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Editorial

We are pleased to bring you the fourth volume of the Southern Journal of Engineering Education. This is the first *volume* that will hopefully contain two *issues* of which this is the first for 2026. The transition to publishing two issues per year rather than one reflects growth in the number of articles being submitted to the SJEE. This encouraging trend is, in part, due to our accreditation by the Directory of Open Access Journals (DOAJ). This means that South Africa's Department of Higher Education and Training (DHET) recognises articles published in the SJEE which is necessary for authors to claim institutional subsidy which obviously encourages South African researchers to publish with us.

However, a look at the contributors to this issue shows significant international authorship including colleagues from the Democratic Republic of Congo (DRC), Namibia, Nigeria and the USA – which we appreciate. This is appropriate for a journal that serves an international audience and is focused, of course, on the Global South. Furthermore, we are pleased that our editorial board (we prefer calling it a 'management team') is becoming increasingly international. When the journal was launched in 2021, all the original team members were South African, but we have recently welcomed Dr Mariam Makramalla from Newgiza University in Egypt and A/Prof Carola Hernandez from Universidad de Los Andes in Colombia.

The proliferation of generative AI (artificial intelligence) in education presents many challenges to academics for both their practice and research. To this end, Dr Sally Ledwaba – one of the management team members – leads the development of the journal's AI policy. This will form part of our broader Ethics and Malpractice Statement that we are working on as we consider applying for indexing with Scopus. One of the challenges with developing an AI policy is that the technology is changing so fast that the policy needs to be framed quite broadly; we don't want to have to update it every six months! Another matter to think about is the target audience for this policy. The most obvious category is **authors** and, of course, we must think about the needs and circumstances of researchers in the Global South. Something which seems to be useful is the requirement of 'AI Discolsure Statement' at the end of an article in which authors disclose the ways in which they have used AI in their production and writing.

We also need to think about **reviewers** to ensure that, according to our peer review policy, the colleagues who are asked to review submissions draw on their real expertise to make an independent judgement. We do not want reviewers to simply feed the manuscript into ChatGPT or another AI tool and submit the output as their review. Such a practice not only raises ethical concerns but also confidentiality and data privacy concerns. From the viewpoint of **editors**, which includes me as the Editor-in-Chief as well as the management team, we are asking ourselves questions like this: is it permissible to use AI to synthesise reviews?

As a thought experiment, I decided to upload the articles in this issue to an AI tool – Google LM – to see whether it provided any useful ideas or patterns to guide, as is customary in editorials, the overview and article summaries. To model the ethic of transparency mentioned above, I have included an AI Disclosure Statement at the end of this editorial.

As a broad theme, the various facets of the student experience are foregrounded in this issue of the SJEE. The first article by **Mbela Kalengay et al.** deals with entrepreneurial mindset of STEM students across three national contexts: Kenya, the DRC and Namibia. The article explores how self-efficacy, social learning processes, and individual goal formation influence the integration of entrepreneurship education. Drawing on social cognitive theory (Bandura) and the theory of planned behaviour (Ajzen), the authors show that an approach that integrates 'cognitive, social, and structural components of entrepreneurship education, rather than relying solely on theoretical instruction' (p. 19), enhances students' entrepreneurial intentions and competencies.

The second article explores university-industry collaboration (UIC) and employs a quantitative research design—PLS-SEM (partial least squares equation modelling)—to investigate the drivers and outcomes within the built environment sector in South Africa. The authors, **John Aliu and colleagues**, conclude that technology transfer and innovation ecosystems—the variable 'TECH'—exert the most substantial influence on UIC outcomes. Beyond innovation, they note that UIC 'significantly enhances skills development and graduate employability by providing students with hands-on experiences that bridge the gap between theoretical learning and practical application (p. 32). Picking up on the theme of students, the article concludes by noting that future studies should adopt a 'more inclusive approach by capturing the voices of students to better understand how UIC translates into real-world benefits for graduates' (p. 49).

The remaining three articles weave together the various dimensions of the student experience: **Witske Meyer and Sally Ledwaba** considers how a faculty-led wellness intervention improved student mental health which in turn had an impact on student success; **Talia da Silva Burke and Karin Wolff** explores student motivation in topic selection for a final-year project course; and **Sidd Sunil Kumar et al.** examines the different ways in which instructors implement and promote care—in the sense of Tronto's ethics of care—in their teaching in a first-year engineering course in the United States. This last article shows how students valued behaviours of care, particularly those that fostered student motivation and engagement, that addressed 'the sense of exclusion often experienced in engineering education' (p. 127).

At this stage you might be wondering to what extent I used AI in this editorial and what the promised disclosure statement is going to look like. This thought experiment deviated from what was intended and I decided to get you, the reader, to reflect on your own biases about identifying AI in writing. The fact is: I did not prompt Google LM (nor use any other AI tool) for this editorial! I uploaded the articles and considered using it but wanted to tackle it myself first. As I was writing, the thread of the student experience surfaced from the last three articles and I drew this thread back into the first two articles, crafting the theme as I wrote. Did you think you were reading an AI output? Or did you think that it was at least AI-assisted? Did the bolding of the authors' names, which is common practice in my editorials, signal AI use to you? Admittedly, I replaced the en dashes with a few of the longer em dashes(—) to throw you off course!

As we all grapple with the impact of this incredible technology on engineering education, I hope this thought experiment nudged you to think about your own biases in reading written work (particularly from students if you are an educator), inspired you to lean more on your *human* intelligence before rushing to use a chatbot, and prompted you to consider what responsible AI use looks for all stakeholders in engineering education research.

Bruce Kloot
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SJEE

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Fostering entrepreneurial mindsets in engineering and science education: a comparative study of Kenya, the Democratic Republic of Congo, and Namibia

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The purpose of this study is to examine how engineering and science programs in Kenya, the Democratic Republic of the Congo (DRC), and Namibia conceptualise and incorporate entrepreneurship education. The study explores how educators and students interpret entrepreneurial dispositions in relation to technical fields and how contextual variations influence the implementation of entrepreneurship education across the three nations. To provide a more comprehensive understanding of regional educational practices, a mixed-methods comparative methodology was employed, combining survey data with semi-structured interviews drawn from educators and students. The study adopts an integrated analytical framework that links self-efficacy, social learning processes, and individual goal formation by synthesising Social Cognitive Theory (SCT) with the Theory of Planned Behaviour (TPB). While qualitative themes examined institutional and cultural factors influencing the incorporation of entrepreneurship within curricula, quantitative data were analysed using regression techniques to identify patterns in students' entrepreneurial orientations. The findings indicate that although there is broad support for promoting entrepreneurship within science and engineering disciplines, practical constraints—such as limited mentorship, weak institutional coherence, and uneven curricular emphasis—hinder full realisation. The study proposes an integrated theoretical framework that connects contextual, social, and psychological dimensions involved in shaping an entrepreneurial mindset within African higher education.

Keywords: entrepreneurship education; entrepreneurial intentions; engineering programs; competencies

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Introduction

Rapid technological change, youth unemployment, and the growing demand for innovation-driven economies have contributed to a paradigm shift in the higher education sector worldwide. Given the discrepancy between formal education outcomes and the abilities that employers require, it is especially critical to equip graduates in Africa with employability and entrepreneurial skills (Ssekitoleko & Dhliwayo, 2023). Considering this, entrepreneurship education has become important for promoting independence, inventiveness, and creativity in a variety of fields, including those that have historically prioritised technical skills like science, technology, engineering, and mathematics (STEM). According to recent studies, students' problem-solving skills, innovation orientation, and confidence in pursuing self-employment are all improved when entrepreneurship education is incorporated into STEM programs (Mapanga & Faleni, 2025, Pinto et al., 2024).

However, successful implementation is still unequal even as legislative frameworks supporting entrepreneurship have proliferated throughout African higher education systems (World Bank, 2019). The anticipated outcomes of entrepreneurship education continue to be undermined by factors such as inadequate lecturer training, limited institutional support, and insufficient collaboration with industry stakeholders (Nchu et al., 2023). Rather than being integrated into technical programs, entrepreneurship education is frequently provided as an elective or supplementary module at many universities in Sub-Saharan Africa (Omoyajowo et al., 2023). As a result, entrepreneurship is perceived by science and engineering students as unrelated to their fields, with greater emphasis placed on theoretical concepts rather than practical innovation. Furthermore, there is a dearth of comparative data regarding how national policy agendas, institutional culture, and resource limitations influence how entrepreneurship education is perceived and implemented in various African contexts. To this end, Namibia, Kenya, and the Democratic Republic of the Congo (DRC) demonstrate varied national settings with converging challenges in the implementation of entrepreneurship education.

The DRC is gradually implementing entrepreneurial training through donor-supported technical education reforms (UNESCO, 2025), Namibia is continuing to expand its National Innovation Policy into tertiary curricula (Republic of Namibia, 2020), and Kenya has integrated entrepreneurship education into most public universities through competency-based frameworks (Moindi & Nyatuka, 2022). Despite these legislative commitments, it is still unclear how instructors and students in scientific and engineering programs view and interact with the concept of developing an entrepreneurial mentality despite these legislative commitments. The current study intends to close this gap by investigating and contrasting the institutional realities, experiences, and perceptions influencing entrepreneurship education in the three nations. The study makes use of the Social Cognitive Theory (SCT) (Bandura, 1986) and the Theory of Planned Behaviour (TPB) (Ajzen, 1991), both of which have been extensively used in recent research to explain entrepreneurial intention and learning (Pinto et al., 2024; Omoyajowo et al., 2023). By combining these ideas, it is possible to investigate how self-efficacy, perceived behavioural control, and personal attitudes interact with institutional and contextual elements to affect STEM students' development of an entrepreneurial mentality. Two significant contributions are made by the study. First, it offers unique comparative empirical data from three African nations with varying institutional and national contexts for entrepreneurship education implementation. Second, it suggests a hybrid conceptual model that connects contextual, pedagogical, and psychological factors that influence the development of an entrepreneurial mentality in science and engineering education. Consequently, the study aims to answer the following specific questions:

1) What opinions do instructors and students in science and engineering programs have on the inclusion of entrepreneurship education in Namibia, the DRC, and Kenya?
2) What contextual and institutional elements affect how entrepreneurship education is implemented in these contexts?
3) To effectively encourage entrepreneurial attitudes in technical fields, how may entrepreneurship education practices be improved?

Literature review and theoretical framing

Foundational theory

Social Cognitive Theory (SCT) (Bandura, 1986) and the Theory of Planned Behaviour (TPB) (Ajzen, 1991) can be used to explain the development of an entrepreneurial mindset in higher education. Regarding how contextual, societal, and personal aspects influence entrepreneurial learning and activity, both theories offer complementary viewpoints.

Social Cognitive Theory. SCT emphasises the reciprocal interaction between individual agency, social influences, and environmental context (Bandura, 1986). Learning occurs not only through direct instruction but also through observation, modelling, and social reinforcement. Within entrepreneurship education, SCT highlights the importance of experiential learning, mentorship, and institutional culture in shaping entrepreneurial competencies (Mapanga & Faleni, 2025; Nchu et al., 2023). The concept of self-efficacy, central to SCT, has been widely associated with students' confidence in applying entrepreneurial skills in practical contexts. Empirical studies show that students who receive mentorship or participate in project-based learning display higher levels of entrepreneurial self-efficacy and innovation engagement (Ssekitoleko & Dhliwayo, 2023). Applied to this study, SCT provides insight into how lecturer modelling, peer collaboration, and institutional support systems contribute to the formation of entrepreneurial mindsets among science and engineering learners.

Theory of Planned Behaviour. TPB complements SCT by positing that human behaviour is guided by three determinants: attitudes toward the behaviour, subjective norms, and perceived behavioural control (Ajzen, 1991). In the context of entrepreneurship education, these determinants influence students' entrepreneurial intentions, which in turn shape the likelihood of entrepreneurial behaviour. Recent research in engineering education emphasises TPB's explanatory power in understanding students' entrepreneurial decision-making. For instance, Pinto et al. (2024) found that engineering students' entrepreneurial orientation is strongly predicted by their perceived control over business creation and the value they assign to innovation. Likewise, Omoyajowo et al. (2023) found that positive entrepreneurial attitudes, supported by enabling learning environments, significantly enhance entrepreneurial intentions in South African universities. TPB is used in this study to interpret how peer and lecturer expectations, perceived control (self-efficacy and resource access), and student attitudes (interest and perceived relevance of entrepreneurship) interact to shape entrepreneurial orientation in science and engineering programs.

Integrating TPB and SCT: the hybrid framework

While TPB explains the formation of entrepreneurial intentions, SCT accounts for the learning processes and contextual enablers that sustain entrepreneurial engagement. Integrating these two theories yields a hybrid conceptual model that recognizes the interplay between: *cognitive factors* (attitudes, intentions, and beliefs); *affective factors* (self-efficacy, motivation, and resilience); and *contextual factors* (institutional culture, curriculum design, mentorship, and socio-economic environment).

This model assumes that entrepreneurial mindset development in STEM education extends beyond cognitive training to include socially mediated learning processes involving interaction, modelling, and contextual reinforcement. The integration further aligns with recent research advocating for multi-theoretical approaches in entrepreneurship education to address the complexity of cultural and institutional variation across the Global South (Mapanga & Faleni, 2025).

Conceptual model for the study

The conceptual framework guiding this research is provided in Figure 1 and illustrates how students' entrepreneurial mindset formation results from the interaction between individual factors (attitudes, intentions, and self-efficacy) and contextual factors (learning environment, mentorship, and institutional culture). This conceptualization provides a theoretical anchor for both the quantitative and qualitative phases of the study: survey instruments measure cognitive and attitudinal constructs derived from TPB, while interview protocols explore social and contextual themes informed by SCT.

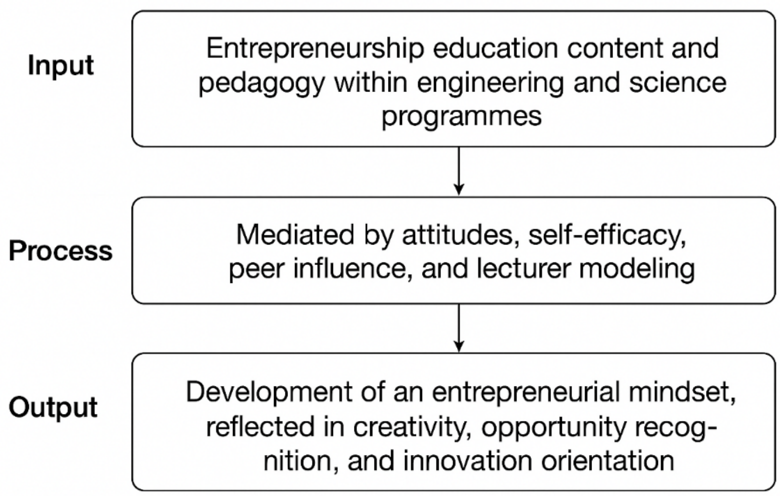

Figure 1: *Conceptual framework of the study*

Summary

The integrated TPB-SCT framework provides a robust analytical lens for examining the interaction between cognitive, social, and contextual factors shaping entrepreneurship education within science and engineering disciplines. It allows the study to assess both individual cognitive processes and institutional contextual influences, thereby providing a richer understanding of how entrepreneurial mindsets are fostered in diverse African higher-education environments.

Research Methodology

Research Design

This study employed a convergent parallel mixed-methods design, whereby quantitative survey data and qualitative interview data were collected simultaneously, analysed independently, and merged during interpretation to provide a comprehensive examination of entrepreneurial mindset development among final-year engineering and science students in Kenya, the DRC, and Namibia. This design allows the simultaneous collection and analysis of quantitative and qualitative data, providing both numerical measurement of constructs such as entrepreneurial intention, self-efficacy, and competences, as well as narrative insights into students' experiences and contextual challenges (Creswell & Clark, 2018; Tashakkori & Teddlie, 2010). The study was guided by the conceptual model described above. TPB was used to examine students' attitudes, perceived behavioural control, and subjective norms in relation to entrepreneurship, while SCT highlighted the role of peer networks, mentorship, and self-efficacy in shaping entrepreneurial engagement. Integrating these theories provided a coherent justification for combining quantitative measurement with qualitative exploration, directly aligning with the study's research objectives.

Population and sampling

The target population consisted of approximately 6,000 final-year undergraduate engineering and science students at selected public universities in Kenya, the DRC, and Namibia. Participants were chosen because they had substantial exposure to entrepreneurship education, either through coursework, incubator programs, or capstone projects, ensuring informed perspectives on the effectiveness and practical impact of entrepreneurial programs. Using Yamane's (1967) formula, a sample size of 450 students was determined to ensure statistical validity at a 95% confidence level and a 5% margin of error (150 students per country). A purposive sampling approach was employed to select students with prior entrepreneurial education, allowing the study to focus on participants with relevant experience. Additionally, qualitative data were collected from 45 students (15 per country) through interviews and focus groups to capture in-depth perceptions, experiences, and socio-cultural influences.

Data Collection Instruments

Quantitative data. A structured questionnaire consisting of five sections was used. These sections are: demographic information (gender, age, discipline, and university); exposure to entrepreneurship education, including class participation, training hours, and engagement in competitions or incubators; entrepreneurial intentions, adapted from Liñán & Chen (2009); perceived behavioural control and self-efficacy, derived from Zhao et al. (2005); and entrepreneurial skills (innovativeness, creativity, leadership, risk-taking, and problem-solving). All these items were measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Reliability testing indicated high internal consistency (Cronbach's alpha = 0.89).

Qualitative data. Interview guides were used to conduct semi-structured interviews and focus groups to explore students lived experiences and contextual influences on entrepreneurship. Open-ended questions addressed four aspects: individual experiences with entrepreneurship modules; challenges in applying entrepreneurial knowledge; the role of mentors and peer networks; and perceptions of the institutional entrepreneurial ecosystem.

Theoretical alignment of qualitative instruments. The development of the interview and focus group protocols was explicitly guided by the hybrid theoretical framework combining TPB and SCT. Questions were designed to capture constructs derived from these theories: entrepreneurial attitudes, perceived behavioural control, and subjective norms were informed by TPB; mentorship, peer influence, and observational learning were informed by SCT. This approach ensured that the qualitative instruments were theoretically aligned, allowing for coherent interpretation of the data within the study's conceptual framework.

Procedures. Interviews were conducted in English or French, recorded with permission, transcribed, and translated where necessary. Semi-structured questions ensured flexibility for probing while maintaining theoretical consistency across all participants and countries.

Data collection procedures

Data were collected over three months in early 2024. The research team collaborated with entrepreneurship centres and faculty coordinators at participating universities. Quantitative surveys were distributed via student mailing lists and WhatsApp groups using Google Forms. After screening, 378 completed questionnaires (84% response rate) were retained for analysis.

Qualitative interviews involved 5–7 students per focus group (lasting approximately 90 minutes) and individual interviews (30–45 minutes each). Participants were recruited from:

- Namibia: University of Namibia and Namibia University of Science and Technology
- Kenya: University of Nairobi and Jomo Kenyatta University of Agriculture and Technology
- DRC: Institut Supérieur Pédagogique et Technique de Kinshasa and University of Kinshasa

All transcripts were anonymized to ensure confidentiality.

Data analysis

Quantitative analysis. Using SPSS Version 27, descriptive statistics summarised demographic and general trends. One-way ANOVA compared entrepreneurial intention and competence levels across students with differing exposure to entrepreneurship education (none, basic, advanced), with Tukey's HSD post-hoc tests identifying significant group differences. Multiple regression analyses, controlling for age, gender, and prior entrepreneurial experience, examined the predictive influence of entrepreneurship education on competences. Analyses were grounded in the TPB and SCT constructs, linking self-efficacy, attitudes, and norms to entrepreneurial outcomes.

Qualitative analysis. Thematic analysis (Braun & Clarke, 2006) was applied to interview and focus group data. The coding process included familiarization with transcripts, generating initial codes, identifying themes (e.g., experiential learning, systemic barriers, social scaffolding), reviewing themes, and producing a narrative synthesis illustrated with participant quotations. Inter-coder reliability was verified with a Cohen's Kappa of 0.82.

Validity, reliability, and trustworthiness

Validity and reliability were ensured through multiple strategies: pilot testing with 20 students across the three countries; use of validated scales adapted from prior studies; triangulation of data sources (questionnaires, interviews, focus groups); member checking to validate qualitative interpretations; peer debriefing, audit trails, and reflexivity diaries to enhance credibility.

Operational definition of entrepreneurship education exposure

For analytical clarity, entrepreneurship education exposure was categorised into three levels. *Basic* entrepreneurship education refers to standalone theoretical modules with limited assessment or practical engagement. *Advanced* entrepreneurship education includes multiple entrepreneurship-related modules embedded within engineering or science curricula and assessed through formal coursework. *Experiential* entrepreneurship education extends advanced instruction by incorporating hands-on learning activities such as incubator participation, capstone projects, start-up simulations, industry mentorship, or community-based innovation projects. This classification enables distinction between instructional input and contextual support structures.

Ethical considerations

All participating universities' Institutional Review Boards (IRBs) granted their ethical approval. Important factors included:

- Prior to participation, all individuals signed informed consent forms.
- Voluntary involvement: participants were made aware of their freedom to discontinue participation at any moment and without consequence.
- Only the research team had access to all anonymised personal data.
- Hard copies were kept in secured cabinets, while digital data was kept in password-protected folders.

To guarantee cultural sensitivity, tools and questions were modified to consider the language and contextual reality of each nation

Results

This section presents the study's findings from the mixed-methods approach, structured to highlight quantitative results, qualitative themes, and their integration using the conceptual model that combines SCT and TPB.

Quantitative results

Sample characteristics. After cleaning the dataset, 432 valid responses were analysed: 137 from the DRC, 150 from Kenya, and 145 from Namibia. The sample comprised 43% female and 57% male students. 68% had completed entrepreneurship courses, and 29% had participated in real-world entrepreneurship activities such as incubators, internships, or start-up competitions. This balanced distribution enabled robust cross-country comparisons.

Descriptive statistics. Students' exposure to entrepreneurship education varied by country:

- Kenya: 82% advanced training (≥3 modules plus experiential learning)
- Namibia: 64% advanced training
- DRC: 41% advanced training

These results are shown in Table 1, illustrating clear cross-country variation in experiential exposure, with Kenya demonstrating the highest level of practice-based engagement and the DRC showing limited access to experiential learning opportunities. Mean entrepreneurial intention scores (5-point scale) with standard deviation were: Kenya ($M = 4.25$, $SD = 0.56$), Namibia ($M = 3.67$, $SD = 0.69$), DRC ($M = 3.10$, $SD = 0.75$), indicating a positive correlation between training intensity and entrepreneurial intention.

Table 1: *Entrepreneurship education exposure by country*

Country	Basic (%)	Advanced (%)	Experiential (%)
Kenya	6	12	82
Namibia	18	18	64
DRC	31	28	41

Impact of education level on entrepreneurial intention. A one-way ANOVA revealed significant differences in entrepreneurial intention across education levels: $F(2, 429) = 12.34$, $p < 0.001$, $\eta^2 = 0.103$. Tukey HSD post-hoc tests indicated:

- No education vs. advanced education: $p < 0.001$
- Basic vs. advanced education: $p = 0.019$
- No education vs. basic education: $p = 0.08$ (not significant)

This suggests advanced experiential education significantly enhances entrepreneurial intention, whereas basic exposure may be insufficient.

Country comparisons. Comparative entrepreneurial intention scores are shown in Table 2. Country-level ANOVAs confirmed significant differences: $F(2, 429) = 18.45$, $p < 0.001$. Pairwise comparisons:

- Kenya vs. DRC: $p < 0.001$, Cohen's $d = 1.51$ (large effect)
- Kenya vs. Namibia: $p = 0.032$, Cohen's $d = 0.68$ (medium effect)
- Namibia vs. DRC: $p = 0.011$, Cohen's $d = 0.82$ (medium-to-large effect)

These differences reflect variations in institutional support, mentorship availability, and practical learning opportunities.

Table 2: *Mean entrepreneurial intention scores by country*

Country	Mean (M)	SD	Interpretation
Kenya	4.25	0.56	High
Namibia	3.67	0.69	Moderate
DRC	3.10	0.75	Low-moderate

Predicting entrepreneurial competencies. Although regression coefficients are reported with country controls, Kenya emerges as the strongest predictor due to higher variance in experiential exposure, while Namibia and the DRC show weaker but directionally consistent effects. Multiple regression analysis (controlling for age, gender, prior experience, and country) indicated that entrepreneurship education significantly predicted entrepreneurial competences (creativity, problem-solving, innovation, risk-taking): Model: $F(5, 426) = 22.67$, $p < 0.001$, adjusted $R^2 = 0.21$. Significant predictors:

- Education level: $\beta = 0.45$, $p < 0.001$
- Prior experience: $\beta = 0.23$, $p = 0.015$
- Kenya: $\beta = 0.19$, $p = 0.032$

Demographic factors (age, gender) were not significant, emphasising the importance of experience and practical exposure.

Perceived behavioural control and social norms. Another critical construct in TPB is perceived behavioural control which is the degree to which individuals believe they can perform the behaviour in question. A scale adapted from Krueger et al. (2000) was used to assess this, and its correlation with education level was analysed. Following Cohen's (1988) conventions, correlation coefficients of 0.30–0.49 are considered moderate, while values above 0.50 indicate strong associations. The correlation between education level and perceived behavioural control ($r = 0.56$, $p < 0.001$) therefore represents a strong positive relationship. This supports Ajzen's assertion that perceived behavioural control directly influences entrepreneurial intention, especially in contexts where external barriers (e.g., resources, mentorship) are variable. Students with access to hands-on experiences reported stronger control over launching a business, even in challenging economies like the DRC.

Qualitative findings

Thematic analysis of 45 interviews and focus groups uncovered three key themes, offering qualitative insight that complements and contextualizes the quantitative findings.

Experiential learning and entrepreneurial confidence. Students reported that hands-on experiences, capstone projects, incubators, and start-up challenges enhanced self-efficacy and perceived control. 'I learned things from working on a real microbusiness for six months that I could never have learned from a lecture' (Kenyan student); and 'Our capstone project involved rural electricity solutions pitched to investors; it made me feel prepared' (Namibian student). Conversely, DRC students lacked such experiences and reported uncertainty and fear of failure, reflecting their lower perceived behavioural control.

