2021). https://innerdevelopmentgoals.org/framework/

Hitt, S. J., Banzaert, A., & Pierrakos, O. (2023). Educating the Whole Engineer by Integrating Engineering and the Liberal Arts. International Handbook of Engineering Education Research, 457.

United Nations (2024, April 24). Capacity building. https://www.un.org/en/academic-impact/capacity-building

NEEDS OF STUDENTS AND EDUCATORS FOR EFFECTIVE ORGANIZATION OF CONTINUING ENGINEERING EDUCATION

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Conference Key Areas: *Continuing education and life-long learning in engineering; Curriculum development and emerging curriculum models in engineering.*
Keywords: *Continuing education, life-long learning, continuing engineering education, needs, curriculum*

ABSTRACT

Universities face increasing demand for Continuing Engineering Education (CEE). However, prospective students' and industry's expectations and needs differ from those associated with traditional university education offerings. Educators thus face new challenges in planning and implementing the curricula whilst navigating the diverse needs of student groups, including undergraduate and graduate students, as well as lifelong learners who want to update or renew their skills, knowledge, and work-life competencies. The workshop organized by the CEE/LLL SIG gathered views from three different perspectives (learner, educator and successful CEE implementation models). Key findings show that there is a desire for a range of CEE offerings, but it is complex - with varying individual learner motivations and needs, challenging for universities to select and develop viable and valuable offerings, as well as the need to develop the skills of their staff further. Also, new technologies have the opportunity to offer greater personalisation and the potential and risks of these need to be explored further. These themes inform further research as well as development activities in higher education institutions.

1 MOTIVATION, GOALS AND LEARNING OUTCOMES

1.1 Motivation

Universities face increasing demand for Continuing Engineering Education (CEE), particularly in a post-COVID world (Ossiannilsson 2022). For example, according to a UNESCO report on trends in LLL (lifelong learning), 53% of HEIs (Higher Education Institutions) surveyed had a unit dedicated to LLL. However, 55.1% of respondents considered employer/labour market involvement a challenge (UNESCO 2023, 33-34). Moreover, 61.4% of respondents reported scientific research on LLL as challenging. Importantly, the survey did not consider lifelong learners' or educators' needs and expectations.

The expectations and needs from the point of view of the prospective students and industry differ from those associated with traditional university education offerings. Thus, educators face new challenges in planning and implementing the curricula, whilst taking into account the diverse needs of different student groups engaged in CEE, including undergraduate students and life-long learners who desire to renew their skills, knowledge, and work-life competences (Lybecker Korning and Nørgaard 2023). Designing the offering to meet students' and educators' needs and expectations requires novel models and approaches for developing and implementing the CEE offerings. This workshop aimed to identify the needs and challenges, as well as successful and innovative approaches and models to develop and deliver CEE offerings.

1.2 Goals and learning outcomes

The workshop aimed to bring together lifelong learners, labour union and industry representatives, educators, university managers, and other CEE staff and interested parties to share needs and requirements for developing CEE both from the point of view of students and educators. At the same time, novel and innovative approaches and experiences for organizing and delivering CEE to meet the stakeholder needs of both groups were aimed to be shared.

The expected learning outcomes included:

- understanding the needs and expectations of life-long learners in terms of how CEE is organized, offered, and delivered, as well as how these needs are identified and used for CEE development
- understanding of the needs of educators in implementing and delivering CEE, challenges to be solved from the perspective of educators
- sharing of approaches and models that have been found successful by educators in practical CEE implementation work

2 WORKSHOP DESIGN

2.1 Questions addressed in the workshop

Based on the goals and expected learning outcomes, the questions addressed in the workshop were the following:

1. How can we better understand the needs and expectations of lifelong learners regarding the organization, delivery, and offerings of Continuing Engineering Education (CEE)? What gaps exist in our knowledge regarding these needs and expectations, and how can they be addressed to inform the development of CEE programs?
2. What are the challenges educators face in implementing and delivering CEE, and how do these challenges impact the effectiveness of CEE programs? How can we address these challenges to support educators better in their CEE delivery?
3. What approaches and models have educators found successful in their practical implementation of CEE programs? How can these successful strategies be adapted and scaled to enhance the delivery and impact of CEE initiatives?