Systemic barriers and unequal access. Structural challenges such as limited facilities, sparse mentorship, and geographic isolation were frequently cited, particularly in rural Kenya and the DRC. 'We learned lean startup theory but have no labs, no funding, no mentors' (DRC student); and 'You miss opportunities if you are far from the city campus incubator' (Kenyan rural student). These barriers highlight that intention is not limited by motivation but by systemic constraints, consistent with TPB's perceived behavioural control concept.

Social support and normative influence. Mentorship, peer networks, and faculty support emerged as key enablers of entrepreneurial intention. Positive role modelling and social encouragement enhanced confidence, whereas discouraging social norms (common in the DRC) inhibited entrepreneurial engagement. 'I believed because they believed in me'

(Namibian intern); and 'Support made things seem doable' (Kenyan peer group). These observations demonstrate SCT's emphasis on observational learning and social reinforcement, as well as TPB's subjective norms.

Synthesis: integrating quantitative and qualitative findings

The combination of quantitative and qualitative findings shows that advanced, experiential entrepreneurship education significantly enhances entrepreneurial intention and competencies. *SCT lens*: observational learning, mentorship, and role models reinforce competence and confidence. *TPB lens*: attitudes, perceived behavioural control, and subjective norms mediate intention. *Country-specific contexts explain variation*: Kenya had high intention scores due to robust institutional support; Namibia showed moderate outcomes; DRC had lower outcomes because of limited resources and negative social norms.

Summary

- Advanced experiential education produces superior entrepreneurial outcomes compared to basic or no training.
- Social and institutional environments moderate the effect of education.
- Perceived behavioural control and self-efficacy are key mechanisms linking learning to intention.
- Country-specific differences highlight the importance of contextualized program design.

These findings provide actionable insights for designing inclusive, practical, and socially supported entrepreneurship programs in Sub-Saharan Africa.

Discussion

This study examined how entrepreneurship education within engineering and science programs in Kenya, Namibia, and the DRC influences students' entrepreneurial intentions and competencies. By triangulating quantitative data from 432 students and qualitative insights from 45 interviews and focus groups, the findings provide both statistical evidence and contextual understanding of the mechanisms shaping entrepreneurial outcomes.

Triangulating quantitative and qualitative evidence

The quantitative results demonstrated that advanced and experiential entrepreneurship education significantly increases entrepreneurial intentions and competencies, as measured by ANOVA, regression, and correlational analyses. Regression analysis indicated that education level and prior practical experience were the strongest predictors of competencies such as creativity, problem-solving, innovation, and risk-taking. Perceived behavioural control and subjective norms further mediated these relationships, confirming the applicability of TPB. Qualitative findings complemented these results by showing that hands-on experiences, mentorship, and peer support fostered self-efficacy and confidence, essential elements of Bandura's SCT. Students emphasised that real-world projects, capstone initiatives, and incubator participation enhanced their ability to translate theoretical knowledge into actionable entrepreneurial behaviour. Conversely, structural barriers such as limited access to facilities, mentorship gaps, and negative social norms (especially in the DRC) constrained intention and competencies, despite positive attitudes toward entrepreneurship.

Country-specific insights

Country-level analysis highlighted significant variation:

- *Kenya*: Students had the highest entrepreneurial intentions (M = 4.25) and benefitted from a mature ecosystem, including industry collaborations, mentorship programs, and accessible incubators. Perceived behavioural control and positive subjective norms were reinforced through these structures, facilitating both intention and action.
- *Namibia*: Students had moderate entrepreneurial intentions, with opportunities concentrated in urban centres. Peer support and faculty involvement enhanced outcomes, but disparities between satellite campuses and urban institutions limited broader access.
- *DRC*: Students exhibited the lowest intentions (M = 3.10), reflecting limited practical opportunities, weak institutional support, and negative social reinforcement. Attitudes toward entrepreneurship were positive, but perceived behavioural control and SCT mechanisms were constrained, preventing translation into actionable behaviour.

These variations underscore the importance of contextualized program design, recognizing that national and institutional ecosystems critically shape entrepreneurship education outcomes.

Integrating TPB and SCT perspectives

The study's findings reinforce the complementary roles of TPB and SCT as shown in Table 3.

- *TPB*: Attitudes toward entrepreneurship, subjective norms, and perceived behavioural control mediate the relationship between education and entrepreneurial intention. Positive reinforcement from peers, mentors, and communities strengthens intention.
- *SCT*: Self-efficacy and observational learning, derived from experiential engagement and exposure to role models, enhance competence and confidence in entrepreneurial behaviour.

The interplay between these frameworks explains how education, social support, and experience collectively influence entrepreneurial outcomes. For instance, Kenyan students' high intentions were driven by both perceived behavioural control and robust social modelling, whereas DRC students' lower intentions reflected structural and normative constraints.

Table 3: *Integrated TPB-SCT entrepreneurial mindset framework*

Dimension	TPB Construct	SCT Construct	Educational Implication
Cognitive	Attitudes	Outcome expectations	Curriculum relevance
Control	Perceived behavioural control	Self-efficacy	Experiential learning
Social	Subjective norms	Modelling and mentorship	Peer and industry support
Context	—	Institutional environment	Policy and infrastructure

Implications for policy and curriculum

The integrated findings suggest several actionable strategies:

Curriculum design:

- Emphasise experiential, project-based learning over theoretical instruction.
- Integrate design thinking, lean startup approaches, and regionally relevant problems into modules.
- Include entrepreneurship across disciplines, not solely in business programs.

Institutional support:

- Establish incubators, makerspaces, and innovation hubs, particularly in rural or under-resourced universities.
- Facilitate access to labs, funding, and online resources to reduce entry barriers.
- Strengthen industry-academia partnerships to align education with market realities.

Social networks and mentorship:

- Develop structured mentorship programs with alumni and industry experts.
- Promote peer-led incubators, venture challenges, and collaborative platforms.
- Highlight successful role models through case studies, storytelling, and campus media.

Country-specific priorities:

- Kenya: Expand rural incubator hubs and digital entrepreneurship platforms.
- Namibia: Extend support to satellite campuses and integrate local economic challenges.
- DRC: Focus on low-cost mentorship initiatives and foundational entrepreneurial infrastructure.

Broader implications for African higher education

The findings highlight that entrepreneurship education is not only an academic endeavour but a social and experiential process. Universities can foster innovation, reduce youth unemployment, and contribute to equitable economic growth by creating inclusive, context-sensitive, and mentor-supported entrepreneurial ecosystems. Success depends on integrating cognitive, social, and structural components rather than relying solely on theoretical instruction.

Conclusion

This study demonstrates that integrating entrepreneurship education into engineering and science curricula in Kenya, Namibia, and the DRC enhances students' entrepreneurial intentions and competencies, particularly when programs are experiential, relational, and context sensitive. Key conclusions include:

- Experiential, practice-oriented entrepreneurship education, supported by institutional and social contexts, significantly enhances entrepreneurial mindset and competencies; basic or theoretical instruction alone is insufficient.
- Social support and mentorship amplify the effects of education, reinforcing self-efficacy and normative approval.
- Contextual and systemic factors including institutional resources, geographic location, and national policy moderate the effectiveness of entrepreneurship programs.
- TPB and SCT provide a robust framework for understanding how education, experience, and social reinforcement shape entrepreneurial behaviour.

These insights suggest that universities should design entrepreneurship programs that combine hands-on practice, mentorship, peer networks, and contextually relevant projects. Such interventions can equip graduates not only with technical skills but also with the entrepreneurial competencies and confidence needed to navigate increasingly complex and innovation-driven economies in Africa. While the convergent mixed-methods design strengthens validity through triangulation, the cross-sectional nature of the data limits causal inference. Future studies could incorporate longitudinal designs and employer outcome data to further validate entrepreneurial impact.

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PLS-SEM analysis of university-industry collaboration drivers in South Africa's built environment sector

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UIC (university-industry collaboration) is essential for bridging the gap between academic research and practical innovation, particularly in developing economies. This study investigates the key drivers and outcomes of UIC within South Africa's higher education and industrial context, with a specific focus on professionals in the built environment disciplines. Using PLS-SEM (partial least squares equation modelling), the study examines the influence of five exogenous constructs – governmental support and policy environment (GOV), organisational design and institutional capacity (ORG), technology transfer and innovation ecosystems (TECH), collaborative networks and social capital (NET) and knowledge transfer mechanisms (KNOW) – on UIC strength and four performance outcomes: innovation and creativity, skill development and graduate employability, knowledge creation and transfer, and research impact on local industry. The research was conducted in the Gauteng Province, South Africa's economic hub and a key centre for construction and infrastructure development. A survey instrument was administered to 204 professionals across academic, government and industry sectors engaged in built environment fields. The findings revealed that GOV, TECH and KNOW were the strongest predictors of UIC effectiveness, while ORG and NET exhibited moderate influence. In turn, UIC strength significantly enhanced all four higher education performance outcomes, with particularly strong effects on innovation and graduate employability. This study contributes novel insights by centring built environment professionals, an often-overlooked stakeholder group, in the UIC discourse. It concludes with policy and practical recommendations for promoting inclusive and sustainable UIC frameworks aligned with national development priorities.

Keywords: construction industry; graduate employability; higher education institution; knowledge transfer; skills development; UIC (university-industry collaboration).

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Introduction

In the context of the 4IR (Fourth Industrial Revolution) and increasing economic complexity, UIC (collaboration between universities and industry) has become a pivotal strategy to drive innovation, knowledge exchange and economic development (Petersen & Kruss, 2019; Aliu & Aigbavboa, 2021; Kamal et al., 2024). Particularly in South Africa's built environment sector, which includes construction, engineering, architecture and related disciplines, the rapid advancement of digital technologies, sustainability standards and urbanisation challenges require coordinated efforts between academia and industry (Mutongoza, 2025). According to the South African Council for Scientific and Industrial Research (CSIR, 2020), the construction sector contributes approximately 4.5% to the country's GDP but faces persistent productivity and skills gaps that hinder growth and competitiveness (Habiyaremye et al., 2022). Universities serve as hubs of knowledge creation, yet without effective linkages to industry, academic research risks remaining isolated and underutilised (Aliu & Aigbavboa, 2021). The National Development Plan (NDC, 2019) explicitly highlights the need to strengthen university-industry collaboration as a key enabler to support skills development, technology transfer and innovation in strategic sectors such as infrastructure and construction (Mutongoza, 2025). This aligns with global trends showing that nations with strong university-industry partnerships experience higher rates of innovation and economic resilience (Zhuang et al., 2025). For South Africa, where the built environment sector is pivotal for economic transformation and employment generation, encouraging dynamic partnerships between universities and industry actors is essential to bridge the gap between research and practice, enhance workforce readiness, and address socio-economic challenges related to urban growth and sustainability.

Despite these recognised needs, empirical evidence remains limited on how key factors – such as knowledge transfer mechanisms, governmental support, organisational design, collaborative networks, and technology transfer – interact to drive effective UIC in South Africa's built environment sector. Moreover, the conceptualisation and measurement of UIC remain contested. UIC is multilayered, involving diverse forms such as joint research projects, consultancy, technology licensing, student internships and workforce training (Al Harrasi & Al Subhi, 2024). Studies reveal a lack of consensus on standard metrics for evaluating UIC effectiveness; traditional indicators like patent counts or licensing revenues often fail to capture the relational and knowledge-sharing dimensions critical to sustainable partnerships (Kamal et al., 2024). In the South African context, research by Mutongoza (2025) shows that relationship quality, trust and organisational alignment are significant determinants of successful UIC, underscoring that collaboration is not merely transactional but relational. Many measurement frameworks also neglect the socio-economic context in which UIC operates, including disparities in institutional capacity, funding, and regulatory environments characteristic of developing economies (Aliu & Aigbavboa, 2021). The built environment sector, in particular, faces challenges in codifying collaboration outputs, as knowledge exchange often involves tacit knowledge, complex project-based interactions, and long innovation cycles (Petersen & Kruss, 2019). Therefore, there is a pressing need for integrative frameworks that consider both tangible and intangible outcomes of UIC – such as innovation diffusion, skills enhancement, and policy impact – to provide a holistic assessment of these partnerships' value and sustainability.

While prior studies such as Petersen and Kruss (2019), Aliu and Aigbavboa (2021), Lubbe et al. (2021) and Mutongoza (2025) have laid foundational insights into the drivers and challenges of UIC in South Africa, there remains a notable gap in empirically examining how these collaborations function specifically within the built environment sector, a critical yet underexplored area given its economic and developmental significance. Existing research often highlights broad themes such as knowledge transfer, trust and organisational alignment, but tends to treat UIC outcomes in a fragmented manner, with limited attention to the interplay between structural, policy and technological factors within this sector (Lubbe et al., 2021). Moreover, many studies struggle to capture the multilayered nature of collaboration outputs beyond conventional measures like patents or licensing, neglecting important relational and socio-economic dimensions that shape collaboration effectiveness in South Africa's unique institutional context.

To address these gaps, the present study adopts an integrative approach that systematically investigates key determinants of UIC in South Africa's built environment sector, including knowledge transfer mechanisms, governmental support, organisational design, collaborative networks and technology transfer. Using PLS-SEM (partial least squares equation modelling), the study examines the strength and significance of relationships among these constructs and their impact on collaboration outcomes such as research output, skills development, and workforce readiness. Guided by this framework, the study seeks to answer the following research questions: (1) How do knowledge transfer mechanisms, governmental support, organisational design, collaborative networks, and technology transfer influence the effectiveness of university-industry collaboration? (2) What are the overall impacts of university-industry collaboration on creativity, research output, skills development and meeting the sector's demand for qualified professionals? The outcomes are expected to provide empirically grounded insights for policymakers, industry leaders and academic institutions to inform targeted interventions, promote sustainable partnerships and enhance alignment between higher education outputs and national development priorities in South Africa.

Theoretical framework

Reviewing the concept of university-industry collaboration

UIC (university-industry collaboration) represents a form of strategic partnership in which academic institutions and industry entities interact with the aim of sharing expertise, advancing innovation and jointly solving practical challenges (Aliu & Aigbavboa, 2021; Kamal et al., 2024). In this study, the foundation for understanding UIC is informed by the theory of social capital, which emphasises the collective value embedded in relationships, shared norms and trust among participants (Al-Tabbaa & Ankrah, 2019). Social capital reflects the strength and quality of networks and the reciprocity that emerges within those associations, both critical components when universities and industries work toward mutual goals. The collaborative efforts between universities and industry actors are particularly relevant in knowledge-intensive and technology-driven sectors, where innovation increasingly arises from complex, inter-organisational relationships. According to Ćudić et al. (2022), social capital facilitates the flow of tacit knowledge and informal cooperation, which are essential in dynamic problem-solving environments like the built environment. In this context, partnerships between universities and construction firms, architectural practices, engineering consultancies, or government infrastructure agencies are structured around knowledge-sharing and mutual value creation, aligning with the conceptual premise that organisations benefit from accessing external knowledge reservoirs (Kamal et al., 2024).

UIC is often framed as a bilateral or multi-stakeholder process in which academic researchers and industry professionals co-develop technologies, train skilled personnel, or create platforms for applied research. As Mutongoza (2025) suggests, these collaborations are designed not only to generate research outputs but also to address practical industry challenges and societal needs. In South Africa's built environment sector, such partnerships are increasingly seen as critical to bridging the gap between theoretical knowledge and on-site application, particularly as the country faces an urgent need for sustainable infrastructure, improved project delivery, and technical capacity building (Habiyaremye et al., 2022). In today's globalised economy, where knowledge is a prime resource, universities are recognised as vital contributors to national innovation systems. As their roles evolve beyond traditional teaching and research, many institutions are embracing their identity as 'entrepreneurial universities' (Meissner et al., 2022). This shift implies greater involvement in commercial activities, such as patent development, spin-offs and consultancy services. In parallel, industries are proactively engaging with universities to access emerging technologies, recruit well-trained graduates and reduce the risks associated with innovation (Al-Tabbaa and Ankrah, 2019). These reciprocal interests have catalysed new models of cooperation, especially in countries like South Africa where policy agendas, such as the NDP (National Development Plan) 2030, emphasise public-private partnerships in education and infrastructure development.

For universities, the incentives for entering UIC include aligning academic outputs with national development goals, accessing alternative funding streams, exposing students to real-world challenges, and enhancing the employability of graduates (Kamal et al., 2024). From the perspective of industry, collaboration offers a route to reduce innovation costs, develop talent pipelines, enhance technical capabilities and strengthen its social license to operate. Companies that invest in university partnerships may also benefit from reputational gains and improved competitiveness in an increasingly innovation-driven marketplace (Meissner et al., 2022). Kamal et al. (2024) provide a useful classification of collaborative formats based on the degree of integration between academic and industry partners. At one end, 'Gamma' collaborations reflect low levels of direct interaction, where industries fund research but allow academic partners full autonomy over content and direction. 'Beta' relationships denote a more engaged model, where industry partners help shape research agendas. The most integrated form, 'Alpha', involves industry directing research efforts closely, often to meet immediate business objectives; however, such arrangements are typically rare, as balancing industry satisfaction with academic rigour and novelty is challenging (Kamal et al., 2024). These models are highly relevant to South Africa's built environment, where some partnerships, such as joint curriculum design or structured internship programmes, fall into the Beta category, while others, such as bespoke consulting for large-scale infrastructure projects, lean toward the Alpha model.

UIC also has non-monetary benefits. For example, collaborations between architecture schools and city planning departments in South Africa have led to community-based urban regeneration projects, where students gain field experience while municipalities benefit from fresh design perspectives (Morkel et al., 2023). Similarly, some engineering departments are partnering with local construction firms to pilot green building technologies, creating platforms for experimentation that would otherwise be too risky for industry alone. These kinds of partnerships help build long-term social value and foster reputational gains for both universities and firms (Stephen & Aigbavboa, 2025). Moreover, universities provide an important conduit for small- and medium-sized enterprises (SMEs) to access R&D capabilities they otherwise lack. In the built environment, many SMEs do not have the internal capacity for technological development or advanced design work. Collaborating with universities gives them access to laboratories, data analytics tools and highly trained interns or researchers (Aliu & Aigbavboa, 2021).

This mirrors trends in European countries, where public funding mechanisms actively support such SME-university linkages (Al-Tabbaa & Ankrah, 2019). Institutional culture also plays a critical role in shaping the scope and quality of UIC. According to Kamal et al. (2024), universities that promote entrepreneurship, offer incentives for applied research, and maintain strong industry-facing leadership are more likely to engage in high-impact collaborations. In the South African context, however, bureaucratic hurdles, misalignment of goals and limited communication between faculty and firms often act as barriers. Additionally, researchers may lack the training or incentives to prioritise industry-oriented work, while firms may underestimate the strategic value of academic partnerships and the importance of academic rigor and novelty in postgraduate research (Mutongoza, 2025).

(H1) Collaborative networks and social capital factors and UIC

Collaborative networks and the quality of social capital are increasingly recognised as vital enablers of effective UIC. These networks provide the foundation for trust, knowledge sharing and mutual engagement, allowing institutions to leverage both formal structures and informal relationships. In particular, dimensions of social capital – such as trust between partners, shared values, long-standing personal relationships and engagement with local communities – play a central role in strengthening UIC. The presence of robust networks fosters stronger inter-institutional ties and enhances the effectiveness of collaborative innovation ecosystems (Stephen & Aigbavboa, 2025). Formal partnerships between universities and industries (NET1) are especially important for structured engagement. These partnerships often involve memoranda of understanding, joint research centres, and innovation hubs that institutionalise collaboration. For example, South Africa's Centres of Excellence, supported by the Department of Science and Innovation (DSI) and the NRF (National Research Foundation), exemplify structured collaborations where universities and industries co-create knowledge and align research priorities (DSI-NRF, 2020). Equally important are informal relationships (NET2), which help navigate bureaucratic challenges and sustain trust. Researchers and industry professionals often maintain long-standing personal relationships that facilitate smoother communication, enhance mutual understanding, and increase commitment to collaborative projects (Petersen & Kruss, 2019). Informal social capital complements formal agreements and is instrumental in initiating new projects or maintaining ongoing collaborations. Engagement with local communities (NET3) strengthens social capital by embedding partnerships within broader socio-economic contexts. Community involvement ensures that research addresses real-world challenges and aligns academic pursuits with societal needs. UICs in South Africa's energy and housing sectors have shown that community participation enhances both the relevance and social impact of collaborative projects (Habiyaremye et al., 2022). Finally, inclusive networks must prioritise historically disadvantaged institutions (NET4). Involving these institutions helps reduce inequalities in research capacity, ensures equitable distribution of collaboration benefits, and expands the reach of social capital across the national research ecosystem. Programmes like the University Capacity Development Programme have been instrumental in fostering inclusive partnerships between historically advantaged and disadvantaged universities in South Africa (Woldegiorgis & Chiramba, 2025). Taken together, these elements suggest that trust, shared values, personal relationships, community engagement and inclusivity within collaborative networks are key dimensions of social capital that positively influence effective UIC. Thus, it is posited that:

collaborative networks and social capital have a positive influence on effective UIC (H1).

(H2) Governmental support and policy environment

Governmental support and the policy environment play a critical role in shaping and sustaining UIC. Public sector involvement often provides the necessary resources, regulatory frameworks and strategic direction to facilitate effective partnerships that drive innovation and economic growth. In particular, government funding (GOV1) is a critical enabler that reduces financial barriers for joint research and development initiatives, enabling universities and industries to undertake high-impact projects that might otherwise be unfeasible (Kamal et al., 2024).

National policies promoting university-industry partnerships (GOV2) reflect a government's strategic commitment to innovation-driven development. In South Africa, the National Development Plan (NDP, 2019) explicitly emphasises strengthening UIC to accelerate skills development, technology transfer and sectoral competitiveness – particularly within priority sectors such as infrastructure and the built environment (Mutongoza, 2025). Complementary to these policies, the DSI implements frameworks that incentivise collaboration, including tax credits and research grants tailored to foster co-innovation (DSI-NRF, 2020). Innovation agencies (GOV3) such as the Technology Innovation Agency serve as critical intermediaries by providing not only funding but also technical support, capacity building and networking opportunities for collaborative projects. These agencies help bridge gaps between academia and industry, ensuring that research outputs are aligned with market demands, and can be effectively commercialised (Woldegiorgis and Chiramba, 2025). The presence of such agencies significantly enhances the translation of research into practical applications, especially for SMEs within the built environment sector. Moreover, government initiatives (GOV4) must be responsive to the specific needs of local industries to maximise impact. Tailored programmes that consider the unique challenges of South Africa's built environment sector, such as skills shortages, infrastructural backlogs and sustainability imperatives, can better support collaborations that address pressing socio-economic issues (Habiyaremye et al., 2022). This alignment improves the relevance and effectiveness of UIC, fostering innovation ecosystems that contribute to national development goals. Taken together, these factors reiterate the critical role of governmental support and policy environment in cultivating successful UICs. Hence, the study hypothesises that:

governmental support and enabling policy environment have a positive influence on effective UIC (H2).

(H3) Knowledge transfer mechanisms

Knowledge transfer is a fundamental element underpinning the success of UIC, serving as the conduit through which academic research is translated into practical applications and innovative solutions. Effective knowledge transfer mechanisms enable continuous learning, innovation and capacity building, which are essential for addressing complex challenges in sectors like South Africa's built environment. Central to this process are joint research projects (KNOW1), which facilitate direct collaboration between university researchers and industry practitioners, fostering mutual understanding and co-creation of knowledge (Kamal et al., 2024). Co-supervision of postgraduate students by both academic and industry experts (KNOW2) is a critical mechanism that bridges theoretical knowledge with practical experience. This approach not only enhances the students' research relevance and employability, but also strengthens the linkages between institutions, ensuring that emerging talent is attuned to industry needs. In South Africa's construction and engineering sectors, such collaborative supervision is increasingly recognised as a best practice to develop skills aligned with market demands (Aliu & Aigbavboa, 2021). Workshops and seminars (KNOW3) play a crucial role as structured platforms for knowledge exchange. They provide opportunities for disseminating research findings, discussing emerging trends, and building networks that support ongoing collaboration (Habiyaremye et al., 2022). These events promote transparency, trust and engagement, which are vital for sustaining long-term partnerships. Furthermore, they enable the diffusion of tacit knowledge that may not be easily codified through formal documentation. Staff exchanges or secondments (KNOW4) represent an immersive knowledge transfer method where personnel move between university and industry settings temporarily. This facilitates deeper experiential learning, fosters cultural understanding, and enhances the capacity of both parties to innovate collaboratively (Lubbe et al., 2021). Particularly in the built environment sector, where projects are complex and multidisciplinary, such exchanges help align academic inquiry with real-world industry challenges. Together, these knowledge transfer mechanisms contribute to more effective, dynamic and sustainable UIC. Therefore, this study hypothesises that:

knowledge transfer mechanisms positively influence effective university-industry collaboration (H3).

(H4) Organisational design and institutional capacity

Organisational design and institutional capacity also play a key role in shaping the effectiveness and sustainability of UIC. The presence of dedicated university units tasked with coordinating partnerships (ORG1) facilitates streamlined communication, strategic alignment and efficient management of joint initiatives (Al-Tabbaa and Ankrah, 2019). Such units act as critical intermediaries, ensuring that collaboration objectives are clear, resources are effectively allocated and mutual expectations are managed. Equally important is the clarity of procedures within industry partner companies for engaging with academic institutions (ORG2). Clear protocols help reduce administrative bottlenecks, enhance transparency, and build trust, which are vital for fostering long-term collaborative relationships (Aliu & Aigbavboa, 2021). In South Africa, where organisational complexities and regulatory frameworks can pose challenges, having well-defined engagement processes supports smoother collaboration, particularly in sectors like construction and engineering that involve multiple stakeholders (Petersen & Kruss, 2019). Addressing historical inequalities and promoting inclusion within collaboration efforts (ORG3) are essential considerations in the South African context, characterised by its diverse socio-economic landscape and legacy of institutional disparities (CSIR, 2020). Inclusive collaboration frameworks help ensure that disadvantaged institutions and communities benefit from knowledge sharing and capacity building, thereby contributing to broader social equity and sustainable development (Mutongoza, 2025). This inclusive approach aligns with the National Development Plan's objectives to reduce inequalities through enhanced skills development and innovation. Effective communication between universities and industry (ORG4) underpins all successful collaborations. Open, transparent and consistent communication fosters mutual understanding, manages expectations, and mitigates conflicts (Petersen & Kruss, 2019). It also supports the co-creation of knowledge and adaptation to evolving project needs, which is particularly important in the dynamic and project-driven built environment sector. Consequently, strong organisational structures and institutional capacity enhance the university-industry interface, enabling collaborations to thrive amidst complexity. This study hypothesises that:

organisational design and institutional capacity positively influence effective university-industry collaboration (H4).

(H5) Technology transfer and innovation ecosystems

Technology transfer and innovation ecosystems represent critical mechanisms that facilitate the practical application of academic research within industry, thereby driving economic growth and competitiveness. TTOs (technology transfer offices) serve as essential conduits by managing the commercialisation process, protecting intellectual property, and bridging the gap between research outputs and market needs (TECH1) (Rocha et al*.*, 2023). In South Africa, where innovation adoption faces structural challenges, effective TTOs help ensure that research generated within universities reaches commercialisation pathways, contributing to local economic development (Lubbe et al., 2021). Innovation hubs, science parks and incubators provide fertile ecosystems that nurture collaboration between universities, industries and startups (TECH2). These environments promote knowledge exchange, resource sharing, and networking opportunities critical to accelerating innovation cycles (Aliu & Aigbavboa, 2021). For example, South Africa's Innovation Hub in Pretoria and the CiTi (Cape Innovation and Technology Initiative) have been instrumental in supporting partnerships within the built environment sector by fostering multidisciplinary collaboration and enhancing technology adoption (CSIR, 2020). SMEs frequently lack the internal capacity or resources to develop or adopt new technologies independently. Therefore, university support for SMEs (TECH3) through technology transfer initiatives plays a significant role in promoting inclusive innovation and sectoral growth (Lubbe et al., 2021). Facilitating technology adoption among SMEs enables these firms to remain competitive and contribute to broader economic objectives, especially in developing economies where SMEs constitute a significant employment base (Mutongoza, 2025). University support for patenting and intellectual property protection (TECH4) further safeguards innovations, incentivises researchers, and attracts industry investment (Kamal et al., 2024). This protective infrastructure is vital to maintaining trust and ensuring that both academic and commercial partners benefit equitably from joint research activities. In due course, collaborations driven by strong technology transfer and innovation ecosystems lead to the development of new products or services tailored for local markets (TECH5), thus reinforcing the economic and societal relevance of university research (Lubbe et al., 2021). Based on these considerations, this study posits that:

technology transfer and innovation ecosystems positively influence effective university-industry collaboration (H5).

(H6) The influence of UIC on higher education performance

UIC plays a vital role in driving innovation and creativity by bringing together academic research and practical industry challenges. This partnership promotes an environment conducive to creative problem-solving and the development of new technologies, often resulting in innovative solutions that may not arise within isolated academic settings (Kamal et al., 2024). For instance, South African universities collaborating with construction companies have successfully developed sustainable building materials, demonstrating how UIC can spark creative breakthroughs that address pressing real-world problems (OUTCOME 1: Innovation and Creativity (Kadhila et al., 2024)). Beyond innovation, UIC significantly enhances skills development and graduate employability by providing students with hands-on experiences that bridge the gap between theoretical learning and practical application (Aliu &

Aigbavboa, 2021). Opportunities such as internships, jointly supervised research projects and industry input into curriculum design ensure that graduates are better prepared to meet workforce demands. Studies reveal that students graduating from universities with strong industry connections tend to have higher employment rates and skills more closely aligned with market needs (OUTCOME 2: Skill Development and Graduate Employability (Lubbe et al., 2021)). Moreover, UIC facilitates dynamic knowledge creation and transfer, promoting a two-way exchange where universities gain insights into industry challenges while sharing research outputs that improve technological and operational capabilities (Habiyaremye et al., 2022). This flow of knowledge enables academic programmes to remain current and relevant by integrating emerging industry trends and challenges, fostering curricula that respond to evolving sector requirements (OUTCOME 3: Knowledge Creation and Transfer). Finally, collaborative research partnerships have a tangible impact on local industry competitiveness and productivity. By jointly developing innovative solutions, improving processes, and supporting the adoption of new technologies, UIC strengthens industry performance (Al-Tabbaa and Ankrah, 2019). In South Africa's built environment sector, for example, university-led research has contributed to advancements in construction methodologies, enhanced safety protocols and more sustainable building practices, thus supporting economic growth and social development (OUTCOME 4: Research Impact on Local Industry (CSIR, 2020)). Together, these outcomes illustrate the broad and meaningful influence UIC exerts on higher education and its role in fostering innovation, skills, knowledge, and industrial advancement. Thus, this study posits that:

university-industry collaboration positively influences innovation and creativity, skills development and graduate employability, knowledge creation and transfer and research impact on local industry (H6).

Table 1 and Figure 1 present the measurement items and the conceptual framework underpinning this study, respectively.

Table 1: *Measurement items for constructs, their codes and supporting literature*

Code	Indicator description	Construct (variable label)	Key references
GOV1	The government provides funding that supports university-industry collaboration.	Governmental Support and Policy Environment (GOV)	Aliu and Aigbavboa (2021); Habiyaremye et al. (2022); Kamal et al. (2024)
GOV2	National policies promote partnerships between universities and industries.		
GOV3	Innovation agencies provide support for collaborative projects.		
GOV4	Government initiatives meet the needs of local industries.		
ORG1	The university has units that coordinate with industry partners.	Organisational Design and Institutional Capacity (ORG)	Lubbe et al. (2021); Habiyaremye et al. (2022); Kamal et al. (2024)
ORG2	Industry partners have clear procedures for working with universities.		
ORG3	Collaboration efforts address historical inequalities and promote inclusion.		
ORG4	Communication between universities and industry is effective.		
TECH1	Technology transfer offices help bring university research to market.	Technology Transfer and Innovation Ecosystems (TECH)	Aliu and Aigbavboa (2021); Lubbe et al. (2021); Kamal et al. (2024); Aliu et al. (2025)
TECH2	Innovation hubs or science parks support university-industry partnerships.		
TECH3	SMEs are supported in adopting technologies from universities.		
TECH4	The university supports patenting and intellectual property protection.		
TECH5	Collaboration leads to new products or services for the local market.		
NET1	There are strong formal partnerships between universities and industry.	Collaborative Networks and Social Capital (NET)	Petersen and Kruss (2019); Aliu and Aigbavboa (2021); Lubbe et al. (2021); Zhuang et al. (2025)
NET2	Personal relationships help support collaboration.		
NET3	Projects include engagement with local communities.		
NET4	Disadvantaged institutions are included in collaboration networks.		
KNOW1	Joint research projects are common in our collaboration.	Knowledge Transfer Mechanisms (KNOW)	Petersen and Kruss (2019); Habiyaremye et al. (2022)
KNOW2	Postgraduate students are co-supervised by university and industry experts.		
KNOW3	Workshops or seminars are used to share knowledge.		
KNOW4	Staff exchanges or secondments help transfer knowledge.		
OUTCOME 1	Innovation and creativity	University-Industry Collaboration Outcomes (OUTCOMES)	Aliu and Aigbavboa (2021); Habiyaremye et al. (2022)
OUTCOME 2	Skill development and graduate employability		
OUTCOME 3	Knowledge Creation and Transfer		
OUTCOME 4	Research Impact on Local Industry		

Research methodology

Design of study

This study adopts an empirical and cross-sectional design to examine the drivers of UIC (university-industry collaboration) and its associated outcomes, specifically in the areas of research impact, graduate employability, innovation, skills development and knowledge transfer. A structured questionnaire was employed to collect quantitative data from professionals within the built environment sector.

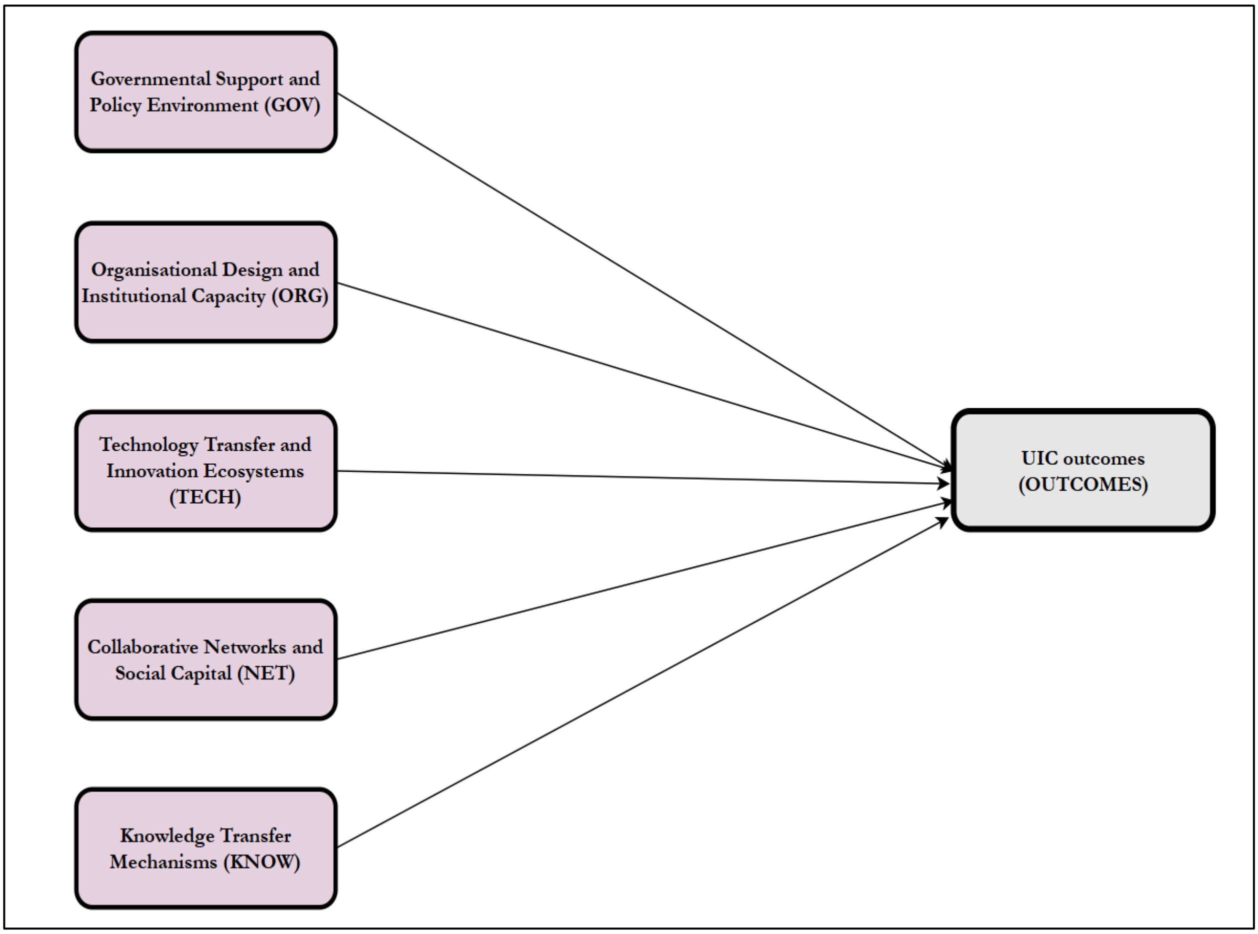

Figure 1: *Conceptual framework underpinning this study*

Sampling procedure and sample size

The target population comprised registered and candidate professionals across key built environment disciplines in South Africa. Membership data were obtained from the official annual reports of relevant regulatory bodies, including ECSA (Engineering Council of South Africa), SACQSP (the South African Council for the Quantity Surveying Profession), SACAP (the South African Council for the Architectural Profession) and SACPCMP (the South African Council for the Project and Construction Management Professions). This approach ensured that all qualified and pre-qualified professionals were eligible to participate. To determine an appropriate sample size, Yamane's (1967) formula was applied using a known population of 40 015 professionals. With a 7% margin of error, a sample size of 220 was calculated. The survey instrument was distributed electronically via Google Forms, targeting professionals with demonstrable knowledge and experience in university-industry engagement. A total of 204 valid responses were received, resulting in a 92% response rate, which exceeds the generally accepted minimum for SEM (structural equation modelling) studies. The high response rate also enhanced the statistical power and generalisability of the study findings. A purposive sampling strategy was employed by targeting only registered and candidate professionals likely to have had exposure to UIC. Specifically, participants were selected from membership lists of relevant professional councils and the survey included screening questions to ensure respondents had direct or indirect experience with UIC activities such as joint research, internships, consultancy, or technology transfer projects. While some candidate professionals may have had limited exposure, only those who indicated familiarity with UIC practices were included in the analysis, ensuring that all respondents could provide informed insights.

Survey instrument design

To develop a suitable survey instrument for this study, we conducted a thorough review of relevant literature to identify the key factors influencing UIC in the built environment sector. The design of the instrument was guided by two primary objectives: first, to ensure that it demonstrated sufficient reliability and validity; and second, to keep the instrument concise and practical so that it would be easy for respondents to complete within a reasonable amount of time. The final questionnaire was divided into four main sections. The first section gathered demographic and professional background information from participants. The second section focused on the potential drivers of UIC and consisted of 21 items organised under five major constructs: governmental support and policy environment (GOV), organisational design and institutional capacity (ORG), technology transfer and innovation ecosystems (TECH), collaborative networks and social capital (NET), and knowledge transfer mechanisms (KNOW). All items were rated on a 5-point Likert scale ranging from 1 = strongly disagree, 2 = disagree, 3 = moderately agree, 4 = agree, and 5 = strongly agree. To provide insight into how the constructs were operationalised in the survey, a few representative items are presented below:

- H1 – Collaborative Networks and Social Capital (NET): 'Our institution maintains strong formal partnerships with industry'.
- H2 – Governmental Support and Policy Environment (GOV): 'National policies effectively promote partnerships between universities and industries'.
- H3 – Knowledge Transfer Mechanisms (KNOW): 'Postgraduate students are co-supervised by both university and industry experts'.
- H4 – Organisational Design and Institutional Capacity (ORG): 'Collaboration efforts address historical inequalities and promote inclusion'.
- H5 – Technology Transfer and Innovation Ecosystems (TECH): 'Technology transfer offices help bring university research to market'.

The third section of the questionnaire addressed the perceived outcomes of UIC. This section included four reflective indicators designed to capture the broader impacts of collaboration, such as innovation and creativity (INN), skills development and graduate employability (SKL), knowledge creation and transfer (KCT), and research impact on local industry (RIL). These outcome variables were aligned with the study's conceptual framework to ensure coherence in analysis. The instrument was pilot tested to confirm clarity, relevance and contextual appropriateness for professionals within the South African built environment sector. All items and constructs were designed to support the application of PLS-SEM (partial least squares equation modelling), which was used to assess the reliability, validity and structural relationships among variables in the final analysis.

Analysis of data

Data analysis was conducted in a structured and sequential manner to ensure the accuracy and reliability of findings. Initially, descriptive statistical techniques were applied using SPSS (Version 25) to screen for missing values, detect outliers, and evaluate key assumptions of multivariate analysis, such as normality and common method variance. To explore the relationships between the latent constructs and to test the hypothesised model, PLS-SEM was employed using SmartPLS 4. This method was selected due to its robustness in handling complex models, its suitability for exploratory research and its ability to accommodate both reflective and formative measurement models (Cheah et al., 2024). PLS-SEM also enables simultaneous estimation of the measurement and structural models, allowing for detailed insights into construct reliability and the strength of interrelationships within the proposed theoretical framework (Hair et al., 2019). Before evaluating the structural paths, the measurement model was rigorously assessed for reliability and validity. Internal consistency reliability was confirmed through CR (composite reliability), with all constructs exceeding the recommended threshold of 0.70. Convergent validity was examined using AVE (the average variance extracted), and all values surpassed the minimum criterion of 0.50, suggesting that the indicators adequately represented their respective latent constructs. In addition, Cronbach's alpha values for all constructs were above 0.70, further supporting internal consistency. Discriminant validity was assessed using both the Fornell-Larcker criterion and the HTMT (heterotrait-monotrait) ratio. These methods confirmed that the constructs were sufficiently distinct from one another. The structural model was then analysed to test the relationships between the exogenous drivers (government support, organisational design, collaborative networks, knowledge transfer mechanisms and technology transfer) and the endogenous outcomes (innovation, graduate employability, research impact and knowledge transfer). To assess the significance of the hypothesised paths, a non-parametric bootstrapping procedure with 5 000 subsamples was performed. This procedure provided robust standard error estimates and confidence intervals for the path coefficients, enhancing the reliability and interpretability of the model outcomes.

Results

Background information of the respondents

The sample in this study was broadly representative of South Africa's built environment sector, encompassing professionals from key disciplines such as engineering, quantity surveying, construction management and architecture. The distribution of respondents across sectors – construction industry (41.7%), higher education institutions (36.3%), and government establishments (22.1%) – aligns with the general workforce composition, providing confidence in the relevance of the findings. The mix of professional experience, with nearly half having 1 to 5 years and over a third having 6 to 10 years, indicates that the results primarily reflect early- to mid-career perspectives. Nevertheless, the study acknowledges that certain groups, such as senior professionals with more than 20 years of experience or smaller sectors within the built environment, were under-represented. Expanding the research to include these groups in future studies would enhance comparability, generalisability, and provide additional insights into the drivers of university-industry collaboration across the full spectrum of professionals.

Measurement model evaluation

The measurement model was evaluated using tests for convergent and discriminant validity. Convergent validity was established through the examination of item reliability, CR and AVE. As recommended by Hair et al. (2019), item loadings above 0.70 were considered acceptable. Accordingly, only items with sufficient loading values were retained in the analysis. The survey instrument was developed based on established literature on UIC, prior validated scales, and expert input from industry and academic stakeholders. Items such as GOV3, ORG1, ORG4, TECH2 and NET2 were excluded from the final model due to low factor loadings (<0.70); however, the remaining items adequately captured the constructs of interest, ensuring the model reflected the key drivers of UIC in South Africa's built environment sector. Table 2 presents the final measurement model, showing that all retained items loaded strongly onto their respective constructs. Composite reliability values for all constructs exceeded the recommended threshold of 0.70, ranging from 0.709 to 0.860, while the AVEs were all above the 0.50 benchmark (Afthanorhan et al., 2021), indicating satisfactory internal consistency and convergent validity across all constructs.

Discriminant validity was assessed using the Fornell–Larcker criterion, which requires that the square root of each construct's AVE be greater than the highest correlation with any other construct (Hair et al., 2019). As shown in Table 3, all diagonal values were higher than the corresponding off-diagonal values in their rows and columns, confirming that each construct shared more variance with its own indicators than with other constructs. This demonstrates adequate discriminant validity. The blindfolding procedure was employed to assess the predictive relevance of the structural model using the Stone-Geisser Q^2 statistic. As presented in Table 4, all endogenous constructs yielded Q^2 values greater than zero, thereby confirming that the model possesses acceptable predictive relevance. Table 5 and Figure 2 illustrate the influence of various drivers – such as knowledge transfer mechanisms, governmental support, organisational design, technology transfer and collaborative networks – on key outcomes including innovation, knowledge generation, impactful research, addressing demand-supply gaps and skill enhancement. The UIC construct explains about 51.2% of the variance in these outcome variables, emphasising its crucial role in shaping these results.

Table 2: *Measurement model results for retained constructs and items*

Constructs	Items	Loading	Composite Reliability	Average Variance Extracted (AVE)
Governmental Support and Policy Environment (GOV)	GOV1	0.778	0.743	0.653
	GOV2	0.838		
	GOV4	0.807		
Organisational Design and Institutional Capacity (ORG)	ORG2	0.931	0.709	0.663
	ORG3	0.677		
Technology Transfer and Innovation Ecosystems (TECH)	TECH1	0.825	0.833	0.660
	TECH3	0.769		
	TECH4	0.813		
	TECH5	0.842		
Collaborative Networks and Social Capital (NET)	NET1	0.770	0.744	0.580
	NET3	0.865		
	NET4	0.631		
Knowledge Transfer Mechanisms (KNOW)	KNOW1	0.830	0.846	0.679
	KNOW2	0.791		
	KNOW3	0.841		
	KNOW4	0.832		
UIC (university-industry collaboration) Outcomes	OUTCOME 1	0.837	0.860	0.700
	OUTCOME 2	0.848		
	OUTCOME 3	0.853		
	OUTCOME 4	0.808		

Note(s): GOV1 = There is sufficient government funding that positively supports UIC; GOV2 = Government policies are supportive of UIC initiatives; GOV4 = Government provides incentives that enhance university-industry collaboration; ORG2 = My organisation has dedicated units or personnel responsible for managing UIC; ORG3 = Roles and responsibilities related to UIC are clearly defined within the organisation; TECH1 = The university provides adequate technical resources that benefit industry partners; TECH3 = The technology developed through research is commercially viable for industry application; TECH4 = There is a clear mechanism in place for licensing university inventions; TECH5 = The university offers support for scaling innovations through industrial partnerships; NET1 = The university is part of an active and vibrant university-industry collaboration ecosystem; NET3 = There are regular forums, meetings, or events that promote engagement with industry; NET4 = Professional networks play a significant role in enhancing the effectiveness of UIC; KNOW1 = Knowledge generated from research is easily accessible to industry partners; KNOW2 = My institution shares research findings with industry through trainings, workshops, or seminars; KNOW3 = There is a structured platform for idea exchange between university and industry; KNOW4 = Research outputs are often tailored to meet the practical needs of industry stakeholders.

Table 3: *Assessment of convergent and discriminant validity using the Fornell–Larcker Criterion*

	Collaborative Networks and Social Capital	Governmental Support and Policy Environment	Knowledge Transfer Mechanisms	Organisational Design and Institutional Capacity	Technology Transfer and Innovation Ecosystems	University-Industry Collaboration Outcomes
Collaborative Networks and Social Capital	*0.762*					
Governmental Support and Policy Environment	-0.156	*0.808*				
Knowledge Transfer Mechanisms	0.150	-0.091	*0.824*			
Organisational Design and Institutional Capacity	0.010	0.054	0.092	*0.814*		
Technology Transfer and Innovation Ecosystems	-0.012	-0.116	0.010	-0.100	*0.812*	
University-Industry Collaboration Outcomes	0.167	0.292	0.386	0.185	0.405	*0.837*

Table 4: *Assessment of predictive relevance (Q^2) using the blindfolding procedure*

Construct	SSO	SSE	Q^2 (= 1-SSE/SSO)
Collaborative Networks and Social Capital	360.000	236.400	0.344
Governmental Support and Policy Environment	360.000	239.040	0.336
Knowledge Transfer Mechanisms	1 200.000	696.000	0.420
Organisational Design and Institutional Capacity	540.000	495.000	0.083
Technology Transfer and Innovation Ecosystems	900.000	549.000	0.390
University-Industry Collaboration Outcomes	3 900.000	2 650.040	0.321

Table 5: *Coefficient of determination (R^2) and adjusted R^2 values for outcome variables*

	R^2	R^2 adjusted
Outcome	0.512	0.500
University-Industry Collaboration Outcomes	1.000	0.999

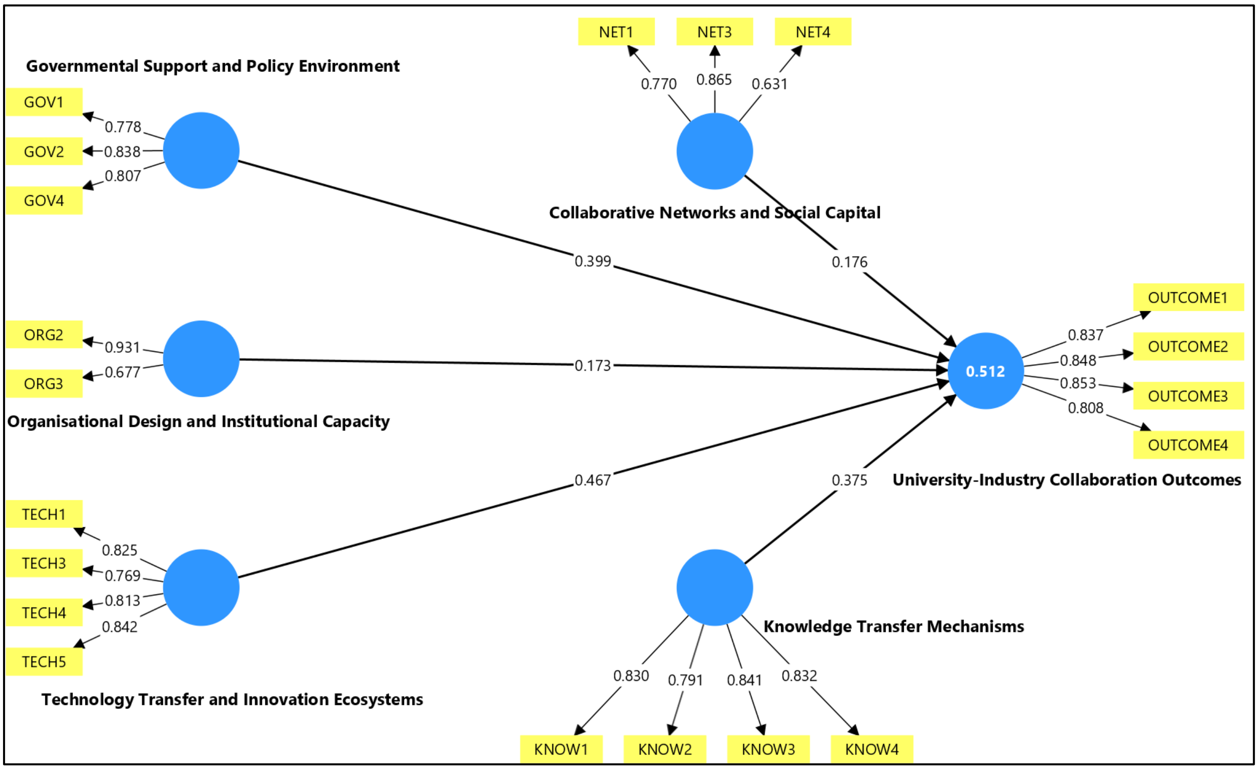

Figure 2: *Measurement model of factors influencing university-industry collaboration outcomes*

Structural model evaluation

Table 6 and Figure 3 present the results of the hypothesis testing, showing that all five proposed relationships in the model are supported by the statistical analysis. Each exogenous variable demonstrated a significant positive effect on university-industry collaboration outcomes, as reflected by path coefficients ranging from 0.173 to 0.467, t-statistics above 2.7, and *p*-values below 0.01. Among these drivers, H5 (technology transfer and innovation ecosystems) had the strongest impact (β = 0.467), followed by H2 (governmental support and policy environment, β = 0.399) and H3 (knowledge transfer mechanisms, β = 0.375). These results highlight the critical role of these factors in promoting successful collaboration between universities and industry, thereby validating the conceptual framework.