2.2 Organization of the workshop

The 60-minute workshop consisted of group work on the three main questions to be answered. The method used was World Café (Löhr, Weinhardt & Sieber 2020), which engages the participants in active dialogue, interaction, and knowledge sharing. Three groups gathered to share and collect answers to the questions. A0-sized papers, pens, and Post-it notes were used to collect the answers. Three rounds of group work took place, each group changing tables for the theme to work on every 10 minutes. Four workshop organizers acted as table hosts, introducing a summary of the results from the previous round to the next group when tables were changed. At the end of the workshop, the results were discussed together, and table hosts presented a summary of the discussions for everyone. The results were collected for analysis and reporting to this revised workshop paper.

Workshop schedule was the following:

10 minutes – Welcome and introduction to method and questions to be answered.

30 minutes – working in small groups, 3 rounds of 10 minutes working

20 minutes – sharing the insights from the three themes and collecting generated materials for further analysis.

There were 12 participants in the workshop working in three groups, in addition to four facilitating hosts.

3 RESULTS

3.1 Understanding learner needs and expectations

The most discussed theme related to student needs and expectations was, whether we at university know, and do learners themselves really know, what they need. Some participants mentioned that the learners' needs and expectations may be high or learners do not recognize the needs themselves. The offering directed to the explicitly stated learner needs may not match the true needs after all, or the expressed needs and wishes may be too broad. In addition, there is a challenge to recognize the right target groups by the universities and educators, and therefore their needs are not known. Also, demographics (such as age) and other background related issues may create differences in the needs.

The second discussed theme addressed the value of the CEE for the learners, who are in work-life-study situation. Two main aspects arose in the discussion. First, the participants raised a question that the learners consider “is it worth my while” to study. The second thing to consider by learners is, how does learning fit with work life and personal life. This also led to discussing the financial and time related aspects of studying. Two aspects were mentioned - who pays for the studies, and whether we are addressing university or paid education. In addition, one of the workshop participants mentioned that he/she proposed to employers that they would provide work time for studies. Therefore, it is important that the offering is perceived valuable from both time and money perspective and the offering needs to create value for the students. This value and its dimensions for different learner groups needs to be understood when designing the CEE/LLL offering.

Some of the discussions also revolved around learners’ motivation to participate. It was discussed whether learners are motivated and whether they are intrinsically motivated or are forced to study. One of the participants mentioned that learners may have low confidence in their own capability to learn, even though they have years of work experience behind them. This also led to discussing how important it is to value the learners as resources themselves in CEE, as they have experience and practice related knowledge based on their work-life-study experience. This can be facilitated through peer learning, however, the value of the practice related knowledge might not be realized by the learners themselves.

To be able to better understand the needs of learners, directly asking them was suggested as the most obvious solution. It was mentioned that this should be complemented by also quantitatively monitoring aspects of their online presence. This would call for using also learning analytics as part of the quantitative monitoring. Qualitative methods could then be used to search for explanations for the behaviour from the learners directly.

3.2 Challenges for educators

The educators discussed some of the topics raised above, specifically around time commitment from the learner (so work-life balance), diverse needs (motivations) including up- and re-skilling, and financial aspects such as who pays (including whether employers should sponsor).

Another aspect of the financial picture is that for the providers (universities) and how to identify CEE offerings that will have sufficient volume to make them financially viable. It was noted that it takes specific resources and skill-sets to develop a CEE offering. This requirement, combined with the often-conservative approach of universities, can make it challenging to make the business case. Oftentimes, this will be a new endeavour for individuals and institutions and there is a lack of guidelines at university level on how to develop effective CEE courses. Additionally, the university needs to invest in its educators so that they can deliver effective CEE courses.