Table 6: *Hypothesis testing results for drivers of university-industry collaboration outcomes*

Hypothesis		Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	*P*-values	Decision
H1	Collaborative Networks and Social Capital → University-Industry Collaboration Outcomes	0.176	0.174	0.065	2.729	0.006	Supported
H2	Governmental Support and Policy Environment → University-Industry Collaboration Outcomes	0.399	0.397	0.050	8.002	0.000	Supported
H3	Knowledge Transfer Mechanisms → University-Industry Collaboration Outcomes	0.375	0.374	0.047	7.933	0.000	Supported
H4	Organisational Design and Institutional Capacity → University-Industry Collaboration Outcomes	0.173	0.174	0.049	3.552	0.000	Supported
H5	Technology Transfer and Innovation Ecosystems → University-Industry Collaboration Outcomes	0.467	0.464	0.044	10.611	0.000	Supported

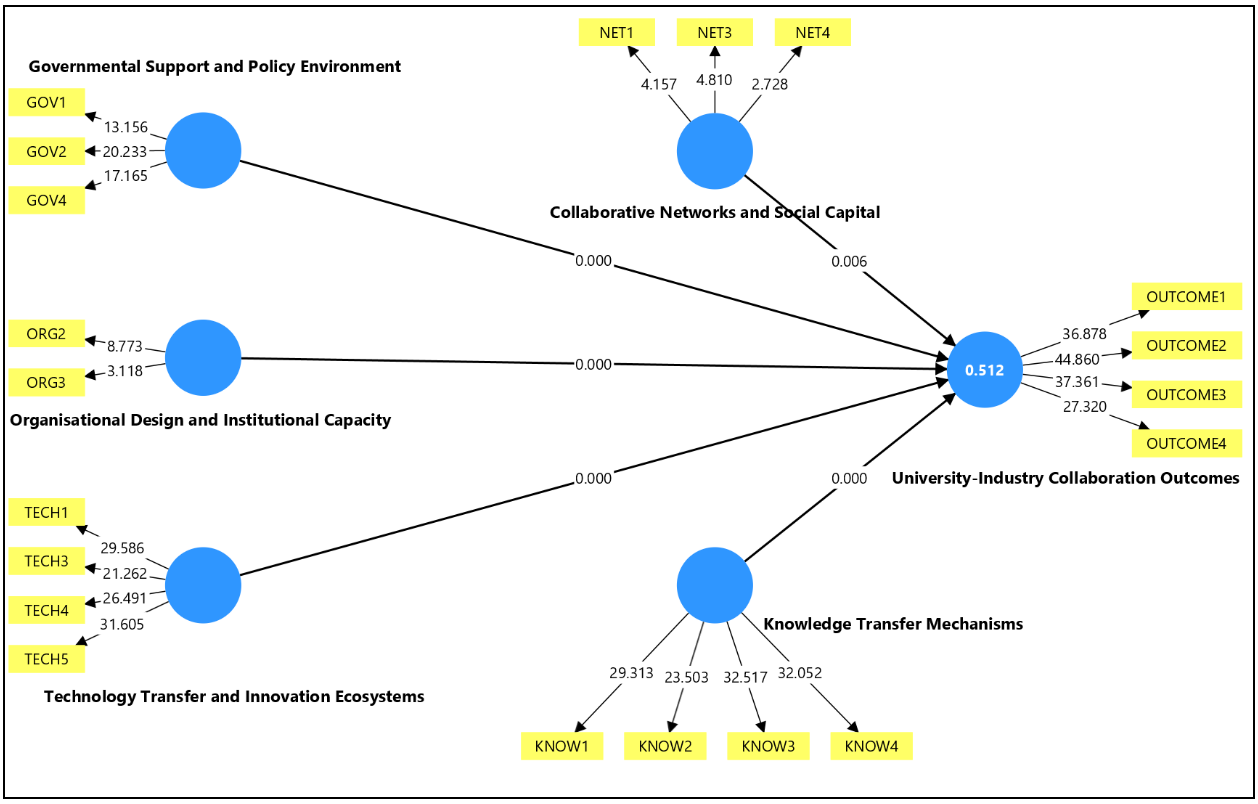

Figure 3: *Structural model of factors influencing university-industry collaboration outcomes*

Discussion

The findings from this study reveal that technology transfer and innovation ecosystems (TECH) exert the most substantial influence on UIC outcomes, with a path coefficient (β = 0.467, p < 0.001). This confirms H5 and underscores the importance of robust innovation systems, knowledge commercialisation processes and collaborative research infrastructures. The strong significance of TECH in the model demonstrates that the causal relationship between innovation support structures and collaboration outcomes is not only statistically valid but central to understanding UIC in South Africa's built environment sector. These findings are consistent with the global literature emphasising the role of TTOs (technology transfer offices), incubators and shared R&D facilities as vital interfaces between academia and industry. For example, Taxt et al. (2022) found that structured innovation ecosystems in Norwegian universities greatly enhanced spin-off creation and knowledge flow. Similarly, Zhuang et al. (2025) documented how strong national innovation frameworks in Singapore and South Korea catalysed university-industry partnerships. In South Africa, while institutions like Stellenbosch University and the University of Cape Town have established knowledge commercialisation frameworks, many others face resource constraints, thus limiting scalability (Stofberg, 2019). The model results substantiate these observations, showing that the presence or absence of functional innovation infrastructures directly drives collaboration outcomes. The South African government's push toward localisation and indigenous innovation through initiatives like the Technology Innovation Agency further supports this dynamic. The fact that TECH emerged as the strongest predictor highlights that co-investment in innovation infrastructure and institutionalised technology transfer processes is essential for UIC to thrive, addressing prior research gaps that emphasise structural constraints in emerging economies (Aliu & Aigbavboa, 2021).

This study also confirms H2 (Hypothesis 2), proposing that governmental support and policy environment (GSPE) significantly influence UIC outcomes. With a strong path coefficient (β = 0.399, p < 0.001), GSPE emerged as the second most significant predictor, reinforcing the quantitative evidence for the government's role in orchestrating and sustaining collaborative ecosystems. Indicators such as government funding supporting UIC, national policies promoting university-industry partnerships and sector-specific initiatives were included in the model. The PLS-SEM results directly support the high-level interpretation that government acts as a critical catalyst in the 'triple helix' of university-industry–government relations (Etzkowitz and Leydesdorff, 2000). In South Korea, well-designed national innovation systems have similarly catalysed industry participation in academic research through incentives, grants, and targeted regional policies (Lee et al., 2017). In the South African context, the significant coefficient corroborates Petersen and Kruss (2019), highlighting the government's dual mandate to stimulate innovation while addressing socio-economic inequities. Despite fragmented funding mechanisms and policy gaps, the empirical evidence from this study indicates that well-aligned governmental initiatives play a transformative role in enhancing UIC. The focus on localised relevance resonates with current innovation policies, such as the White Paper on Science, Technology and Innovation (DST, 2019), while contrasting with low-income contexts where government involvement may be weakened by instability or underfunding (Mutongoza, 2025).

The third hypothesis (H3) was supported, with knowledge transfer mechanisms (KTM) showing a statistically significant path coefficient ($\beta = 0.375$, $p < 0.001$). The construct was measured through indicators such as joint research projects, postgraduate co-supervision, knowledge-sharing workshops and staff exchanges. The PLS-SEM findings empirically confirm that these structured mechanisms significantly enhance UIC outcomes, providing a quantitative foundation for the high-level argument that formalised knowledge-sharing is critical. Joint research projects create shared goals and mutual investment in outcomes, while postgraduate co-supervision integrates academic rigour with practical insight, often linked to sustainable innovation (Aliu et al., 2005). This aligns with Ćudić et al. (2022), who found that formalised knowledge-sharing mechanisms enhance UIC effectiveness more than informal exchanges. Similarly, Azman et al. (2019) reported that institutionalised knowledge-sharing events in Malaysian universities improved technology commercialisation and innovation outputs. The positive result for H3 in South Africa suggests that structured knowledge co-creation remains foundational in emerging economies, particularly where historical divides have hindered trust. The PLS-SEM model thus provides strong empirical support for these conceptual insights.

Although hypotheses H1 and H4 were supported with lower path coefficients ($\beta = 0.176$ and $\beta = 0.173$ respectively), the results indicate that organisational design and collaborative networks are influential but not dominant drivers of UIC in South Africa. H1 proposed that organisational design positively influences UIC outcomes, measured via indicators such as clear collaboration procedures and inclusion initiatives. The PLS-SEM results confirm that internal governance and operational frameworks matter, though historical mistrust and bureaucratic inertia moderate their impact (Petersen & Kruss, 2019). H4 posited that collaborative networks positively affect UIC outcomes, assessed through formal partnerships, community engagement and inclusion of disadvantaged institutions. The model shows that networks contribute to collaboration but with moderate strength, reflecting South Africa's fragmented R&D system compared to the dense networks in Germany or Japan (Brennecke and Rank, 2015; Bergenholtz and Waldstrøm, 2011). These empirical results support the conceptual argument that networks and organisational alignment are necessary, but they require complementary knowledge-sharing mechanisms and institutional support to drive robust UIC outcomes.

R^2 (the coefficient of determination) for the endogenous variable in this study was 0.512, indicating that approximately 51.2% of the variance in UIC outcomes is explained collectively by the five exogenous constructs: governmental support and policy environment, collaborative networks and social capital, organisational design and institutional capacity, technology transfer and innovation ecosystems, and knowledge transfer mechanisms. This represents a moderate to substantial effect size, particularly notable in the social sciences, where complex, interrelated factors often influence outcomes (Hair et al*.,* 2019). The R^2 value affirms the model's explanatory strength and supports its validity in capturing key drivers of successful UIC within South Africa's built environment sector. Comparative studies show varied R^2 levels across different regions and sectors. For instance, Ćudić et al. (2022), in a PLS-SEM study across EU and Western Balkan countries, reported a high R^2 of 0.827. Also, Kamal et al. (2024) found a more modest R^2 of 0.481 in their investigation of UIC drivers in Bangladesh, where knowledge transfer mechanisms, governmental support, organisational design, technology transfer and collaborative networks played central roles. The R^2 of 0.512 found in this study places South Africa's UIC discourse in a relatively strong position. However, it also indicates that nearly half of the variance remains unaccounted for, highlighting the need for future research to explore additional moderating or mediating variables. These may include trust, regulatory coherence, digital infrastructure, or historical inequalities in higher education, factors particularly relevant in the Global South. Longitudinal studies could also provide insights into how these relationships evolve over time.

Implications

From a practical standpoint, the results emphasise the strong influence of knowledge transfer mechanisms (H3, $\beta = 0.375$, $p < 0.001$) and technology ecosystems (H5, $\beta = 0.467$, $p < 0.001$) on effective collaboration between universities and industry. These path coefficients indicate that structured knowledge-sharing activities and well-developed innovation infrastructures are statistically the most critical drivers of UIC outcomes in South Africa. This implies that when institutions actively invest in tools like knowledge hubs, intellectual property support offices and innovation accelerators, their ability to form sustainable partnerships with industry significantly improves. Some South African universities have already taken steps in this direction, creating technology transfer offices and innovation laboratories that connect academia with real-world construction and engineering problems. However, such structures are not consistently available across the higher education space. Many institutions, especially those serving historically marginalised communities, still lack the infrastructure or support to manage knowledge exchange processes effectively. The model's findings reinforce the need for targeted interventions to expand these capabilities, aligning with earlier observations that gaps in innovation infrastructure and institutional capacity limit UIC effectiveness.

Theoretically, this study reinforces the importance of institutional design (H1, $\beta = 0.176$, $p < 0.001$) and ecosystem readiness (TECH, H5) in driving meaningful collaboration. Although H1 showed a weaker effect, it confirms that internal governance and organisational procedures are necessary foundations for collaboration, particularly when coupled with stronger drivers such as TECH and GSPE. The study contributes to UIC literature by validating a context-specific model that considers the dynamics of South Africa's built environment and the unique challenges faced in emerging economies. By demonstrating differential weights among the five constructs, the PLS-SEM results provide a nuanced understanding of which drivers matter most, directly addressing gaps in prior research where all factors were often treated as equally important. The inclusion of predictive relevance measures such as the Stone-Geisser Q^2 further confirms the robustness of the structural model, offering a useful framework for researchers seeking to study collaboration in similar settings. Overall, the findings illustrate that collaboration is a function of measurable, interacting constructs rather than solely goodwill or policy mandates, strengthening the causal argument laid out in the hypotheses.

From a societal perspective, the study reveals that stronger UIC could play a transformative role in addressing urgent challenges in graduate unemployment, infrastructure development and innovation-led economic recovery. The model shows that outcomes such as skill enhancement, research output, and workforce readiness are significantly explained by the combined effect of TECH, KTM and GSPE, highlighting that these structural and policy inputs have measurable societal implications. Beyond high-level policy or institutional intent, the quality and consistency of collaboration infrastructure directly impact graduate readiness and institutional contribution to societal progress. The relatively weaker impact of organisational design and collaborative networks (H1 and H4) points to systemic issues where some universities remain poorly equipped structurally and administratively to engage with industry at the scale or speed required. This aligns with earlier gaps identified in the introduction regarding fragmented institutional capacity, and highlights opportunities for future interventions. Addressing this gap is essential not only for academic reform but for national development, as more agile, industry-aligned institutions are better positioned to produce graduates capable of contributing to infrastructure resilience, housing delivery, and sustainable urbanisation.

Limitations and future research

While this study offers valuable insights into the drivers and outcomes of UIC within South Africa's built environment sector, several limitations point to opportunities for future research. Firstly, the study was geographically limited to the Gauteng province. Although Gauteng is a central hub for industry and higher education, its economic and institutional context may not reflect the broader national context. Future research should expand to include other provinces such as KwaZulu-Natal, and the Western and Eastern Cape, where regional disparities in policy implementation, resource allocation and professional networks may yield different collaboration patterns. Additionally, while the study captured a broad range of professionals across disciplines, experience levels, and sectors, certain groups – such as senior professionals with over 20 years' experience, or professionals in under-represented sub-sectors – were limited in the sample. This may influence the generalisability of the findings, and future research should aim to include these groups to enhance comparability, robustness and the overall representativeness of the analysis.

Secondly, this study captured the perspectives of registered and candidate professionals in the built environment, which is valuable for understanding practical experiences and expectations from the field. However, while the study incorporated the perspectives of academic leaders and government stakeholders, who play critical roles in shaping and sustaining UIC initiatives, it did not include the views of students, whose experiences and employability outcomes are directly impacted by these collaborations. Future studies should adopt a more inclusive approach by capturing the voices of students to better understand how UIC translates into real-world benefits for graduates. Thirdly, the research was confined to UIC, excluding Technical and Vocational Education and Training (TVET) institutions. Given the importance of TVETs in addressing mid-level skills shortages in construction and engineering, future research should explore how UIC functions in these institutions and how partnerships might differ in structure, expectations and outcomes compared to those at universities. Lastly, this study was cross-sectional in design, providing a snapshot in time. As UICs evolve over project lifecycles and policy shifts, future longitudinal studies would be valuable in understanding the sustainability, transformation and long-term impacts of these partnerships, especially in the context of technological disruption from the 4IR.

Conclusion

This study provides valuable insights into the critical drivers underpinning effective university-industry collaboration within South Africa's built environment sector. By empirically testing five key constructs – collaborative networks and social capital (H1), governmental support and policy environment (H2), knowledge transfer mechanisms (H3), organisational design and institutional capacity (H4), and technology transfer and innovation ecosystems (H5) – the study demonstrates their relative importance in shaping UIC outcomes. Through a quantitative approach using a structured questionnaire administered to registered and candidate professionals, data were analysed using PLS-SEM to examine the relationships between these constructs. The analysis confirms that collaborative networks and social capital; governmental support and policy environment; knowledge transfer mechanisms; organisational design and institutional capacity; and technology transfer and innovation ecosystems collectively form the foundation for sustainable and impactful partnerships between academia and industry. Among these, technology transfer and innovation ecosystems (H5, $\beta = 0.467$, $p < 0.001$) emerged as the strongest driver, followed by governmental support and policy environment (H2, $\beta = 0.399$, $p < 0.001$) and knowledge transfer mechanisms (H3, $\beta = 0.375$, $p < 0.001$), reflecting a nuanced hierarchy of influence that aligns with both global literature and South African institutional realities. While collaborative networks and social capital (H1) and organisational design and institutional capacity (H4) contribute positively, their relatively lower path coefficients indicate areas where structural and relational improvements are needed.

This research extends prior UIC studies by explicitly linking PLS-SEM findings to practical, theoretical and societal implications. Robust UIC not only enhances innovation and research productivity but also strengthens the development of industry-relevant skills, bridging gaps between academic preparation and workplace readiness. The model's predictive relevance ($Q^2 > 0$) and explanatory power ($R^2 = 0.512$) confirm its utility as a framework for understanding and evaluating UIC in emerging economies, highlighting the measurable impact of well-defined constructs rather than relying solely on policy or goodwill. Policymakers, institutional leaders and industry stakeholders are encouraged to prioritise these determinants, recognising that strategic investments in collaborative networks, knowledge-sharing infrastructure, policy support, and technology transfer mechanisms can drive educational quality, economic competitiveness and sectoral resilience, particularly in the context of rapid technological change and the Fourth Industrial Revolution. Finally, while the study offers strong evidence of key drivers, it is acknowledged that certain questions – such as longitudinal impacts, student perspectives, and regional variation beyond Gauteng – remain open for future research, emphasising opportunities to refine and expand the model in subsequent studies.

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Reconstructing the engineering student culture by promoting student wellness

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Poor success and high attrition rates among engineering students at South African UoTs (universities of technology) require urgent, systemic intervention. Traditional curriculum reforms have failed to address the underlying cultural and mental health challenges that normalise chronic stress and discourage help-seeking behaviours. This study investigates the impact of a faculty-led wellness intervention as a strategy for improving academic performance and student retention within engineering education. The intervention is grounded in Ubuntu philosophy, which promotes interconnectedness and community well-being, and bioecological systems theory, which highlights the influence of social and institutional environments on individual development. These frameworks guided the design of wellness strategies that addressed both interpersonal and systemic barriers to student success. We evaluated the intervention's effectiveness at a South African UoT using a mixed-methods case study. Student attendance and performance trends were tracked between 2022 and 2024, focusing on a high-risk first-year module with approximately 70 students per cohort. At-risk students who were identified by assessment marks ≤45% or attendance ≤ 65% were offered structured academic and wellness support. Pre- and post-intervention data were compared using HEMIS (Higher Education Management Information System) records and statistical analysis of pass rates and attrition. Following the 2024 intervention, the module demonstrated a 35% increase in success rates and a 50% reduction in year-on-year deregistration. Among students who participated in the intervention, 27% passed the module, and 66% of those achieved distinctions. These findings suggest that culturally grounded faculty-led wellness programmes can meaningfully improve student outcomes while challenging traditional engineering education norms.

Keywords: Mental health, engineering education, success rate, engineering student culture, wellness

Introduction

This article examines the challenges related to mental health and wellness faced by engineering students at a South African UoT (university of technology). It evaluates whether faculty-led interventions can enhance academic performance and improve student retention. The article

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presents findings from a wellness programme aimed at addressing the systemic, cultural, and psychological barriers that students encounter in high-pressure engineering education environments.

High dropout rates and low academic resilience continue to pose significant challenges for higher education in South Africa, particularly within UoTs. Although curriculum reforms have been implemented to enhance academic outcomes, they have not sufficiently addressed the escalating mental health crisis affecting students (Mapaling et al., 2024). Engineering students face immense academic pressure, long hours of study, and a culture that often prioritises endurance over well-being. These challenging conditions are linked to increased levels of stress, anxiety, depression, and even suicidal thoughts (Jensen & Cross, 2021; Korsten et al., 2021).

Research consistently indicates that engineering students face a higher risk of mental health challenges compared to their peers in other fields (Campbell et al., 2021; Pandey et al., 2022). In South Africa, these challenges are exacerbated by financial stress, academic overload, and insufficient psychosocial support. Approximately 30% of undergraduate engineering students report experiencing symptoms of moderate to severe stress, anxiety, and depression (Jensen & Cross, 2021), along with an increased risk of suicide (Korsten et al., 2021). A study conducted in the Nelson Mandela Bay Municipality found a 16% prevalence of suicide attempts among university students (Alabi, 2022).

Despite the gravity of these issues, engineering students often refrain from seeking help, tending to internalise their distress and equate self-sacrifice with academic success (Wright, 2023; Godfrey & Parker, 2010). This detrimental culture is marked by sleep deprivation, emotional burnout, and isolation, all of which are reinforced by demanding curricula that provide little opportunity for self-care or community engagement. While wellness-based reforms have emerged globally, most research tends to focus on institutions in the United States and often overlooks the unique socio-economic and historical factors that influence South African students. There is an urgent need for locally relevant approaches that address not only academic underperformance but also the cultural and institutional systems that impact student well-being. These interventions are particularly timely given the anticipated shortage of qualified engineers in South Africa (Korsten et al., 2021).

Growing awareness regarding mental wellness has not translated into sufficient research on undergraduate engineering students in South Africa (Jensen et al., 2021). Jensen (2021) argues that engineering education needs to move away from a culture of excessive pressure and adopt proactive support structures focused on wellness. However, achieving this shift requires collaborative engagement among institutional stakeholders. Additionally, there is a lack of empirical research on how harmful norms are internalised and how wellness interventions can change these perceptions over time (Korsten et al., 2021).

This study aims to evaluate the implementation and impact of a faculty-led wellness intervention programme on student performance, retention, and well-being in a high-risk first-year engineering module at a South African UoT.

The objectives of the study are to:

1. Identify the academic and psychosocial challenges experienced by at-risk engineering students;
2. Examine how Ubuntu philosophy and bioecological systems theory can inform a holistic intervention approach;
3. Assess the programme's impact on student attendance, pass rates, and attrition;
4. Explore how faculty-based wellness initiatives can challenge harmful cultural norms in engineering education.

The intervention was guided by two theoretical frameworks: Ubuntu, which emphasises interconnectedness and mutual care (Van Breda, 2019), and bioecological systems theory (Bronfenbrenner, 1979), which highlights the impact of social, institutional, and environmental systems on student development (Sheafor & Horejsi, 2012). Together, these frameworks offer a culturally relevant and systems-aware foundation for transforming engineering education through wellness.

The article will start with a review of the existing literature on student mental health and wellness in engineering education. Following this, it will outline the theoretical frameworks that underpin the intervention. The methodology will then be presented, detailing the intervention design and the approach to data analysis. The next section will discuss the findings and their implications for policy and practice. Finally, the article will conclude with recommendations for integrating wellness into engineering education in South Africa.

Literature review

What is mental health, and why does it matter?

The World Health Organisation defines mental health as 'subjective well-being, perceived self-efficacy, autonomy, competence, intergenerational dependence, and self-actualisation of one's intellectual and emotional potential, among others' (Härtl, 2001). Marques et al. (2011) postulate that mental health interventions should endeavour to develop psychological resilience, to increase a person's capacity to enjoy life, and to strike a balance between daily activities.

Mental health has been a topical issue since the early 2000s. A global commitment was made by including mental health as a Sustainable Development Goal (Docrat et al., 2019). Studies have shown that mental wellness in individuals is declining rapidly due to many contextual factors, such as exposure to social media, natural disasters, poverty, and many more. Young people are identified as a population at high risk, and many studies have advocated the prioritisation (Danowitz & Beddoes, 2018), as well as the development, of relevant policy frameworks to address the issues of undertreated mental health problems (Wang & Sheikh-Khalil, 2014). Most importantly, it has been demonstrated that neglecting mental health concerns has serious, long-lasting repercussions on young people's growth and development. This has resulted in a domino effect on economic prosperity at a much broader level, such as career development, and in social and personal spheres.

The prevalence of engineering students affected by mental health issues

Although many factors influence students' wellness and ultimate success over the years, mental wellness has been globally documented as one of the leading factors across various disciplines. Throughout their studies, students will encounter a plethora of stressful events that affect their academic performance, varying from psychosocial and financial challenges, extra-curricular activities, as well as challenges related to the study content. Students at South African universities are reported to have a high prevalence of mental health challenges, leading to a significant increase in suicidal ideation among students (Mogashana & Basitere, 2021). Although research indicates substantial increases in psychopathology among college students in recent decades, little trend data is available to examine prevalence rates across time (Lattie et al., 2019).

The challenge is rooted in the induction of students into institutions of higher learning. Gumede and Ajani (2020) found that South African learners transitioning into universities were often confronted with typical academic challenges such as academic writing in higher education, English as the primary language of teaching and learning, lack of basic computer skills, which were once again exacerbated by the students' reluctance to approach the institution for access to support services (Gamede & Ajani, 2020). Subsequently, many students are said to struggle with transitioning from secondary to tertiary education, such that they develop signs of anxiety and depression, ultimately struggling to find a sense of belonging (Mason, 2017). A study conducted on first-year students at two prestigious South African institutions discovered a high prevalence of developing mental health challenges (Mogashana & Basitere, 2021). However, some students may be more vulnerable to mental illness due to factors such as test stress, loneliness, and other psycho-social factors, e.g., poverty and educational background. It is undeniable that the multiplicity of the challenges experienced by students contributes to ailing mental health.

Several pedagogical interventions are available to assist engineering students with stress management and continuous motivation during their studies. Understanding and identifying the most suitable pedagogical intervention requires understanding the factors motivating engineering students and playing a role in their study approach. Studies show that engineering students who are primarily intrinsically motivated may benefit from less prescriptive assignments. Such assignments offer more freedom to choose from formative assessment topics in which they have a greater personal interest, essentially cultivating their investment in their studies. Extrinsically motivated engineering students, who typically consider the final summative grade to be the most important, may be less influenced by pedagogical styles and could benefit from a structured approach (Savage et al., 2011).

Research indicates that approximately 40% of engineering students typically do not progress past the first year, and that 30% of the remaining students who do manage to continue fail critical fundamental subjects throughout the chosen engineering course or discipline. The primary cause of student failure and poor throughput rates has traditionally been attributed to a lack of preparedness for the high academic rigour required by engineering studies. While most academic courses require a minimum of four hours of independent study for one hour spent in the classroom to truly solidify and grasp the application principles of complex problems and theories (Boylan-Ashraf, 2018), engineering courses and studies generally require double that amount to consolidate theoretical knowledge into practical application.

The argument above is indicative of only the beginning of the challenges typical engineering students might face throughout their academic journey. As students progress through their studies, both their internal and external sources of motivation tend to decline, potentially reducing their engagement and participation in academic activities (Jensen, 2021). These findings are aligned with relevant studies highlighting the particularly high stress levels of engineering students; however, Jensen (2021) notes that the literature has not thoroughly examined how stress has become embedded within engineering culture, its broader implications for academic programmes, or how the effects thereof can be mitigated. The studies describe a particularly bleak outlook, with the rigour and selectivity of engineering programmes perpetuating a meritocracy of difficulty where student success can be attributed to the notion that successful students have been 'able to take it'.

Understanding student well-being

Student development is a multifaceted process that requires efforts from multiple stakeholders. As such, we argue that the development of a well-rounded, future-ready engineering graduate must occur in and outside the classroom, acknowledging the complex nature of human development while considering a student's psychosocial well-being. Essentially, Blockland (2019), as cited in Mogashana & Basitere (2021), maintains that student support interventions need to be holistic in nature and need to help students achieve success through tapping into and developing their intangible inner abilities.

The promotion of well-being in the classroom has aided students in overcoming obstacles, recovering from negative experiences, and maintaining a high quality of life (Bache & Scott, 2018; Norrish et al., 2013; Schwanen & Atkinson, 2015; Wong et al., 2006). There are two main types of well-being: (1) hedonic, which includes seeking pleasure and avoiding pain (often due to extrinsic factors); and (2) eudaemonic, which includes seeking to reach one's full potential (often due to intrinsic factors – Ryan & Deci, 2008). As such, Perkins et al. (2021) encourage engineering educators to transition from a fixation on academic achievement to a mindfulness of student wellness in and outside the classroom.

Engineering student culture

Although undergraduate students in general are reported to experience high levels of stress and anxiety as a result of a heavy workload (Korsten et al., 2021), the engineering discipline seems to be set apart from the rest, characterised by a unique culture that embodies masculinity and patriarchy, and deprioritises student well-being (Perkins et al., 2021). Instead, the undergraduate student culture is characterised by a system of tough competition and the denial of mental health-related challenges in engineering students.

The institutional and learning environment significantly influences the engineering and engineering education culture, which is shaped by an individual's home, community, school, and workplace, thereby creating a culture and norms that provide situated experiences. These greatly influence the understanding, identity, interest, and, most importantly, the approach to finding solutions to engineering problems (Carberry & Baker, 2018). As such, understanding a student cohort's cultural dynamics is critical when developing supportive frameworks, academic interventions, or determining the depth of understanding of prior knowledge. These factors are essential for effectively lecturing or introducing engineering subject content to a student cohort, regardless of the level of standardisation of the subject content or the approach to teaching; however, this can be particularly challenging in a UoT with large student intakes.

The challenges posed by these larger groups are especially evident when attempting to foster a learning environment that promotes the importance of student interaction, engagement, and participation, which has been shown to cultivate student involvement for learning, positively affecting cognitive growth. However, Van de Merwe and Maharaj (2018) identified four specific factors influencing South African engineering student success, namely the problematic school system, the high dropout rates, financial constraints, specifically expensive programme costs, and the requirement of professional accreditation by the Engineering Council of South Africa (Van der Merwe & Maharaj, 2018).

Carberry indicates that Western society has adopted a culturally influenced belief that engineering is a driving force behind innovation and technology, which subsequently fosters entrepreneurship through accredited programmes that educate students in applied sciences, computing, engineering, and engineering technology. However, an unintentional consequence was the development of a distorted masculine engineering identity, neglecting the conceptual principle that engineering supports society by improving lives and communities (Carberry & Baker, 2018).

Revisiting the concept of intrinsically and extrinsically motivated students, it is necessary to consider the effects of student attendance at engineering lectures and classes on student throughput and pass rates. Purcell (2007) notes that a linear regression analysis on attendance data sets showed a strong correlation between lecture attendance and examination performance. Every 10% increase in student attendance at lectures showed a 3% increase in examination performance, which agrees with the outcomes of other studies. However, despite this correlation, it was found that a typical engineering student at a traditional university attended only 68% of classes and lectures (Purcell, 2007). In response to this statistic, most traditional universities in South Africa require students to maintain an 80% lecture attendance rate to pass the module as a prerequisite, together with a minimum final mark of 50% or above.

Boylan-Ashraf's (2018) research underpins the significance of high class-attendance rates as a factor influenced by student motivation. In short, attending scheduled class sessions is essential for students to understand the importance of independent study time. Without attending, students are unlikely to dedicate sufficient time to independent study, which is necessary to develop further the concepts discussed during the missed class (Boylan-Ashraf, 2018).

However, a large part of the engineering culture among students can also be defined by their approach to studies, knowledge creation and knowledge acquisition, where students often approach their exams, module content and studies in general with a short-term, exam-focused mindset rather that striving for the proper comprehension and long-term retention that lecturers often highlight are key to the successful and timeous completion of their studies, rather than viewing each module or subject they complete as a foundational building block for learning that facilitates comprehension in future subjects. Students often view each year or exam as an academic hurdle to be overcome and quickly forgotten, focusing solely on passing the subject rather than developing a deeper understanding that bridges the gap between theoretical knowledge and practical application, thereby promoting critical thinking and complex problem-solving.

As a result, once these students transition from their first or second years, they face compounded challenges, having to relearn foundational concepts from the previous year to effectively grasp the content introduced in the new modules, and relearn what was essentially viewed by the lecturer as prerequisite knowledge. This cycle unfortunately reinforces the perception and culture perpetuated in engineering studies that the coursework can be excessively demanding as students struggle to process the new materials with the gaps in their prior learning and knowledge.

Chitkara (2014) emphasises that studying is a skill which students are not naturally proficient in, and that, like any other skill, it requires deliberate development through effective study habits before a student can truly excel academically, and at-risk students can significantly improve their academic performance through participation in student development and support interventions at an early stage (Chitkara, 2014). This also encourages students to actively participate in their learning journey, fostering a sense of ownership and responsibility early on, and highlighting the need for early identification and reporting

The reluctance of students to seek academic assistance stems from several interconnected factors. Many students, particularly those experiencing academic difficulties, avoid help-seeking behaviours out of a fear of confirming their perceived inadequacies, or realising that their chosen direction of study might not align with their interests (Bandura, 1977). However, Bean and Metzner found that the effective implementation of institutional interventions can significantly impact a student's decision to complete the course, primarily when the interventions are focused on addressing both academic and psychological challenges (Bean & Metzner, 1985).

An explanation of the faculty-based student wellness programme

The wellness intervention implemented by FEBE (the Faculty of Engineering and the Built Environment) in the selected UoT is grounded in a multi-systemic, humanitarian approach, rooted in the African philosophy of Ubuntu.

Guiding philosophy: Ubuntu as a foundation. Ubuntu, a Nguni term meaning 'I am because you are', emphasises humanity, compassion, and interconnectedness. It reflects a belief in the collective responsibility to support one another and uphold dignity (Van Breda, 2019; Muwanga-Zake, 2009; Murithi, 2007). This philosophical foundation guides the programme's design and intentions but does not function in isolation. As Rankopo and Diraditsile (2020) note, Ubuntu also represents the practical use and sharing of community resources to promote collective well-being. Thus, while Ubuntu informs the ethical and cultural vision of the programme, its implementation involves structured, measurable, and collaborative interventions (Rankopo & Diraditsile, 2020).

Programme structure and stakeholder roles. The student wellness programme is embedded within the Executive Dean's Office and implemented through the Faculty Student Success Coach Office It is one of the core institutional structures supporting undergraduate student development across academic, personal, and social domains.

Key stakeholders involved in the programme include:

- *Lecturers and academic staff*: provide referrals and monitor student engagement
- *Student Faculty Representatives*: act as communication bridges between students and faculty
- *Institutional counselling services*: offer professional mental health support
- *Senior student mentors*: support first-year students and high-risk modules
- *Support staff*: facilitate workshops, monitor progress, and manage resources

This collaborative structure enables early identification of at-risk students and coordinated, context-specific responses. The programme offers a combination of academic and psychosocial support services. These are summarised below and aligned with the programme's goal of reducing attrition, improving student success, and promoting wellness in engineering education.

Practical components of the wellness programme. The faculty-based student wellness programme offers a structured combination of academic and psychosocial support services. These services are designed not only to improve academic outcomes but also to enhance students' well-being, in alignment with the programme's overarching goals of reducing attrition, fostering student success, and transforming the culture of engineering education to prioritise care, resilience, and holistic development.

Social development interventions. To cultivate a supportive and inclusive environment, the programme offers a variety of social development initiatives. Students are provided access to career counselling and personal development services to equip them with the tools to navigate both academic life and future career pathways. In addition, students participate in workshops focused on stress management, substance abuse awareness, emotional well-being, and personal safety. These sessions are intended to reduce stigma and provide practical strategies for managing the demands of academic life. Judgment-free support spaces are also available, where students can openly discuss personal or academic challenges in a safe, supportive environment.

A key part of the social development initiative is the peer mentoring system, in which senior students are assigned to high-risk modules and to first-year student groups. These mentors offer experiential guidance, helping their peers navigate complex course material and manage workload expectations. Another cornerstone of this initiative is the Life Skills Module, a compulsory, credit-bearing course for all first-year engineering students. The module emphasises essential competencies such as time management, emotional intelligence, teamwork, and strategies for seeking academic or emotional support when needed. It helps lay the foundation for a more reflective and resilient engineering student experience.

Academic support services. Alongside social development, the programme provides a range of proactive academic support services, primarily delivered through the Faculty's Academic Coaching Office. These services are designed to address academic challenges before they escalate into failure or disengagement. The academic interventions include tutoring and educational assistance, particularly targeted at historically high-failure modules. Students also have access to academic advising, which helps them develop structured study plans and make informed decisions about their academic journey.

The programme runs frequent workshops on writing, study skills, and exam preparation, helping students to improve their academic performance through skill development rather than just content mastery. In response to the particular challenges posed by engineering coursework, the office also offers specialised training in STEM learning techniques**.** This support is further complemented by the integration of digital learning resources via the institution's Learning Management System (LMS), making study materials and tools accessible at any time.

These academic services are continually adapted throughout the semester to meet students' evolving needs. Regular monitoring of assessment performance and attendance trends allows the office to identify students who may benefit from tailored interventions and to invite them to engage with support early, rather than reactively.

Identification and monitoring of at-risk students. A core component of the faculty-based wellness programme is the early identification and continuous monitoring of students who may be at risk of academic failure or disengagement. This proactive approach ensures that intervention occurs before students reach a critical point, reinforcing the programme's preventative and student-centred ethos.

Students are flagged as at-risk based on two key indicators: assessment performance below 45% and class attendance below 65%. These thresholds serve as early warning signals, enabling faculty and support staff to initiate timely, appropriate responses. Once a student meets one or both criteria, they are confidentially referred to relevant academic or wellness support services.

Ongoing monitoring and support. The system does not stop at identification; it emphasises continuous engagement and follow-up. To protect student privacy while ensuring effective intervention, confidential feedback loops are maintained with lecturers, allowing academic staff to stay informed without accessing sensitive details from counselling or support sessions.

In addition, attendance at wellness and academic support sessions is carefully tracked**,** helping the programme evaluate each student's level of engagement and the impact of specific interventions. Based on this data, personalised support plans are co-developed with students, tailored to their specific academic or emotional needs, and built around their willingness to engage with available services. By promoting voluntary participation in the programme, rather than enforcing mandatory intervention, the system helps to foster trust and reduce the stigma often associated with seeking help. This approach reflects the Ubuntu-informed values of respect, empathy, and shared responsibility, ensuring that students remain at the centre of their own academic and personal growth journeys.

Framework and methodology

The bioecological systems theory, developed by Bronfenbrenner, is one of the most prominent theories that uphold the reciprocal relationship between humans and their environment. This theory advances perspectives in understanding 'how communities, socio-economic factors, and political issues trigger individuals' mental health problems' (Chigangaidze, 2021). Bronfenbrenner (1979, p. 3) defined human development as 'a lasting change in the way in which a person perceives and deals with his environment' (Bronfenbrenner, 1979). The theory further explains that interactions between an individual and complex, multilevel, and dynamic socio-ecological systems significantly impact their development. This hypothesis posits that developing humans are nested within the core hub of ecological systems. Four well-known socioecological systems made up Bronfenbrenner's original theory, namely microsystem, mesosystem, exosystem, and macrosystem. He later added a fifth element, known as the chronosystem. A brief discussion on the different elements of the theory is offered:

a) Microsystem: the individual's immediate environment in which they exist and are in regular contact. The theory emphasises a strong relationship in which a developing person's conduct is influenced by their surroundings and, in turn, influences those surroundings.

b) Mesosystem: interactions and processes occurring inside microsystems. The mesosystem was characterised as a 'set of interrelations between two or more settings in which the developing person becomes an active participant' (Bronfenbrenner, 1979).

c) Exosystem: a system 'consisting of one or more settings that do not involve the developing person as an active participant, but in which events occur that affect, or are affected by, what happens in that setting' (Bronfenbrenner, 1979). A developing individual in this system does not actively participate in or directly interact with the social ecology, yet system components nevertheless impact them.

d) Macrosystem: the broader culture and ideological worlds, belief systems, societal values, political trends, and community practices are powerful elements in an individual's development (Mulisa, 2019).

e) Chronosystem: this phase recognises that an individual is an ever-evolving system. Therefore, it examines the changes in individuals' lives as they age and the socio-historical context of the local community (Tudge et al., 2022).

In the context of bioecological systems theory, the university support programme discussed above views students as complex systems with different extensions contributing to their function. Most importantly, as per the theory, we also recognise that students have agency over their lives.

Therefore, for any intervention to succeed, students must make conscious decisions to apply the provided strategies, ensuring they excel academically. Mulisa (2019) further indicates that bioecological theory is an instrumental theory that can aid higher education practitioners in better understanding complex student learning environments. The theory also emphasises that many factors contribute to students' success in higher education. Hence, there is a need for more programmes, such as those offered at the UoT, to support engineering students and ensure a fertile, nurturing learning environment.

The Faculty Student Success Coach Office acts as the central hub for the wellness programme, providing three interconnected services: academic support (including tutoring, exam preparation, and STEM learning techniques), social development (focusing on career counselling, stress management, and interpersonal skills), and peer mentorship, all aimed at fostering community.

As a community-centred approach, the senior student mentors and tutors provide experiential guidance on the successful navigation of the engineering programme, working in conjunction with professional staff to deliver specialised workshops and one-on-one support, not only from a lecturer's perspective, but also from a student's perspective, as a community-centred approach reflecting the Ubuntu principles of collective responsibility.

When the monitoring and report system works effectively, the at-risk students are proactively identified and invited to personal sessions and workshops as an early intervention. However, one of the programme's primary functions is to encourage students, identify and acknowledge their struggles, and to voluntarily engage with and access student support services at the first onset of academic, mental, physical, or socio-economic challenges.

Implementation and evaluation methodology

This study used a mixed-methodology approach to evaluate the efficacy of the suggested interventions and reporting structure. It combined a quantitative analysis of student success and pass rates from 2022 to 2024 with a qualitative assessment of student participation in the interventions. While the proposed interventions and reporting structures were implemented in 2024 at a UoT faculty-wide, across all engineering disciplines and subjects, this study focused specifically on reporting a high-risk module for first-year students as a representative case study.

This representative case study module was selected based on the consistency of lecturer participation in the timely identification and reporting process of at-risk students; the varied academic performance prior to the implementation of the proposed theoretical framework and interventions; and the availability of reliable data across all three years of the study period. The sample size of 60 to 70 students per annual cohort, investigated in the representative case study, aligns with recommendations in Cohen et al. (2002), which state that sample sizes of 30 or more participants are generally sufficient for statistical analysis in educational settings. The

Faculty Student Success Coach's Office facilitated all interventions and student communication.

Although the personal interventions of the students identified as at risk were the focus, the Faculty Student Success Coach Office invested extensively in a focused advertising campaign highlighting access to the faculty and institutional student support interventions as a general service available to all students. The department-hosted webinars on exam preparation, stress management, and time management, as well as 'how to study' sessions for high-risk modules, were available to all UoT students. The study complied with the relevant ethical principles, considering the uniform implementation of the interventions, faculty-wide and without discrimination.

Student identities were protected throughout the reporting and intervention process, and data were anonymised for analytical purposes. Exceptional care was taken to ensure that students identified as at-risk were not stigmatised or otherwise disadvantaged, and the reporting structure, process, and evaluation criteria were explained to all students. All interventions and reporting were implemented to support student wellness, mental health and academic success, as were the principles of Ubuntu described in the theoretical framework.

The methodology and interventions were guided by the theoretical framework detailed above and Bronfenbrenner's original theory, allowing consideration of multiple systemic factors influencing student mental health, stress, and performance, including the immediate environment, interactions among support structures, and institutional policies and practices. Further, the broader cultural and societal influences within the engineering studies environment were considered to facilitate holistic interventions while acknowledging the complexity of the factors influencing an engineering student's success, mental health, and overall well-being.

The 2022 to 2023 data were analysed in depth to establish student performance trends, examining individual assessment outcomes, class attendance, and online Learning Management System (LMS) participation and engagement. This analysis aimed to distinguish between temporary adjustment issues, which are particularly common among first-year students, and more concerning social, mental, or academic challenges that persist and worsen over time, often resulting in course deregistration or failure.

The findings provided lecturers with evidence-based guidelines and systematic identification strategies to facilitate early reporting and proactive interventions. By recognising the warning signs of a more persistent problem before academic deterioration further, the programme aimed to prevent the escalation of academic and mental health pressures that often compound student difficulties.

Systematic analysis framework based on academic performance trends. The assessment performance analysis followed a systematic progression, beginning with an initial evaluation of the first formal assessment combined with class attendance data, then evolving into a historical analysis as subsequent assessments accumulated throughout the year. This approach tracked whether students showed significant performance deterioration and whether declining assessment results correlated with changes in class attendance patterns.

Initial risk identification criteria for early identification and reporting. As part of the initial evaluation, when specifically analysing the student performance in the first assessment mentioned above, all students scoring 45% or below were classified as high risk, regardless of class attendance records. The purpose of this initiative was to enable the Academic Excellence Office to conduct general well-being checks, with a particular focus on first-year students, to identify potential financial, learning, or disability challenges that could be mitigated at an early stage.

Additionally, students with attendance of 65% or below were flagged as at-risk regardless of assessment scores, since literature demonstrates that students who fail to attend classes are reluctant to engage with study content and typically fail to compensate through reflective or self-paced study. This trend is evident when evaluating a student's assessment performance over a whole academic year, in conjunction with their class attendance, which shows a proportional decrease in both.

Historical assessment performance analysis. As the academic year progressed and both formative and summative assessments were completed, students who maintained 50% performance and regularly attended interventions and classes were closely monitored by the lecturer and academic office as borderline cases.

The 2022 to 2023 data analysis revealed that the second assessment typically proved most indicative of the trajectory the student would follow for the rest of the year as the initial adjustment period passed, and clear trends could be established for class attendance, intervention and LMS participation and engagement. Academic performance allowed for a definitive assessment of whether the student performance was improving or deteriorating, once again enabling targeted intervention strategies, especially for continuous evaluation subjects or year modules.

Data collection methods. The module's success and pass rate were systematically analysed to track the quantitative metrics and data for student cohorts from 2022 to 2024, which were obtained from HEMIS (Higher Education Management Information System). A student was identified as at-risk based on the faculty's reporting system, and framework detailed above, which lecturers implemented by tracking student class attendance and assessment performance.

As such, following the completion of the official assessments, students who complied with the criteria outlined above were reported to the Faculty Student Success Coach's Office for intervention.

This office documented student attendance and engagement in counselling services, as well as lecturing staff reporting frequency, which was communicated to the department and shared with the respective students. The Office monitored student participation in activities designed to support their academic success. These interventions focused on stress management, time management, study planning, setting personal and educational goals, and improving study techniques.

Data analysis. Using comparative statistical analysis, the quantitative data were analysed using inferential statistics to compare the pre-intervention success rates established in the 2022 to 2023 success rate data analysis with the 2024 post-intervention success rates; and to evaluate the difference in performance between at-risk students who participated in the interventions compared to the performance of the non-participants, using the Faculty Student Success Coach Office database for intervention participation records.

The success rate was evaluated as the percentage of enrolled students achieving a final grade of 50% or above, including deregistered students as part of the class group to obtain a conservative measure that accounts for student attrition. The pass rate was the percentage of registered students who achieved a final grade of 50% or above, excluding students who deregistered throughout the year, and focused specifically on students who completed the module.

The year-on-year statistics of the pass and success rates were compared. The analysis was used to determine whether the success rate improved, whether the number of students who deregistered for the subject decreased, and whether there was a correlation between the level of participation in wellness interventions, academic performance improvement, and the continuation of studies.

Results and discussion

A review of the Faculty Student Success Coach Office intervention statistics, assessing students throughout the period following the implementation of the Office's reporting and support structure, revealed notable observations among the at-risk students. The representative case study shows that 45% of the identified students struggled with both poor attendance and academic performance in formal assessments.

In comparison, 55% of the students complied with the UoT's prerequisite 80% class attendance policy, but still performed poorly in formal assessments, underscoring the reality that attendance alone does not necessarily guarantee meaningful comprehension, learning, or academic success. This finding aligns with Boylan-Ashraf's (2018) research, emphasising that class attendance must be coupled with academic and social integration for meaningful engagement. The disconnect between attendance and academic performance suggests that students may be experiencing passive participation, being physically present in class without cognitive or emotional engagement (Choi & Hur, 2023).

In 2024, reports focusing on at-risk students indicated that 73% of those identified, and who were contacted by the Faculty Student Success Coach Office for participation in academic and wellness interventions, still failed the module, while 27% managed to pass. Notably, 66% of the students who passed did so with distinction. This underscores findings by Freeman et al. (2014) that intervention effectiveness in engineering education may be particularly beneficial to students who are intrinsically motivated and somewhat engaged, while those facing multiple barriers may require a more intensive individualised support initiative aligned with Bronfenbrenner's micro and meso-system interventions.

Freeman et al.'s (2014) research on active learning supports the 2022 to 2023 data analysis, which demonstrates that regardless of the pass marks, regular class attendance is essential for maintaining academic momentum. The representative case study further supports this analysis, confirming that the decline in class attendance inevitably leads to deteriorating academic performance, irrespective of the severity of the decline.

Despite efforts by the Faculty Student Success Coach Office to engage students and provide support, participation in the proposed interventions and wellness programmes, and class attendance remained inconsistent, with some students failing to fully commit to participating. These findings coincide with Bandura's (1977) self-efficacy theory, highlighting the reluctance of students with low academic success and self-efficacy to seek assistance or participate in academic interventions. Consequently, this reluctance often contributes to the pervasive and toxic engineering culture of 'toughing it out', which celebrates struggling through engineering studies and the formation of communities around shared pain and suffering rather than fostering a supportive environment focused on development, mental health, and wellness, or popularising the participation in intervention programmes.

However, the analysis of the year-on-year success and pass rates for the representative case study module, detailed in Table 1, shows that initially, there was a 7.7% decrease in the success rate preceding the implementation of the proposed interventions. Following the successful completion of the proposed interventions in 2024, there was a significant – 35% – increase in the overall student success rate compared to 2023. This is supported by the corresponding increase in pass rate, with a 23.5% increase in the 2024 pass rate compared with 2023.

Table 1: *Success and pass rates from 2022 to 2024*

Year	**Success Rate (%)**	**Pass Rate (%)**
2022	56.00	66.00
2023	51.67	62.00
2024	70.00	76.56

When analysing the success rate improvements between 2023 and 2024, in the context of Bronfenbrenner's ecological systems theory, the 18.33% increase in the 2024 success rate suggests that the proposed theoretical framework and interventions successfully address micro- and mesosystems. From a microsystem perspective, the individual counselling, study skills, and academic interventions appear to have improved students' immediate learning environment and ultimately their coping strategies. It also seems that these interventions improved students' confidence in applying their newly acquired knowledge, while mesosystem interventions not only improved communication between lecturing and support staff but also empowered lecturers to identify and report at-risk students early.

Although viewed in the light of a representative case study, the improvement in the 2023 to 2024 success rate, compared to the decline observed in the 2022 to 2023 success rate, suggests that the sustained efforts to campaign for awareness of the faculty-wide intervention programme may indicate a shift in the engineering culture wherein help-seeking behaviour was normalised. This connects to the concept that institutional interventions grounded in Ubuntu philosophy can promote a cultural shift from celebrating individual struggle to fostering collective support.

These findings should also be examined in conjunction with the student registration and deregistration statistics detailed in Table 2, which show a 50% decline in the 2023 to 2024 deregistration rates following the implementation of the intervention programme, compared to the 179.23% increase in the deregistration rates observed from 2022 to 2023. While the results indicate a notable improvement in student performance, there is still room to refine individual interventions to promote students' voluntary participation.