Also, equity, diversity and inclusion were highlighted, particularly when those looking for CEE courses will have particular motivations, so for educators they need to provide opportunity for contextualisation and personalisation. Different ideas were discussed, including self-paced learning, a mixture of delivery modes (online, synchronous and asynchronous, hybrid), use of problem- and challenge-based learning, as well as the potential use of AI; the use of AI is a clear area for future investigation.

3.3 Successful models and strategies for CEE implementation

Firstly, it was recognised that there is not a single model and that there are a range of models. These models covered different dimensions:

1. Formal versus non-formal/in-formal learning: the participants shared that there are a range of ways for practising engineers to learn, including formal courses, informal learning, Communities of Practice, and that recognising this diversity is important.
2. Diverse offering (size of formal learning): some participants argued that a Higher Education Institution needs to have a diversity of offering, namely short (e.g., weekend courses), micro-credentials, semester-long courses and full Masters programmes;
3. Diversity of topics: some participant's institutions only offered CEE courses in areas in which they had expertise, whereas others had a mixture of technical courses and courses around management and leadership;
4. Different Learning Management Systems (LMS): based on the diverse offerings then a mixture of both the university's own LMS or a platform (such as EdX or FutureLearn). The use of platforms for MOOCs was seen as beneficial as these platforms support marketing and other back-office functions.
5. With credits and without credits: credits were understood in two main ways - a) ECTS credits; and b) recognition. The second (recognition) was more supported by participants, including the ability to share achievements digitally. For ECTS credits then this was recognised as not always being of relevance and importance to learners, teachers or to companies.

In terms of strategies, then understanding the needs and demand for CEE offerings was identified as critical. For some CEE offerings, this will mean that industry involvement is essential, and that co-creation of the offering (outcomes and syllabus) works best. To achieve this collaboration and recognise that defining requirements is often iterative, then effective approaches to manage change and gain consensus are required; often this is through key people that can bridge any different usage in language between different groups and can manage this change effectively.

Examples were shared where government funding has been a key enabler of successful CEE offerings as this had enabled universities and employers to work together around an agreed focal area.

Success was seen by participants in different ways - for students about broadening learning, supporting career development, enhancement of social and professional networks, and for the university about building reputation (e.g., in an area of expertise), connecting to the community, as well as financial.

Finally, the participants recognised that currently universities were not engaging sufficiently with alumni - as co-creators a) to identify need and demand, and b) to design and deliver CEE offerings - and this was a strategy that was identified to enhance future CEE offerings.

4 FUTURE RESEARCH AND DEVELOPMENT NEEDS

In conclusion, the workshop explored the needs and motivations for CEE from three different perspectives. The discussions highlighted a number of shared topics that are worthy of future investigations: 1) how to determine needs of learners and opportunities of sufficient scale to make CEE offerings viable and valuable for learners; 2) need for greater guidance for universities on how to approach developing CEE offerings, which is linked to 3) the need to provide educator training and support to be able to deliver CEE offerings effectively including contextualisation and personalisation of learning. It was discussed that 4) AI and other technologies have potential benefit to educators and students alike to personalise, which 5) can help better align to learners' motivations and it is important for those offering CEE courses to understand these appropriately.

REFERENCES

Löhr, K., Weinhardt, M., and Sieber, S. "The "World Café" as a participatory method for collecting qualitative data." *International journal of qualitative methods* 19 (2020): 1609406920916976.

Lybecker Korning, I.M., and Nørgaard, B. "European And National Strategies Supporting The Implementation And Development Of Continuing Engineering Education At Scandinavian Universities." (2023).

Ossiannilsson, E.S.I. 2022. Resilient Agile Education for Lifelong Learning Post-Pandemic to Meet the United Nations Sustainability Goals. Sustainability, 14, 10376. https://doi.org/10.3390/ su141610376.

UNESCO Institute for Lifelong Learning and Shanghai Open University. *International practices of implementing lifelong learning in higher education: research report.* 2023.

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