Table 2: *Student registration from 2022 to 2024*

Year	Deregistered Students	Students	Deregistration (%)
2022	4	67	5.97
2023	10	60	16.67
2024	6	70	8.57

Although the case study sample is relatively small, this trend may suggest a gradual shift in students' perception of academic support and intervention programmes, moving away from traditional engineering culture. This shift could be linked to the faculty's awareness campaign, which actively promoted intervention, guidance, wellness, and support initiatives, aligned with Bean and Metzner's (1985) model for student attrition, which emphasises the focus of interventions on both academic and psychological well-being, ensuring that these resources are accessible not only to at-risk students, but to the entire student cohort; and that, most importantly, that the students are aware of this support and how to access it.

However, the varying success rates among intervention participants, specifically the 27% passing students following the interventions, with only 66% of those students achieving a distinction, indicate a need for a more tailored approach for individual student intervention profiles, necessitating future research to identify factors that could not only predict intervention success, but also improve intervention recommendations at an individual level focusing on a student's intrinsic motivations.

Conclusion

Although numerous research articles and studies have examined the importance of mental health and wellness among engineering students, there is a need for additional research in a South African context, particularly among students at the UoT. Such research should examine how best to support student learning while promoting student wellness and mental health. The research should be embedded in a student cohort with diverse economic, academic, and cultural backgrounds. The individual student's prior knowledge and environmental exposure should be considered, as they all affect the extent to which the student can relate to and ultimately comprehend the practical examples and learning materials.

The need for such research is emphasised by the decline in mental well-being and the increase in stress levels observed among engineering students at institutions where student throughput is prioritised. The need is underscored by a student culture that has historically perpetuated an unhealthy approach to learning rather than fostering one that encourages engineering students to understand their material. There is a general lack of appreciation for applying theoretical knowledge to practical solutions, while effectively utilising all available resources to promote student mental and academic wellness.

While the analysis of year-on-year success and pass rates from 2022 to 2024 provides evidence of the efficacy of the wellness intervention programme implemented within the Faculty of Engineering and the Built Environment, the results and findings detailed in this article must be interpreted with the limitations of a representative case study in mind.

Although Cohen et al.'s (2002) recommendations for educational research consider a sample size of 30 or more participants sufficient for statistical analysis in educational settings, this limit limits the applicability and generalisability of the findings across different departments, despite the framework being implemented faculty wide. Further, while the framework provides interventions and support at all levels of study, the analysis of the HEMIS data focuses primarily on the efficacy of interventions for first- and second-year students in one high-risk module.

Ethically, these interventions should be available to all students regardless of department, academic performance level, or year of study, as withholding beneficial support measures from any student could potentially exacerbate and contribute to a student's mental health or academic difficulties. As a result, this consideration prevents the establishment of traditional control groups, necessitating a heavy reliance on historic HEMIS data for analysis of findings and results. This data examines individual assessment performance, pass rates, success rates, student registration statistics, and historically unreliable attendance records.

It is also important to acknowledge that the improvements in success rates and student attrition in the 2024 academic year could be attributed to exosystems such as improvements in teaching methods and assessment strategies, while the cultural specificity of the intervention framework based on Ubuntu principles may limit the application of similar frameworks to other cultural contexts without making significant changes.

An in-depth analysis is recommended on the implementation of structures and support systems that promote student engagement and participation. The significant improvement in 2024 demonstrates that addressing student wellness through a bioecological systems approach rooted in Ubuntu philosophy can significantly enhance academic outcomes in engineering education for at-risk students and the remaining cohort. However, the 73% failure rate observed among students who were contacted and identified as at risk indicated that, while the overall approach might be practical, the individual interventions require further refinement, with a focus on promoting student engagement and participation not only in the intervention but also in class.

These findings challenge the traditional engineering education culture found in UoTs, normalising and perpetuating high-stress learning environments that discourage help-seeking behaviour, and prioritising mental health and general well-being as fundamental influences on academic performance. Instead, they support a more holistic approach that recognises the interconnectedness of wellness and academic performance and acknowledges the importance of proactively addressing mental health concerns rather than reactively. The findings especially highlight the importance of continuous monitoring and reporting of student performance and attendance as an ongoing mechanism that supports a guided learning approach, while encouraging students to take responsibility for their learning journey and the achievement of their personal and academic goals.

The results validate the investment in and implementation of the proposed theoretical framework and approach. They also suggest that when fully integrated into faculty culture and practices, such approaches can substantially improve student retention, progression, and academic success in engineering programmes as well as the long-term mental health, physical health, and well-being of not only engineering students but ultimately engineers in industry and practice.

All the above factors support the necessity of successfully implementing and integrating student development and support programmes into academic institutions and student culture. The significance of open discussions regarding the importance of mental health, wellness, and awareness in an academic engineering culture must be emphasised, while recognising that the success of these programmes largely depends on the active participation of students and lecturers. However, it is worth noting that the sustained commitment and availability of any interventions at a UoT require adequate resource allocation, support, and concerted development for diverse student cohorts.

This study aligns with evidence supporting comprehensive, culturally informed student support initiatives in engineering education. The initial improvement in success rates and student attrition supports the development of sustained, systematic interventions and structures aimed at transforming the engineering culture, actively promoting student wellness, voluntary student participation, and supportive communities.

The integration of Ubuntu philosophy into the framework, alongside bioecological systems theory, provides a foundation and a culturally relevant approach for UoTs in the South African education context. However, the success of the programme and the replicability of its results depend on institutional commitment, continuous development, and student-centred engineering teaching strategies that foster an environment that promotes student participation, engagement, and comprehension.

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Engineering capstone projects: student motivation in selection and impact of allocation procedures

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The engineering capstone project is a crucial bridge between academia and practice, enabling students to demonstrate graduate-level competencies, with the project topic central to students' experiences. In the South African context, these projects are typically conducted individually and driven by academic research interests. This study explored students' motivation in topic selections using a qualitative survey of current final-year students together with a review of the impact of alternate allocation systems through a quantitative analysis of five years of historical project selections. Findings show that students' choices are primarily driven by affective factors such as personal interest, confidence, excitement, and engagement. Prior academic performance showed only a weak correlation with capstone performance, raising caution with regard to the validity of its use as a key criterion for allocation. Student satisfaction was deemed highest when they received one of their top-choice topics, while staff satisfaction was linked to balanced student ability across supervisors. Comparisons of allocation methods suggest that systematic approaches based on academic performance result in lower satisfaction for both students and staff compared to optimisation procedures. The study recommends offering a diverse range of topics incorporating meaningful connections for students and prioritising interest-based allocation over academic metrics.

Keywords: capstone projects; cognitive-affective-systemic motivations; student motivation; capstone allocation

Introduction

Capstone projects are a significant culminative learning experience where students are given the opportunity to apply knowledge, skills and proficiencies gained in their course to substantial real-world projects, similar to what would be encountered in practice (Brackin et al., 2011; Steiner et al., 2015). The inclusion of a capstone project is a specific requirement from accreditation bodies such as the Accreditation Board for Engineering and Technology (Stresau & Steiner, 2020) and is used to demonstrate professional competence in specified graduate outcomes (Rasul et al., 2016). Capstone projects are considered the 'best reflection of how well the current university curricula match industrial needs' (Liu, 2023, p. 1) and are often used as a proxy for the quality of the programme as a whole (Jawitz et al., 2002). Ultimately, the capstone project provides a 'bridging' experience between academia and practice (Parker, 2017) and allows students to demonstrate that they are prepared for professional practice (Steiner et al., 2015).

Capstone projects can take multiple forms: they can be design or research-based, related to industry-sponsored projects or academic research interests, and can be completed either individually or in teams (Ward, 2013; Jawitz et al., 2002; Brackin et al., 2011). Capstone projects are often considered from the educator's perspective, i.e., considering what learning objectives and competencies should be addressed with a focus on the values and skills that students should gain as part of the process. Many engineering capstone projects are designed with labour market needs in mind, such as the Conceive-Design-Implement-Operate (CDIO) approach (CDIO, n.d.), which mimics what engineers might do in industry. Such approaches seek to develop technical and professional competencies, but are not always feasible in different engineering disciplines, nor in resource-constrained contexts.

What is seldom considered is the students' perspective of motivation, interest and potential engagement. The project that a student works on is the 'heart of the capstone experience' (Brackin et al., 2011, p. 1164), and Parker (2017) suggests that 'students invest themselves emotionally' (p. 41) in these projects. As such, cognisance must be given to the nature of the projects and the factors that allow for the specification of projects that cater to student values and objectives (Whalley et al., 2017). Cheville (2010) noted that the attributes of successful design projects are that they are viewed as worthwhile, have relevance to the engineering discipline, involve the use of modern and emerging technology, and are generally appealing to students. 'Projects have intrinsic appeal when they include innovative technology, allow a wide range of creative solutions, and/or are related to current cultural issues' (Brackin et al., 2011, p. 1165). Students have been shown to perform well on capstone projects when the projects are perceived as authentic and when the product is cared about and has utility (Christensen & Rundus, 2003).

There is limited literature that directly explores what students consider as important in the selection of capstone project topics and that recognises them as subjective agents who have an influence on the project outcomes. No literature discussing alternate allocation strategies and the impact this has on student project selection or experience was identified. Hart & Polk (2017) surveyed 83 mechanical, biomedical, and electrical engineering students, asking them to rate the importance of 14 predetermined factors in their selection of topic preferences for an individual project. They found that the three most important factors were: obtaining engineering experience in a particular field or technical area, gaining exposure to a company for employment opportunities, and working on an industry-sponsored project. Desire to work on a 'faculty-sponsored project' (p. 1423), i.e., an academic research project, was ranked as least important. Ward (2013) noted that 'active industry involvement' (p. 215) is a key element of capstone projects in mechanical engineering at the world's top-ranked engineering universities. A similar preference for industry over internal (faculty) projects was noted by Latorre & Meier (2023).

Whalley et al. (2017) explored the value that computer science students undertaking a capstone project placed on five core areas, namely difficulty, experience gained (framed in relation to employability skills), social value (positive social benefit), fun, and topic familiarity. Students were asked to give each value a score resulting in a total score of 100 for all five values. The results from 28 students out of a cohort of 111 showed that difficulty and experience gained were the most important factors, with topic familiarity being the lowest. In semi-structured interviews with 19 students aimed at identifying the affective response of computer science students during the capstone project, Parker (2017) identified the 'importance of project impact' (p. 40) noted by students in discussions relating to project selection as a key driver for engagement and motivation.

This research study explores the aspects that influence student selection of topics for individual research-based capstone projects in a Global South context at a research-intensive institution. The intention of the study is to assist academic staff in providing projects that engage the students, whilst meeting the relevant academic requirements, and ensuring that the capstone project is an effective bridge between academic and professional practice. The research question is: *What drivers motivate student interest in the selection of final-year projects?* This prompts a secondary research question: *How can project allocation strategies impact the overall number of students working on projects of primary interest?* Understanding what students value when interested in various projects will assist in creating allocation strategies that maximise the number of students working on projects that are meaningful to them and where they believe they have impact.

Theoretical framework

Education is a process which, according to the philosophy of Pestalozzi, considers a holistic approach and nurtures intellectual, emotional, and practical development in the whole person following the 'Head, Heart and Hand' principle (Brühlmeier, 2010), also commonly reflected in the 'Know-Be-Do' model in leadership development. This integrated approach aims to develop well-rounded individuals who can think critically, act ethically, and contribute meaningfully to society through both thought and action. Pedagogies, curriculum, and student support should be provided in a manner which reflects these principles. Educational learning objectives were classified by Bloom (1956) into three domains: *cognitive* (thinking, mental skills, knowledge), *affective* (feeling, emotional skills, attitudes), and *psychomotor* (doing, physical skills). Together, these domains guide educators in designing balanced and comprehensive learning experiences. Tait (2000) defined three functions of student support which can be considered as aligning with each of these domains: cognitive support related to the provision of standard course materials and learning resources; affective support to provide an environment that enhances self-esteem; and systemic support related to the provision of student-friendly administrative and information processes. This combined holistic model of education, learning and student support is represented in Figure 1.

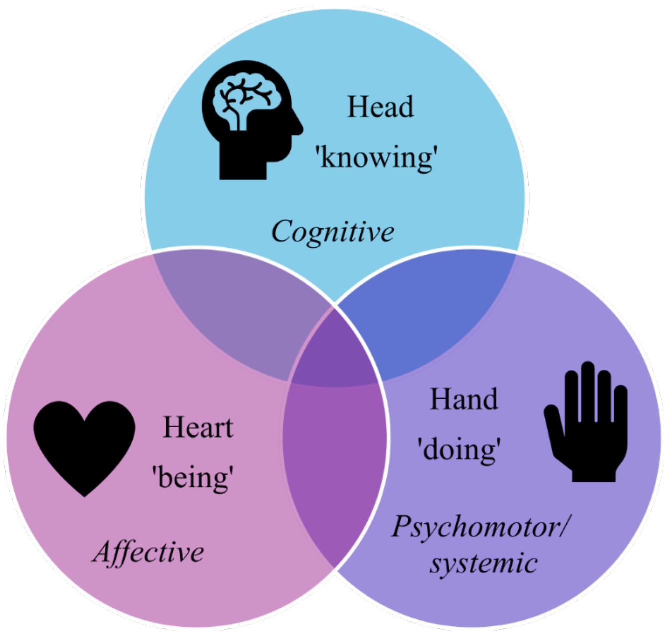

Figure 1: *Holistic model of education, learning and student support*

These complementary theoretical frameworks have been used to frame this investigation into understanding what drives student interest in capstone projects when they are required to make a selection of preferred topics. The cognitive-affective-systemic (CAS) model has been used in research investigating student spatial thinking (Schreve & Wolff, 2023), postgraduate learning communities (Lewis et al., 2021) and scaffolded virtual reality strategies (Kruger et al., 2021). In this paper, the CAS domains have been used as a lens to consider the drivers of student preferences and articulate the relationship between the three core aspects of the student learning experience in context.

Context

Globally, engineering education has seen continued pressure to meet the needs of our dynamically evolving society, industry, and profession. Increasing challenges in recruitment, retention and employment in STEM (Science, Technology, Engineering and Mathematics) related fields (Sithole et al., 2017) have seen dedicated strategies to develop engineering staff, engage schools in STEM activities, and collaborate across academic-industry boundaries. These strategies have long informed curriculum design and pedagogical innovation in engineering. The research in this paper is located at a research-intensive institution in South Africa. The engineering faculty is similarly engaged in ongoing programme renewal initiatives, as are most engineering faculties and schools in South Africa, particularly in light of the release of updated International Engineering Alliance (2021) graduate competency profiles and the subsequent review of national engineering standards. As such, the faculty has a dedicated developmental engineering education focus and has been proactive in addressing the first-year transition challenges and key knowledge-building approaches beyond the first year. Many of these initiatives, however, have been focused on what the educators see as necessary. Although student focus groups are included in the design and implementation of the current strategies, their voice is absent in the context of their final-year design projects. The single case-study-based research in this paper offers the opportunity to bring the student voice into the space of ‘engineering curriculum renewal’ in context (Wolff et al., 2025).

In this paper, the focus is on the capstone project of the Civil Engineering department, which is proactively addressing programme improvements using the overarching CAS domains. A more recent focus has been on student vacation work portfolios designed to support holistic theory-practice bridging (Way et al., 2024) and evaluative judgement research to improve student problem-solving capabilities (MacRobert, 2025). Examining the final-year capstone project builds on the departmental research on the holistic student experience of the curriculum and opportunities to improve this. The project is conducted individually in the second semester of the final year (fourth year) of the course. The module comprises 30 credits (300 notional hours) and forms a major component of the assessment of competencies in multiple Graduate Attributes as defined by the Engineering Council of South Africa (ECSA) accreditation requirements (ECSA, 2023). Students are provided with a list and short description of available project topics towards the end of the first semester. The topics are predominantly influenced by the research interests of the academic staff, with no specific industry sponsorship. This is common in either resource-constrained contexts or those institutions which are specifically focused on research. A range of topics across the seven subdisciplines represented in the department are provided, depending on the number of staff in each field, i.e., geotechnical, informatics, management, pavements, structures, transport and water. In the past five years the cohort size has ranged from 43 to 77 (average 62), with the number of available supervisors ranging from 19 to 23.

An event is held to present information about each of the research groups in the department, and students are encouraged to talk to the staff about the projects at this event (or to schedule a meeting). Students have one week to consider the available topics and are then required to submit a list of their top ten topics in order of preference but are restricted to selecting only two topics from a single supervisor. This aims to encourage a wider distribution of selections across all supervisors, especially for newer or less sought-after staff.

The allocation system awards all unique first choice selections first, i.e., if only one student has selected a certain topic number, then that student is guaranteed *that* topic. Students have no formal way of knowing the selections of others, so their impression of how popular a topic is will be based on their discussions with peers. Where multiple students have selected a particular topic as their first choice, the topic is awarded to the student with the highest prior academic performance. The average mark of all third-year modules is used to determine this performance mark, which is essentially a meritocratic approach. For any students who are in the process of completing third-year modules at the time of the allocation, these modules are given a mark of 0 in the calculation of the average. Students without a topic after these first two steps are listed in academic rank order, and the allocation proceeds from the top of the list, assigning the highest available preference remaining. Any students without an allocated topic after the completion of this process are required to participate in the second round of allocations, together with any invalid or missing initial selections. Students are provided with the results of the project allocations at the end of the first semester.

Methodology

Within the broader faculty-wide engineering education research space, a number of sub-projects are interlinked and follow a pluralist methodology, including quantitative and qualitative strategies. As a new appointment to the institution, the first author was given the portfolio of coordinating the capstone project in the Civil Engineering department. This, together with an existing relationship with the faculty engineering education research (EER) team, provided an opportunity to engage in an alignment and practice-sharing review of the management and assessment procedures of capstone projects across the various engineering departments in the faculty, which forms the background for this particular study. This included collaborative discussions with the capstone project coordinators and with the faculty EER team, and formal feedback to staff via faculty workshops entailing data covering approximately 550 final-year students and approximately 150 staff. An empirical review of the effect of disciplinary differences on management and assessment procedures is planned for future research.

From this broad faculty-wide context, an opportunity was available to focus more closely and explore the student perspective using the project data from a single department, with particular focus on students as subjective agents. The empirical review noted that the student voice was largely missing from consideration in the management and assessment of capstone projects, with little understanding of what was important to students when they were selecting their project topics. It was also noted that the topic allocation procedures varied widely across the departments, something which even the staff were surprised about in the presentation of the review at the faculty workshops. A qualitative survey of the cohort of 74 students currently undertaking the project in the department was undertaken to gain insight into the values and influences driving project selection as well as to determine if the allocation strategy employed was influencing this. As the project topic is very important to students, it is worthwhile to consider how various allocation systems might result in more students getting higher preference topics. The qualitative results were thus substantiated with a quantitative analysis of alternate allocation strategies using the topic selection data of 296 students over five years, with the aim of determining various metrics of performance from the student and staff perspective.

An electronic survey was sent to the final year civil engineering students registered for the research project in 2025. 74 students were registered for the module; 63 students submitted their project choices (2 students did not indicate their topic preferences and 9 students had proposed their own topic to a supervisor of choice prior to the general pool selection and thus did not participate in the selection and allocation process). The survey was sent to all students who submitted their project choices (n = 63) after the project selections were received, but before the allocations were completed, to ensure that the process was fresh in their minds. The analysis was conducted by the dedicated research team on the sub-project who collaboratively reviewed and verified the results. While only 12 students completed the survey, the collaborating researchers believed their responses worthy of examination as they offered rich and nuanced insights for this exploratory work.

The survey comprised three sections:

1. An open-ended question that asked students to reflect on the factors that influenced their top three choices. The aim of this was to generate data that could provide insight without restricting students along pre-defined factors.

2. A rating of 11 influencing factors on a five-point Likert scale ranging from 1 (not important at all) to 5 (very important). Again, students were asked to consider only the factors that influenced their top three choices. The influence factors and CAS model mapping of each of these is shown in Table 1; where a factor relates to multiple CAS elements, these are listed in order of significance. These factors were determined from considerations of what was expected to be important to students in the selection process from prior experience and from the literature review. The motivation for selecting a particular CAS dimension is given for each factor.

3. A yes/no question aimed to determine the impact of the allocation procedure, paired with an opportunity to provide further motivation for the answer given.

Table 1: *Influence factors and mapping to Cognitive-Affective-Systemic (CAS) domain of self and learning*

No.	Influence factor	CAS	Motivation
1	Desire to work with a particular supervisor.	**A**	Driven by a good perception of the supervisor, reports from previous students of good support and/or high marks when working with a specific supervisor.
2	Desire to work within a specific field of specialisation.	**C**	Driven by a specific type of knowledge or application.
3	Clarity of information available about the project.	**S**	Clear visualisation of the scope of the project and what the research will entail.
4	Desire to work on a laboratory project.	**S**	Usually related to clear methodologies, practical applications, hands-on learning, 'doing'.
5	Desire to work on a project with fieldwork investigation.	**S**	Usually related to clear methodologies, practical applications, hands-on learning, 'doing'.
6	Desire to work on a desktop project (no laboratory or fieldwork components).	**C-S**	Underpinned by a strong cognitive focus and desire to work in a more theoretical realm with a secondary component of clear systemic expectations of skills (e.g. programming, numerical)
7	Ability to envision the required methodology to complete the project.	**S-C-A**	Focus on *methodology* related to skills and proficiencies (S), which allows for a grasp of the related concepts (C) and thus instil confidence / comfort for the student for the topic (A).
8	Ability to envision the intended outcome of the project.	**C-S-A**	Focus on *outcome* related to grasp of the related concepts (C), which gives the basis for the required skills and proficiencies (S), which thus instil confidence / comfort for the student for the topic (A).
9	Topic was personally relevant or important to me.	**A**	Related to the emotions, feeling and attitude of the student.
10	Topics were related to subjects that I have enjoyed.	**A-C**	The 'enjoyment' relates to the affective experience and learning, which has a secondary component of a specific type of knowledge from an academic learning environment.
11	Topics were related to projects that I have enjoyed during vacation work.	**A-S**	The 'enjoyment' relates to the affective experience and learning, which has a secondary component of a specific skill or application area from a practical environment.

The paper proceeds as follows: the qualitative survey results first are unpacked with thematic coding of the open-ended question to identify key themes (Braun & Clarke, 2006; Cohen et al., 2011). The second aspect of the survey is then presented, i.e., a review of the ratings of the various influence factors and mapping of the results to the CAS domains, which is followed by a brief review of the insight gained in the final question of the survey related to the influence of the allocation systems on project selection. This leads into the quantitative analysis of the allocation systems where the details of the different systems used are summarised, followed by an analysis of the performance of these systems from the student perspective (primarily based on the assumption that greater student satisfaction is related to being allocated topics higher up in their selection list); and from the staff perspective (exploring the relationship between prior academic performance and final project mark, as well as the distribution of students of varying academic performance to each staff member that results from each allocation system). Finally, the discussion brings together the findings and observations from the research.

Discussion of survey results (qualitative review)

Open-ended question

The open-ended question was presented as follows: 'Consider the topics that you selected as your top three preferred topics. Describe in as much detail as possible why you chose these topics. What factors were important to you when making your selection?'

The primary theme that emerged from the responses was **personal interest** in a topic, with a strong affective notion often expressed with words such as 'passion', 'fun', 'excited' and a sense of liking the topic and/or supervisor. This included genuine interest in the topic or field, prior interest in a specific research area due to personal experience and alignment with personal strengths or favourite modules.

> [The topics] were things that I had personally been interested/invested in since before topic selection [S1].

> Interest (how excited they make me feel) [S6].

> My main reason for this preference is my genuine passion for pavement engineering [S8].

> Most of my topics are transport-related because I really do like it [S9].

The second key theme was related to the systemic **practical and logistical project specifications**, expressed as the positive desire to work on laboratory topics, or the negative desire to specifically avoid either laboratory or fieldwork topics. Those that were positively seeking laboratory topics expressed an interest in practical application of theory and the desire to gain a new skill set.

> I wanted to make sure I learn more than just the literature behind the topics but also gain lab skills in the process [S1].

> I enjoy getting my hands dirty and learning through doing [S8].

> I would like to do lab work … so that I can be able to understand fully and interpret test results we receive from lab [in work context] [S12].

The third theme related to the relevance of the topic to **employment**, either in relation to prior vacation work experience (influencing familiarity and confidence with certain topics), career opportunities / employability (relevance to future career plans, desire to gain experience valued by future employers) or alignment with current job responsibilities.

> The chance to build on my previous vacation work experience in a meaningful way [S8].

> Future employer influence (try gain specific experience, e.g., structures) [S7].

> I am wanting to work in that industry in the future so I feel the topic would help me prepare for that [S5].

The **supervisor** linked to the topic was noted as an influencing factor in the selection; this was related to a positive rapport with the supervisor or strong affective sense of 'enjoyment' and perceived quality of supervision.

> My first choice was … because she is a very good lecturer, she is a good leader as well [S9].

> Supervisor (it would be nice to have a supervisor you enjoy) [S6].

> I … get on well with the lecturer and find his topics interesting and challenging – which is what I was looking for [S5].

Prior academic performance was noted as the final theme indicated by multiple respondents, with students specifically mentioning choosing topics linked to modules that they had performed well in.

> I had to check my marks with my top three preferred topics [S7].

> Transport Science has been one of my strong modules over these 2 years [S9].

An interesting factor noted by one respondent was the confidence in their ability to perform well; this response noted that one of the key influences was 'how well I know I would perform in such a topic' [S10]. This highlights the potential importance of self-efficacy in the capstone projects, defined by Bandura (1977) as belief in one's own ability to succeed.

The key takeaway from the open-ended description of motivation for topic selection is the strong affective connection that students felt with various topics. This was coupled with the recognition of the ways that their prior experiences and preparation through their course influenced their decision – either positively or negatively, e.g., academic performance in certain subjects, vacation work experience, and/or relationship with academic staff.

Influence factor rating

The results of the ratings for the influence factors are shown in Figure 2. At first glance, the following observations are evident: factors related to the project specifications (i.e., clarity of available information, laboratory work, fieldwork, desktop studies) have the widest spread, with the latter three having approximately equal numbers of 'important' and 'unimportant' responses. The relationship between the topic and enjoyment of subjects had a purely positive inclination with all students indicating that this was either important (42%) or very important (58%) to them.

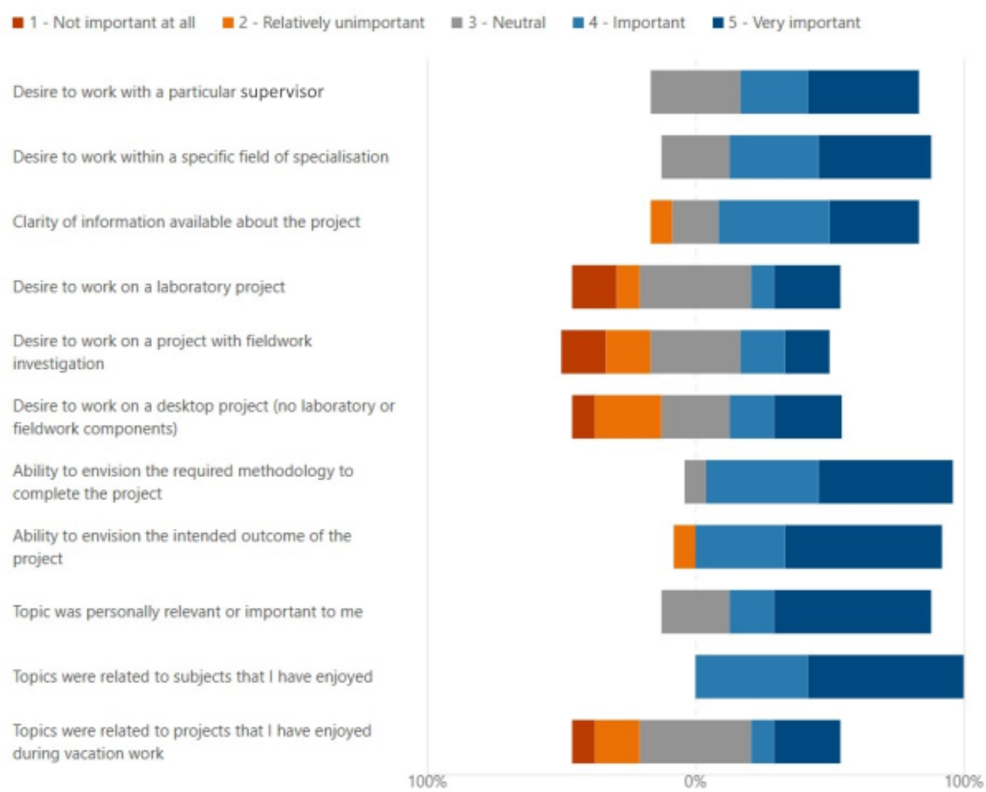

Figure 2: *Summary of responses of influence factors influencing project selections*

To allow further analysis of the responses, a weighted average rating was calculated using a weight ranging from –2 for 'Not important at all' to 2 for 'Very important'. The value thus gives an indication of the nett importance relative to the zero-neutral value. These results were then ranked in order of overall importance, as presented in Figure 3.

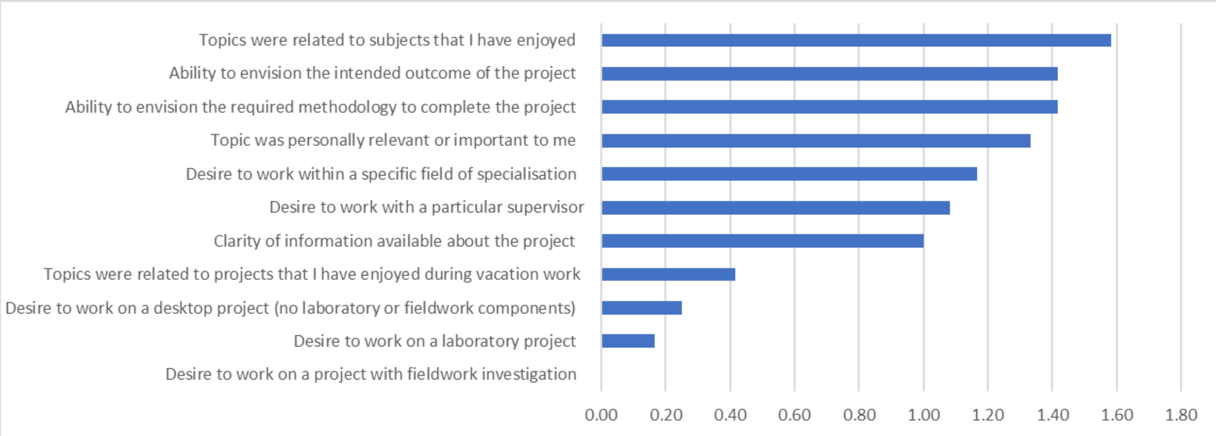

Figure 3: *Weighted average rating of influence factors*

The revised presentation of the results emphasises that the most important influence factor was whether the topic was related to the subjects that the students had enjoyed prior to making the selections. In the CAS model framing, this was indicated as being a primarily affective orientation as it is primarily linked to how students feel about themselves or a subject. This is likely underpinned by a cognitive aspect, as this feeling may well be linked to academic performance or aptitude and can also be linked to the self-efficacy concept introduced in the prior open responses.

The second most important factor was a tie between the ability to envision both the required methodology to complete the project and the intended outcome of the project. These are linked to what Hart & Polk (2017) referred to as a student's 'comfort-level' [*sic*] with a project in the selection process, which is determined by students' previous knowledge and experience. In the CAS framework, these were categorised as encompassing all three domains, with the methodology having a stronger systemic orientation (a student has a sense of the process and tools required) and the outcome having a stronger cognitive orientation (a student can envision the solution). All of this is underpinned by an affective sense of the student's confidence (affective dimension) in their own ability to tackle the project. Again, the self-efficacy component of the student's belief in their ability to succeed comes through as a strong motivation for their topic selection.

The third highest overall rating score was awarded to 'topic was personally relevant or important to me', which was linked to an affective sense of feeling and being. This aligns with the results from the thematic coding which showed that one of the key drivers was personal interest in a topic and connects to the idea of 'emotional investment' by students in capstone projects (Parker, 2017, p. 41) and the importance of ensuring that topics 'excite and engage' students (Hart & Polk, 2017, p. 1422).

The systemically oriented influence factors related to project specifications (laboratory work, fieldwork and/or desktop studies) which were noted as showing the broadest spread in Figure 2 have the lowest weighted averages (Figure 3). This was not necessarily because these were not important, but rather because, as noted in the thematic coding, these specifications created a stronger polarisation, with some students specifically desiring some of these aspects balanced by those who were actively seeking the opposite.

One of the surprising results was the relatively low importance placed on the desire to work with a particular supervisor. This was noted in the thematic coding as one of the drivers, although the prevalence was lower than expected. Similarly, the rating of the influence factors also showed this as ranking in the middle of the available factors with a large portion of neutral responses. Sentiment in the department had largely been that this was one of the most important factors that students considered, in line with international research on what students' value in supervisors (Davis, 2020). This does not mean that it was *not* an important factor: the biggest motivation was the subjects students enjoyed, which in turn might be impacted by a combination of the lecturer (affective) and subject matter (cognitive).

The weighted average rating of the influence factors from Figure 3 was combined with the dominant CAS domain expressed in each factor identified in Table 1 to determine the average weighting of each of the three domains. The results are mapped in Figure 4. This confirms that in this model, affective considerations come to the fore when students are selecting their project topics; the sense of self and people-orientation is key with how a student *feels* about a topic presiding above what they *know* about it.

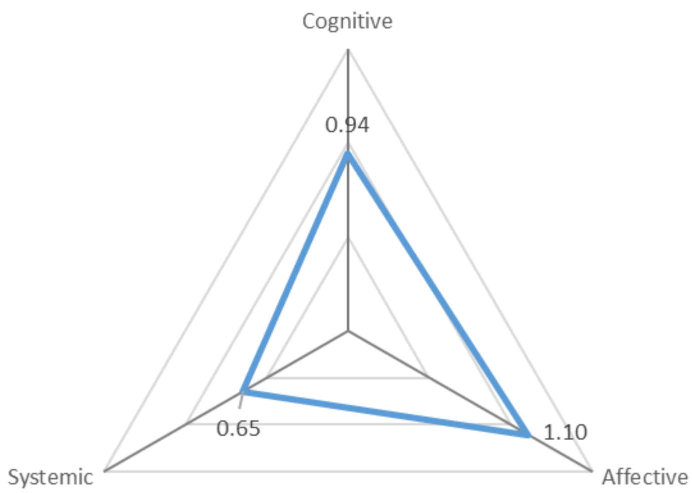

Figure 4: *Average result of CAS mapping considering dominant domain addressed in each influence factor*

The survey was intended as a tool to understand why students chose the topics that they did, and what was important to them in this process. The first two questions were designed as complementary means of sourcing information on this by first giving respondents the freedom to describe their experience and thought processes and then requesting input on pre-selected factors. A triangulation exercise comparing the codes identified in the open-ended responses, and each respondent's dominant CAS domain based on their influence factor ratings, showed strong alignment between these two questions, thus increasing confidence in the findings.

Influence of allocation system

The final section of the survey aimed to understand to what extent, if any, the allocation system used for topics influenced the students' selection. The current topic selection process has several restrictions placed on students (notably allowing only two topics per supervisor) and uses prior academic performance as input in the allocation system. This section was included with the awareness from the broader research context that different departments in the faculty use widely varying allocation systems. The research was particularly interested in how the use of prior academic performance impacted the freedom that students felt they had in their selection, and the extent to which this constraint provided benefits to either the students or academic staff when allocations were conducted. The aim was that this could inform improved allocation procedures that take the student perspective into consideration.

The question was asked in two parts with a yes/no question ('Did the topic allocation procedure used in the department affect your choices?') and the optional space to provide additional reasons for the answer. It was clear from the responses that the allocation procedure used in the department did indeed affect their submitted choices. This impact was noted in two ways: (1) an interest in more than two topics that were listed by one supervisor, and (2) the influence of the academic ranking. Selected quotes giving further insight on the latter component are noted:

> I couldn't disregard the fact that some students will have a first choice over mine and I had to keep in mind who I will be competing with to secure my desired topic [S4].

> I couldn't pick the topic I wanted to do the most as I knew someone stronger academically wanting to do the same one [S5].

> A topic I wanted to choose as my first choice was hotly contested. People with better marks than me had chosen it as their first choice. This forced me to go with something else as my first choice [S6].

Even if students did indicate that the allocation system influenced their choices, some of the comments reflected positively on the overall fairness of such:

> That being said, the rules you have in place are understandable [S3].

> Personally, I would have the system be set up differently. However, overall, I believe it's mostly fair [S5].

> The procedure encouraged me to think strategically and ensure that all my choices were topics I could still learn from and contribute to meaningfully [S8].

The findings suggest that students are strategically adjusting their selections based on the allocation system. This provides impetus to ensure that this system performs optimally without undue impact on the student or staff experience of the project, and that any constraints or considerations are rationally driven. This provides the basis of the second part of this study which quantitatively reviewed the performance of several alternate allocation strategies, presented in the following section.

Alternate allocations and implications (quantitative analysis)

The topic allocated to a student is the 'heart' of the research project, and the qualitative results showed a strong affective motivation in the selection of preferences. Students noted that the allocation system does have an influence on their selections, particularly in the way that academic performance is used. It is thus worthwhile to consider how various allocation systems might result in more students getting higher preference topics, whilst other systems might be more oriented to suit the requirements of academic staff. This allows the exploration of student agency and whether or not the use of prior academic performance is a value-adding element of the process. This second part of the investigation turns to the systemic and cognitive aspects of the project allocation procedures to understand how this can support the affective nature of the importance of the topic to students.

As noted previously, the broader context of this research is a review of final-year project practices across the engineering departments in the institution. One of the observations was that departments followed a variety of topic allocation procedures with the one described in the current context representing one approach. Key differences were related to the use of prior academic performance and whether or not supervisors were able to give input into the final selections. The practices ranged widely from systematic rule-based allocations incorporating academic rank order, to optimisation-based allocations with an aim of maximising student and supervisor preferences. One department conducted a manual allocation aiming to ensure that each supervisor received a balance of 'strong' and 'weak' students according to prior academic performance. These were used to select alternate allocation strategies and performance metrics for further testing.

Allocation systems tested

The testing of the allocation systems was conducted using the student topic selections in the Civil Engineering department from 2021 to 2025, comprising a total of 296 students. Cohort data and full details of the procedures followed for each allocation system are available in a supplementary report available on request. Four allocation systems were considered:

1. **Unique first rank:** status quo, i.e., unique choices, first-choice conflicts, followed by academic rank order.
2. **Strict academic rank:** students are academically ranked, and topics are allocated based on remaining availability.

3. **Monte Carlo (MC) optimisation (random):** MC simulation (20 000 iterations) with random allocation order and optimisation of the number of first-, second- and third-choice allocations.

4. **MC optimisation (with marks):** MC simulation with optimisation considering both academic performance and topic preference.

Three of the allocation systems incorporate academic performance to some extent; the MC optimisation (random) aims to consider the effect of removing this aspect entirely. It is noted that a change in the allocations could change the student selections and thus the validity of 'testing' alternate allocations is limited, with the results thus only able to give broad indications of potential changes.

Allocation systems results: student perspective

The performance metrics of the allocation systems that were considered related to the student perspective of satisfaction were the percentage of students receiving a first-choice topic, the percentage of students receiving a top-three choice, the number of students with no topic allocated (and thus needing to participate in a second round of allocations), and the number of top-quartile students with a 'suboptimal' (below third-choice) allocation. The aggregated results for the five years of data are shown in Table 2, with the best and worst value for each metric highlighted green and red respectively. The full results detailed per year and per metric are given in the supplementary report noted previously.

The system using strict academic rank performs worst in terms of the percentage of students receiving their first-choice or a top three topic, although in the latter case it performs similarly to the unique-first-rank allocation system. Unsurprisingly, the optimisation allocations perform best in awarding students one of their top three choices, with the random system only marginally better than that where marks are considered (difference of 4 students in absolute terms). However, the indiscriminate nature of the random optimisation results in this system having the most top-quartile students with suboptimal allocations.

The status quo system (unique first rank) performs well at awarding a first-choice topic (same as optimisations), as well as ensuring that top quartile students are highly likely to be awarded a top three choice. Optimisation offers improvements in a top three allocation to all students, and if marks are included in this process, this can be done with minimal additional risk of top students receiving low selections as well as an improvement in the number of students receiving topics in the first round of allocations.

Table 2: *Performance metrics of alternate allocation procedures from the student perspective (2021–2025)*

Allocation system	First choice topic awarded (%)	Top 3 choice topic awarded (%)	No topic awarded in first round	Top quartile students with suboptimal allocation
Unique first rank	58	76	18 (6%)	5 (2%)
Strict academic rank	47	74	9 (3%)	1 (0%)
MC optimisation (random)	58	83	14 (5%)	13 (4%)
MC optimisation (with marks)	58	82	9 (3%)	6 (2%)

Allocation systems results: staff perspective

A key consideration in topic allocations from the staff perspective relates to the perceived ability of the student to work independently and perform well in the project. Prior academic performance is usually used as a proxy for this, which is why this features prominently in most existing allocation systems used. There is a prevailing perception that 'high demand' supervisors get 'better' quality students and thus get better research done and/or are required to spend less effort to supervise the students.

The first aspect of the review looked at historical performance data for 2021 to 2024 for students who had completed the research project (238 students). This was interrogated to explore correlations of prior academic performance and project allocation to final project mark, as well as relationships between supervisor 'demand' and final project mark. These showed only a weak correlation between prior academic performance and final project mark (Pearson correlation of 34%), and somewhat surprisingly no correlation (13%) between a student receiving a higher preference topic and their ultimate performance in the project. When looking at supervisor demand, defined as the number of students selecting a particular supervisor divided by the number of topics offered by that supervisor, and student performance, the results showed a Pearson's correlation of 48% to prior academic performance. This highlights that the high-demand lecturers had only a moderate correlation with being allocated well-performing students. Interestingly, there was a stronger correlation between supervisor demand and final mark (57%), making this a stronger influence on student final mark than the student's own prior academic performance. This may be an indication that certain supervisors were awarding higher marks which might in turn have been influencing demand if students were aware of these tendencies, although causality cannot be demonstrated in these results.

The second aspect of allocations considered from the staff perspective was the perception of fairness and the idea of balancing the relative number of academically strong and weak students assigned to each supervisor. Thus, the range of average marks and extent to which an allocation system was able to achieve 'equal' averages of students could be seen as an important performance metric in allocations. To test this, the average mark of the students assigned to each supervisor was determined for the four allocation systems and student cohort (296 students) described previously. The overall cohort average was subtracted to give a *relative* indication of each supervisor's average. The aggregated results of the distribution of averages for the supervisors considered in the 2021 to 2025 allocations are shown in Figure 5. The systematic rank-based allocations resulted in the widest spread of averages with more staff receiving clearly separate groups of 'stronger' and 'weaker' students of up to ±10% deviation from the overall student average. This effect was more marked in the strict academic rank allocation than the unique-first-rank system. The optimisation procedures significantly reduced the spread with a range of only ±6% from the overall student average. Similar overall performance is noted whether marks are included or not. This shows that whilst the optimisations have been set up to maximise the student satisfaction metrics, these can simultaneously result in a better outcome from the staff perspective too.

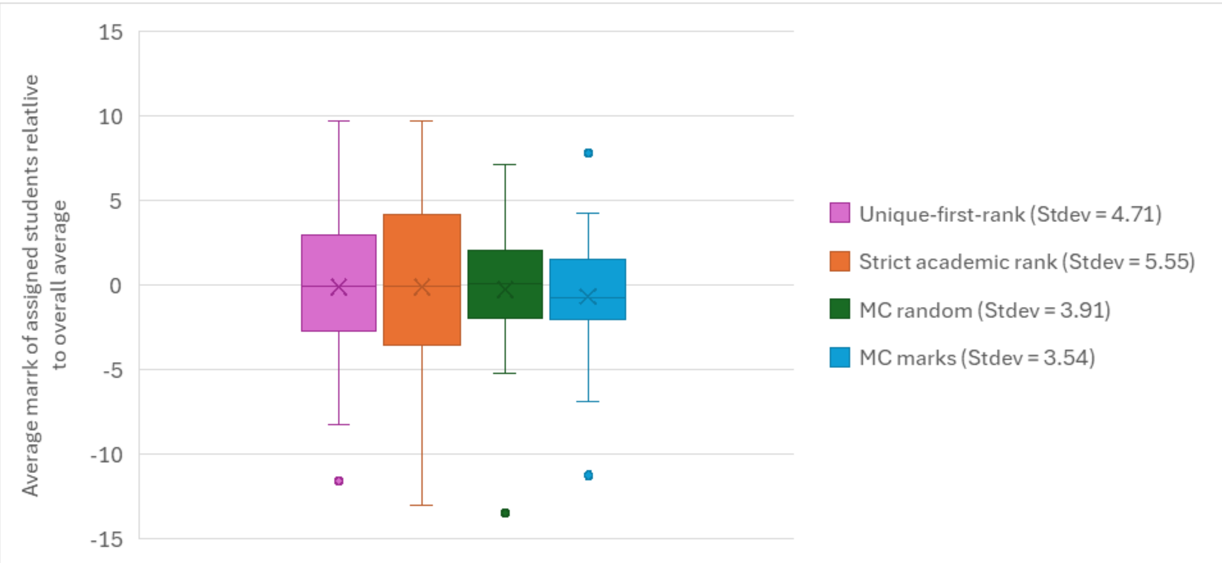

Figure 5: *Distribution of relative average of the students assigned to each supervisor for each of the four allocation systems (aggregated results for 2021–2025 shown)*

Discussion

The aim of the study was to gain insight into the influencing factors motivating student capstone project topic selections. As noted, more understanding around this would assist academic staff in providing projects that engaged students and created an effective experience through which students would be able to demonstrate their proficiencies and preparedness for independent work at the level required for a successful graduate. The study also aimed to explore alternate allocation strategies and compare impact from the student and staff perspectives. Understanding the importance of the project topic to students would encourage the creation of allocation strategies that would ensure that the maximum number of students could work on topics of higher-order preference without compromising staff expectations. If students are unmotivated and uninterested in the topic, this could detrimentally impact their ability to meaningfully engage in the opportunity to showcase their acquired competencies. Conversely, 'A successful capstone project energizes all the participants' (Brackin et al., 2011, p1172).

The identified motivations were viewed through the lens of the cognitive-affective-systemic (psychomotor) domains from the holistic model of education, learning and student support. The results showed that the affective realm was dominant, with personal interest, excitement, and relationship to 'enjoyment' of prior academic experience coming to the fore. This aligns with observations from Parker (2017), who noted that the affective response is a key contributor to 'engagement and professional identity formation during the university-to-work transition' (p. 41) during the capstone project experience, and highlighted the emotional investment that students make in a project. The importance of affective aspects of project definition are also highlighted in that successful projects are 'viewed as worthwhile' (Cheville, 2010, p. 3) and 'have a "cool" factor' (Brackin et al., 2011, p. 1165) and supported by Christensen & Rundus (2003) where a link is made between better performance and more authentic topics.

The affective experience was supported by a cognitive element, particularly in relation to prior academic performance (a student might 'enjoy' a subject or topic because they did well in it). Systemic considerations had the lowest overall priority, however, which was largely due to preferences either in favour of or against specific skills-related aspects such as laboratory work. Some students specifically sought out these topics for the skills they would provide or based on aptitude for practical work (for example), whereas others did the opposite. This highlights the importance of ensuring that there are a range of topics that cater to various preferences and abilities. The literature noted that projects linked to industry, employment opportunities or fields of specialisation – all systemic factors – ranked highly in student interest (Hart & Polk, 2017; Ward, 2013; Latorre & Meier, 2023). By contrast, in the current exploration, these did not feature prominently in either the ranking of influence factors or open-ended discussion detailing motivation for topic selections.

In reviewing a wider cohort, prior academic performance showed only moderate correlation to final project performance over a period of four years. This is an important consideration given the emphasis placed on this when considering student aptitude for specific topics, and the use of prior academic performance in topic allocations. Interestingly, the preference of the topic that the student is awarded showed no correlation to performance, i.e., students with a first-choice topic were no more likely to perform better than those with a tenth-choice topic. This lack of correlation does not, however, indicate that the project topic is *not* important, as performance is largely cognitive (related to the student's academic ability) and systemic (related to assessment procedures), whereas much of the experience of the capstone project is affective.

One aspect of the allocation system which was shown to be a key constraint on students when making their topic selections was the practice of using prior academic performance in a way that systematically awards higher performers topics higher on their selection list. There are advocates for and against this practice: proponents argue that the capstone project is the only chance students get to choose what they want to do based on their own merits, and top students may be rewarded for their previous hard work by being able to pick a topic (or at least having a high likelihood of receiving their top preferences). On the contrary, a particular concern noted with this system is that it tends to fail the weaker students as they are likely to be undertaking a topic that may be at the bottom of their list (or they are second rounded) with a young lecturer with limited experience in supporting student projects. From a practical perspective, in the specific context studied, lower ranked students may be more likely to discontinue with the project after the initial allocations are completed once the first semester results are finalised. This may incentivise ensuring that higher ranked students have some priority in the allocation of topics, particularly where these are in high demand.

The results of the allocation system testing showed that the systematic academic rank-based procedures performed poorly both from the student perspective (i.e., the percentage of students awarded a first-choice or top three choice topic), and from the staff perspective (i.e., creating a balance between the academic abilities of students assigned to each staff member). The optimisation algorithms performed best in terms of the number of students awarded top-choice preferences, and in creating a more even balance between staff by reducing the range and variability of the average assigned mark. The outcome of such optimisation will depend on the weight assigned to various factors and the selected optimisation criteria. The sense of a lack of transparency in the use of optimisations was noted by staff in suggestions to use such a system; if it can be demonstrated that both student and staff metrics are improved, and if there is clarity on the criteria used to select the optimum allocation, this should alleviate these concerns. The performance of the optimisations with and without marks were on par; thus, if transitioning from a systematic, rule-based allocation explicitly based on marks, use of the optimisation together with marks might be a more palatable option that still gives some credit to top academic performers. However, given the lack of clear correlation between prior academic performance and project performance, the idea of using prior academic achievement in allocations should be more loosely treated to allow more students the advantage of the option to complete a project that they have expressed a strong interest in.

Concluding remarks

The capstone project represents a large investment of time and energy for students and for staff acting as supervisors and coordinators of these projects; these should thus be structured to add as much value as possible to all affected parties. For students, this may mean working on a highly preferred topic, whereas for supervisors, this may mean working with highly motivated and capable students.

Students are most interested in topics which show practical relevance to industry and a relationship to current social and cultural issues. This creates a sense of excitement and engagement, increasing the value of the project to the students and giving them the best possible opportunities to showcase their competencies as professional graduates. The ability to envision both the required methodology to complete the project and the intended outcome of the project were indicated as key influencing factors. This highlights the importance of self-efficacy and the preparatory experiences, both academically and from vacation work, that influence a student's perception of their own skills and grasp of academic (cognitive) concepts.

Allocations of topics to students should give more credence to the subjective student viewpoint, particularly as the affective component of holistic education is dominant in the capstone project experience. Current procedures tend to focus on rewarding high achievers (cognitive focus) which transfers into strong systemic allocation. Placing more emphasis on being able to award more students a higher-preference topic should take precedence over rewarding prior academic performance, especially if correlation of prior academic performance is weak, and given the probable disadvantage to 'weaker' students of using such. Ultimately, there is no 'best' way to conduct allocations, and this will depend on a balance of perspectives and what importance is assigned to various aspects of the staff and student perspective.

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Exploring the applicability of Tronto's ethics of care in first-year engineering education

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In this paper, we examine the different ways in which instructors implement and promote care in their teaching in a first-year engineering course. Using a case study informed by Tronto's ethics of care framework, this paper identified innovative actions and behaviours that instructors have used in their classrooms. Through in-depth interviews and class observations, we identified behaviours fitting each of Tronto's four ethical elements (Tronto, 1993), including being attentive to students, taking responsibility for meeting their needs, being competent, and understanding how students are responding to their teaching, by being responsive. For example, being available and in close proximity to the students by walking around the classroom and actively checking how students were responding, are examples of strategies satisfying the attentiveness element. The responsiveness element had the greatest number of distinct strategies identified. Based on student evaluation data, we were able to show the ways in which students valued these behaviours. This innovative study outlines a comprehensive list of specific teaching behaviours and techniques that educators who want to improve their teaching practices and student outcomes can use to successfully implement care in the classroom.

Keywords: ethics of care; case study; engineering education; first-year

Introduction

Students in engineering courses face an array of challenges. Khalaf et al. (2013) argue that the lack of real-world engineering problems in the first two years causes a number of problems, including low student retention in engineering programmes (see also Veenstra et al., 2009). This delay in making explicit connections to engineering can be addressed by using problem-based learning in first-year courses (Nielsen, 2020). A prevalent problem among first-year students, particularly in the engineering field, is a lack of a sense of community, which on the individual level can be viewed as a low sense of belonging. Scholars point to the broader culture of engineering education as exclusionary (Pearson et al., 2018).

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Looking at the broader higher education literature, there is a group of researchers suggesting that the central issue in teaching, generally, is a lack of care (Thayer-Bacon & Bacon, 1996; Barrow, 2015). According to Barrow (2015), caring teaching behaviours inspire students to meet and surpass instructors' expectations, create positive changes, and challenge the norms and boundaries imposed in the classroom. Another engineering education study, Hong & Shull (2010), explored the impact of professor attitudes on undergraduate engineering students. When asked about their worries and difficulties with the major, the students mentioned how upsetting they found it that the instructors did not even bother to find out which classes they had to take (Hong & Shull, 2010). When asked what they thought had positively impacted their learning in their engineering course, students mentioned they felt more connected with their instructors when they interacted with them outside of class and showed genuine concern for their success. Because of this connection, students had a more favourable image of professors and found them to be more approachable and easier to connect with. This, in turn, had a positive impact on their learning.

While this general literature tends to focus on individual instructors, we argue that the broader cultural landscape and how this impacts the classroom calls for a theorisation of care that moves beyond the impulses of an individual instructor. In sourcing a more critical approach to the topic of care, we were drawn to the theorisation of the ethics of care, as put forward by Tronto (1993). Specifically, we looked at work by Bozalek et al. (2014), who used Tronto's theory to evaluate a professional development programme at their institution focused on improving teaching and learning. Taking our direction from Bozalek, we designed a qualitative study looking at the implementation of care in a first-year engineering classroom, grounding our study in Tronto's conceptualisation of care, and exploring how care might be operationalised in lecturers' everyday teaching practices. The study was framed around the following research questions (RQs):

Overarching RQ: How is care understood, enacted, and experienced in teaching in a first-year general engineering programme at Virginia Tech?

Sub-RQ1: What were the instructor's intentions with regard to implementing care in the classroom?

Sub-RQ2: How did the instructors enact care in the classroom?

Sub-RQ3: What do students describe to be helpful for their learning as related to their perceptions of the instructors' enacted behaviours in the classroom?

Theoretical framework

The concept of the 'ethics of care' first appeared in a highly cited paper by Tronto in the 1980s, which had talked about how future feminist moral thinking must be broader and more theoretical, and despite the biological disparities between men and women, an ethic of compassion transcends these distinctions (Tronto, 1987). Since then, Tronto has gone on to emphasise the need for care and robust care policies in institutions (Tronto, 2010), in a paper which examined how to determine whether institutions offered quality care, and argued for the need for 'care institutions'. Other researchers like Noddings and Bozalek have also significantly contributed to literature on care. Noddings, in one of her papers, initiated a basic framework of what care looks like, and attributed traits such as interacting, thinking critically, and responding reflectively in connection with care (Noddings, 2012). Tronto initiated the conversation about care and Noddings brought this conversation into the educational space more specifically and briefly defined what it might look like. From this, Bozalek and colleagues took this conceptualisation into the context of higher education by using a political ethics of care as a normative framework to evaluate a model of teaching and learning in professional development. In this paper, they identified the five elements of care as attentiveness, responsibility, competence, responsiveness and trust (Bozalek et al., 2014).

According to Tronto, showing care implies that one is there for something or someone else. Apart from self-care, care is normally neither self-referring nor self-absorbing when it is given (Tronto, 1993). The breadth and normative orientation of Tronto's notion of care can be seen in this definition:

> … a species activity that includes everything that we do to maintain, continue, and repair our 'world' so that we can live in it as well as possible. That world includes our bodies, ourselves, and our environment, all of which we seek to interweave in a complex, life-sustaining web (Tronto, 1993)

Tronto's framework identified four phases of caring: caring about, taking care of, care-giving, and care-receiving. The *caring about* phase includes identifying a need and deciding whether or not it has to be satisfied to first acknowledge the need for care. To effectively complete this step, one must comprehend the need by placing oneself in the shoes of another person or group (Tronto, 1993). The *taking care of* phase involves acknowledgment of the need and subsequent decision-making toward its resolution. This stage is realising that action can be performed to address these unmet needs rather than solely concentrating on what the specific needs are and not doing anything to address this. For *care-giving* to take place, this typically entails physical labour and almost always involves interaction between the caregivers and the people receiving care. The *care-receiving* phase recognises that a person in need of care will eventually respond to the care being provided to them. This is important to consider since this is the only way we can understand whether the caring needs have been met or not.

As a result of these four phases of caring, Tronto developed her four ethical elements of care. These include attentiveness, responsibility, competence, and responsiveness, which are discussed here in turn.

Attentiveness

Attentiveness indicates that we cannot possibly meet others' needs if we are not aware of these (Tronto, 1993). At its most basic level, caring entails recognising a need and meeting that need, which is why the first moral need for caring is to simply pay attention. The philosopher Simone Weil also emphasised that meaningful human contact requires the ability to pay attention (Tronto, 1993).

Responsibility

Tronto states that responsibility is central in an ethic of care, but it can also be problematic if viewed from a standpoint of political theory (Tronto, 1993). When looking at it through the lens of political theory, responsibilities are usually defined as the need to follow rules and regulations that are established by commitments we have made. Tronto emphasises that instead of continuing to utilise obligation (rather than legal provisions) as the foundation for understanding what individuals should do for one another, we would be better off focusing on a more open-ended view of responsibility (Tronto, 1993).

Competence

This element of care concerns whether the need for the care has been met or not. When proper care is not provided despite good intentions and even acceptance of responsibility, the need for the care is ultimately unmet. Competence is a crucial element to include as a moral dimension of care because of the bad faith displayed by individuals who would 'take care of' an issue without being willing to provide any type of care. Competence makes it possible to have the confidence that the care work is being done in an effective manner (Tronto, 1993).

Responsiveness

The last element of Tronto's ethic of care framework is responsiveness, relating to the receptivity of the recipient of care to the care being given (Tronto, 1993). This is also related to the competence element where, even though someone's care needs are being attended to and the intention of the care being provided is good, it is not necessary that this care will be well received by the care-receiver. Since the care-receiver's needs are ultimately the highest priority, we must understand how they are responding to the care and, if it is not well received, then the approach needs to be altered.

It should be noted here that Tronto later extended her four initial elements of care to include a fifth 'caring with' category which described the importance of the distribution of care and the need for all to care together (Tronto, 2013). For this study, however, we will only be using Tronto's four ethical elements of care from her earlier formulations.

When considering how an ethics of care might apply to engineering education, there seems to be a natural link to the significant literature that has emerged on the need to develop empathetic engineers (Walther et al., 2018). Furthermore, along with empathy being identified as a key factor in engineers' overall career success (Hecker, 1997), it is also associated with discussions regarding students' ability to consider the perspectives of other stakeholders and to incorporate these insights into the design and the decision-making process (Walther et al., 2018). In the context of engineering, empathy has been portrayed by scholars as being a fundamental element of ethical reasoning, since students require this attribute in order for their designs to satisfy customers' needs (Hess & Fila, 2016). Much of the empathy literature is mentioned in accordance with ethics and, in a way, empathy and care are interconnected in terms of both being qualities that humans need for the betterment of some external party.

This however is quite different from this study as much of the literature on empathy and ethics deals with student characteristics, mentioning how they are important characteristics that students need to have when they eventually become professional engineers. In this study, however, we look at how care is used and implemented in teaching specifically. As opposed to focusing on students exhibiting these characteristics, the emphasis is placed on the teacher to understand how care can be enacted in teaching in the classroom.

Research design

For this research, a qualitative case study was chosen since we wanted to explore in detail how care is understood, enacted, and experienced in the classroom. To do so, this study was conducted at Virginia Tech in the USA, a research-intensive university with a large engineering programme, taking in more than 2 500 first-year students annually, split into sections of 72 students per class. For this study, we focused specifically on the second course in the first-year general engineering programme's two-course sequence. This course serves as an introduction to the field by emphasising topics like data collection and analysis, mathematical modelling, engineering problem-solving, design, contemporary software tools, and professional standards and expectations (Virginia Tech, 2022). Moreover, instructors were chosen as participants who had taught this course at least twice in the past, as well as having obtained teaching-related awards. This yielded three instructors – and the sections they taught – as the focus of this study. These characteristics were chosen since we wanted to create a scenario where we were most likely to see care being implemented in the classroom.

For data collection, the three instructors underwent two semi-structured interviews, their classes were observed, and students completed evaluations.

The interviews were conducted to better understand the instructor's intentions with implementing care, hence answering the first sub-research question. The first interview was to gain a deeper understanding of the instructors' perspectives on care and its implementation, as well as their background, general opinions, and perceptions of care, and why they believed it might be important. The purpose of the second interview was to understand how instructors specifically considered and implemented care in accordance with Tronto's framework on the ethics of care, and hence the fundamental concepts used to design these interview questions came from Tronto's four phases of caring.

Three in-class observations were carried out to understand how instructors enact care in the classroom, hence answering the second sub-research question. These observations were spaced apart during the semester since each class is roughly divided into three portions throughout the course of the semester. Tronto's four ethical principles served as the foundation for the creation of an observation protocol. Following the initial observations of each instructor, the observational framework was adjusted in light of the findings. Since it was anticipated that this observational framework would improve with each observation, a few minor adjustments were made each time an observation was made.

The final data collected were student evaluations conducted every semester at this institution. These were used to answer the third sub-research question. One of the questions asked in this survey was, ‘What did the instructor do that most helped your learning?’ Responses to this question provided rich data on students’ experiences.

With regard to analysis, both interviews were conducted and recorded through Zoom. This meant that transcripts could be generated at the conclusion of both interviews along with the timestamps. To understand the main themes, descriptive coding and pattern coding were carried out. Descriptive coding involves assigning a word or a short phrase to summarise the basic topic of a segment of data (Saldana, 2014). Finding themes that were shared by the descriptive codes in the first cycle coding was essential in order to connect these themes to the various components of Tronto’s theoretical framework. To carry out this process, pattern coding was carried out for the second cycle of coding in order to search for the common themes and patterns from the first-cycle codes, and these were matched against Tronto’s ethic of care framework (Miles et al., 1994).

When analysing the in-class observations, each of these behaviours was compared with the initial observational framework for each instructor. Any new actions seen by instructors were added, and the observational framework was updated.

When analysing students’ evaluation comments, tactics used by their teachers that students frequently identified were noted. Since the comments were open-ended, many students provided extensive responses, indicating that they had given careful thought to their observations, and their opinions were important to take into account. Therefore, these remarks were also considered in this analysis.

Findings

This section answers the research questions by presenting the different *intentions* and *approaches* participants used in *implementing* (Sub-RQ1) and *enacting* (Sub-RQ2) care that were mentioned in participant interviews, seen through classroom observations, and *described by students* (Sub-RQ3) under each of the four ethical elements from Tronto’s care framework. Table 1 presents the strategies identified in the findings, which are discussed in more detail in this section.

Table 1: *Summary of instructor strategies for each of Tronto's ethics of care elements*

Ethical Element	**Strategy**
Attentiveness	Signalling availability and building proximity
	Carrying out check-ins
Responsibility	Student relevance
	Making students do the work
	Promoting verbal interactions
	Flexibility
	Clear communication
	Implementing student feedback
	Providing a well-organised and planned system of learning
Competence	Assessing students
Responsiveness	Soliciting student feedback

Attentiveness

Regarding this element, the instructors' *availability and closeness to the students*, as well as their propensity *to check on the group's progress*, were found to be the two key techniques they mentioned in their interviews. To be available and in close proximity to the students, instructors mentioned how they placed a high priority in *moving around the classroom to observe students' needs*. In relation to checking on the group work, instructors depicted how they found it necessary to *approach each student group and spend time with each one to ask them questions* and gain an understanding of how each individual student group was progressing in relation to their project.

From the in-class observations, to signal their availability and build proximity, instructors were observed walking around the classroom while students were working. Two of the instructors were observed going directly to the students and checking on them to see how they were doing, while one instructor preferred to be more passive and walked around the classroom close to the students' desks. This action made students feel more comfortable in asking questions since the instructor was nearby and students did not have to call out for help if required. To specifically emphasise their availability, all the instructors were observed verbally telling the students that if they had any questions or concerns, they were able to simply put up their hands and either the instructor or one of the teaching assistants would attend to them.

With the aim of soliciting student feedback, instructors were observed going up to each individual student group and briefly asking them questions and checking on their progress. One instructor had also taken a pen and paper and spent five minutes with each group to take notes on tracking each team's progress. Another approach instructors used was to ask students at the start of the class how things were going. This resulted in students feeling more at ease in discussing their degree programme, other classes, and when they had further exams and assignments due. One instructor had also added a question slide in his Google Slides and made this available to all students. This created an opportunity for students to ask him any questions about the class, or anything generally. The purpose behind this was to get students who were more hesitant in opening up in person in the classroom to raise their voices.

The analysis of the student evaluation comments found that students mentioned that their instructors were 'very attentive and helpful' since instructors would always 'walk around during the class and so this made it easy to ask questions'. Students also described instructors to be 'very accessible and close by' if they needed anything. Along with this, students also described how they found the instructors very approachable and stated that they 'felt very human and approachable and always told us to come up to them if we had any questions'. The availability of instructors was seen as helpful since 'either the instructor or the teaching assistant was always available to answer questions', and the instructors would 'always give us the option to go to their office hours'. On top of this, students appreciated the instructors regularly checking in on them too. They stated in their evaluation surveys that instructors 'always set up times to meet with us as a team to make sure we were on track'. This was described as useful since students mentioned that if instructors had not gone around individually asking each student team questions 'we would have not asked some of the questions if we had to direct them towards the whole class, rather than to the instructor personally'.

Responsibility

Regarding responsibility, the teachers suggested the following strategies in their interviews: student relevance, making students do the work, student engagement, flexibility, clear communication, implementing student feedback, and providing a planned and well-organised system of learning.

Some of the methods instructors mentioned they liked to employ included providing culturally/technologically relevant courses, putting oneself in the students' perspective, building on prior knowledge, focusing on prior struggles, and using inclusive examples. Instructors also emphasised the importance of allowing students to figure out things on their own and make them do the work. To achieve this, instructors stated they liked to give students the freedom to explore as well as allowing them to learn from their own mistakes and guiding them in this process as opposed to directly giving them the answers.

Having clear communication was another strategy – instructors mentioned in their interviews that they aimed to consciously give clear and concise instructions. This included sending out regular announcements and updates but also included giving better instructions for assignments. They also highlighted the significance of explaining how whatever material they taught was related to the learning outcomes of the course to aid students in making this connection. Regarding the implementation of student feedback, instructors stated how they did this by employing the use of a common themes slide, ensuring that they responded to the classroom generally and not specifically to individual students as well, as by filtering useful and non-useful feedback. The final strategy mentioned under this element was to provide a well-organised and planned system of learning, and to achieve this, instructors spoke about the need to have an organised system of learning in the classroom.

In relation to making students do the work, one instructor was clearly seen to make students take ownership of their own learning and actively participate in their work. To do this, the instructor would ask questions to the class regarding a certain topic and would divide them into smaller groups, followed by full class discussion. The instructor would encourage students to find the answers and would simply fill in any gaps that they had about the concepts, as opposed to telling them the answers.

To promote verbal interactions in the classroom, some of the instructors were observed to start the class by asking the students, 'Tell me something I don't know'. Many of the students raised their hands quickly, showing that they were interested and excited to share the facts they had prepared. One of the instructors was observed to take the first five to seven minutes of class to just generally converse with the entire class about how their lives were going.

Instructors also described the importance of flexibility, and this was seen in the classroom when one of the instructors allowed a student to submit their assignment late. This instructor also cancelled one class session to allow student groups extra time to work together on their project. While the other instructors were not observed to give any extensions to students, they were observed to regularly tell students that if they did need an extension, they were able to ask for this.

In relation to clear communication, it was seen that at the commencement of the class, all the instructors did well in making any necessary announcements and outlining the main points of the lesson. The instructors typically took five to ten minutes to explain to the class where they were in the course, where they were headed, what assignments and deadlines were coming up, and what they would be doing in class during that time. One instructor went into great depth to provide directions for a particular assignment. They were observed taking 10 to 15 minutes during this class period to look over all the tasks that would be due in the upcoming four weeks.

Instructors were also observed to respond to the feedback they had received from students generally and made sure to not do so specifically with regard to each student. One instructor was observed summarising their feedback to students where the instructor had posted a question that most students would have asked initially and then addressed this problem by including the solution on the slideshow and holding a discussion with the class about it.

In the analysis of the student evaluation comments, it was shown that students believed instructors put in effort to make the courses relevant to the students. They described how instructors had 'always used examples we could easily relate to and presented the assignments and lessons in a way that all students could understand'. This shows how instructors prioritised the inclusive nature of their classroom. Students also mentioned how the examples used were always relatable, as one student depicted 'I liked how they used real-world examples that we could understand and relate to before giving us tasks'.

Students also spoke about the extent to which instructors allowed them to take control of their own learning. They described how they felt as though they were able to figure things out on their own, and how the instructor's ability to allow them the freedom to explore things on their own helped in their learning. One of the student comments explained how the instructors 'allowed us a lot of freedom and choice in our learning' and how 'they allowed us to have creative freedom in the class'.

Instructors providing an engaging and interactive classroom environment were also mentioned in many of the students' evaluation comments. Students reported how the class environment felt very comfortable and positive, and as a result, they always felt encouraged to come to class. One student stated that 'the instructor did a good job in creating a welcoming environment, allowing for student interactions and bonds to develop'.

In relation to the flexibility strategy, most of the student comments were about instructors being flexible with office hours as well as assignment due dates and the ability to submit work later. One student mentioned how one instructor was 'flexible and understanding of delays or personal life that could affect grades/due dates which I appreciate'.

Students also mentioned the instructors' ability to always provide clear communication in the classroom. Students mentioned how one of the instructors would regularly explain the purpose behind every task being carried out in the classroom and noted that 'the instructor explained both the practical applications and educational reasoning behind every activity and assignment. Everything we did felt like it had a purpose and was valuable'.

Not many students spoke about the instructors implementing their feedback. In fact, there was only one student who explained how instructors would 'make sure to get our feedback, listen to it and take it into account'.

There were however many student comments in relation to how each instructor was very organised and had a well-planned system of learning in the classroom. Students described how each class had a regular structure to it which made it easy for them to understand what to expect from each class. They explained how 'the structure of each class period was the same throughout the entire semester. This made it easy to lock in and focus on the class because I knew what to expect'. Due to this regular structure, there were no surprises and students said that they 'had no issue in trying to figure out what we had to complete during the week'. Students also explained that an important element of this organised learning was the instructors' ability to provide feedback: 'it was very helpful that they could provide timely and thorough feedback, both on assignments and general questions'.

Competence

The *assessment of students* was the only strategy that came out of the instructor's interviews in relation to the competence element. The approaches instructors discussed to carry out this assessment included the *general assessment of learning outcomes which used assignments and projects to talk to students in and out of the classroom* to ensure students were on track to achieving the learning outcomes of the course, and to also talk to other faculty members so that there was more information available on what the concepts and topics were that students in the programme struggled with.

In the classroom observations, it was seen that all the instructors would regularly go up to students to talk to them and ask questions. However, what exactly these questions were and whether they were informally assessing students' knowledge of the material in the course was undetermined.

The students' evaluation comments talked about how the instructors 'looked out for the well-being of the students and checked if we understood the material or not'. Students felt as though instructors wanted to make sure that students understood the content being covered in the class and that they understood everything. One student explained this by saying 'they kept asking us questions to ensure we understood the content, and if we didn't know, they would go over it again so we could do well and succeed in the class'. The idea of instructors ensuring that students understood the material was reinforced by another student's comment: 'they were always coming around to ask us if we had any help, any questions and whether we understood what was going on'.

Responsiveness

Since this element revolved around instructors understanding how students were responding to the care being provided, one strategy instructors mentioned in their interview was to *actively solicit feedback from the students*. To carry this out, instructors talked about how they *used in-class reflections, exit surveys, mid-term evaluations, conversing with students* as well as *peer evaluation* and *student evaluation responses*.

In the classroom, like the competence element, instructors asked the students questions. This could be in relation to how students felt the instructing team was doing as a form of obtaining feedback from them. Since the specific conversations were not heard, the content of these questions could not be determined. The only other strategy the instructors used to obtain feedback from students was exit surveys. Instructors were observed to ask their students a series of questions about their experiences with the activity they completed in class, the things they found difficult, and what they would like to see more of in the future. Instructors then gave students this survey as a miscellaneous assignment to complete and submit before the next class meeting to successfully obtain this feedback.

Students mentioned in their evaluation comments how instructors did a combination of conversing generally with students in the class and carried out class reflections to obtain students' feedback. One depicted that the instructor 'was always very open to feedback as they always like to hear from us, which I liked a lot since it makes us all more engaged'. Students also mentioned how they appreciated the fact that they felt that their opinions were heard: 'they would always ask us how the class was going and wanted our feedback on it and would take our ideas into account'. Another student went on to describe how even though they found the process of giving feedback annoying, they respected the fact that their voice was heard: 'the reflections, while annoying, were helpful to help the instructor understand how the class could be better'.

Discussion

This section presents a discussion of the main strategies from the instructor's interviews in relation to how they intended to implement care in the classroom and the relevant literature on the topic.

Attentiveness

The instructors mentioned two main strategies they used to satisfy the attentiveness element: availability and proximity, and student check-ins. To be available and emphasise instructor availability to the students, instructors mentioned they liked to walk around the classroom to be close to the students. The latter was mentioned as useful since students were more inclined to ask questions as a result, and they also felt less hesitant to reach out to the instructor. Interestingly, Dyer et al. (2018) also describe the benefits of close instructor proximity to the students but for a different reason. They depict how students are more likely to be off task and pay less attention if a teacher is further away, and that the inverse also holds true (Dyer et al., 2018). In this sense, the findings of this study did not directly connect with what literature currently says on proximity since the instructors who mentioned and were seen doing this were doing so for the express purpose of making students feel comfortable asking questions.

The instructors also talked about how they believe emphasising their availability and walking around the classroom was effective in making sure they could be aware and recognise if students had questions or certain needs. The importance of walking around the classroom and emphasising availability was also emphasised in a study by Cole (1999). She described how going around the classroom to check up on students or teams of students for roughly half a minute could be useful to better understand whether students might have questions and were on task or not. She emphasised that the main purpose of this strategy was to obtain an immediate assessment of the students' work by talking to them (Cole, 1999). This study presents the act of walking around the classroom and talking to students as a way of informally assessing the students. In our study, however, the instructors mentioned that the benefit of walking around the classroom specifically satisfied the attentiveness element, while talking to students to ask them if everything was making sense satisfied the competence element, and the two approaches can be viewed separately. This disaggregation is due to our use of Tronto's framework and the definitions of each element.

The effectiveness of student check-ins in order to be aware of the different student needs was another strategy instructors mentioned that satisfies the attentiveness element. To carry out student check-ins, some approaches instructors mentioned involved carrying out team check-ins as well as putting up slides of prompts to encourage students to ask any questions they might have. The benefit of carrying out team check-ins was further emphasised by Cole (1999), who discussed how sitting down with a group for a longer period of time and interacting with them and watching them work was a lot more beneficial in understanding what issues students might have, and what they might need from the instructor. An approach one of the instructors mentioned was to carry out check-in questions with students for the purpose of understanding how they were doing in the semester and to also better understand their needs (see Saphier et al., 1997).

Responsibility

As mentioned previously, the responsibility element saw the greatest number of approaches being mentioned by the instructors, and these approaches were divided into seven main strategies. The first strategy was about making the material being taught in the classroom relevant to students. Instructors spoke about the importance of making sure all the material being presented in class was relevant to students and that more inclusive examples and learning styles were to be used. The significance of this is also represented in literature about culturally relevant teaching, indicating how it will help embed students' background and culture into the course curriculum, and will hence help negate any of the adverse effects of the more dominant culture (Leonard & Guha, 2002). The instructors in our study also spoke about approaches suiting what some of them termed different students' learning styles. Leonard & Guha (2002) describe similar points when explaining how a part of conducting student-relevant teaching is to ensure instructors remain aware of and cater to students' unique ways of knowing, behaving and communicating.

There were also many approaches the instructors mentioned that centred around the idea that students should be made to 'do the work'. This includes approaches such as making them take control of their own learning, learning from their mistakes, and generally imparting lifelong learning. Literature also aligns with the instructors' thinking as it has been shown that independent learning is beneficial for students as this increases their general motivation and confidence, improves their academic performance, allowing them to better be aware of what their own limitations are, and to understand how to better manage this (Meyer et al., 2008).

Some research, however, does mention that despite the benefits of allowing students to take control of their own learning to a certain extent, what learners prefer may not necessarily always be what is best for them (Kirschner, 2013). This was a difference between the findings of our study and the literature, since this point was not clearly emphasised by the instructors at any point. Instructors mentioned their priority of making students manage their own learning process and this is a form of self-directed learning, a process by which learners are in control of and manage their learning process, which has been shown to positively correlate with lifelong learning (Boyer et al., 2014).

Other strategies mentioned in relation to this element included promoting verbal interactions between students and engaging them to be flexible, as well as communicating clearly. Promoting verbal interactions between students and allowing them to form peer relationships has been shown to engage learners (Leach & Zepke, 2011). Research has also shown that allowing students to have verbal interactions that lead to their engagement in a range of different educational activities provides them with a higher quality of learning (Coates, 2005).What is not emphasised in literature is not merely interactions between students and the instructors, but also promoting interactions between students and their peers, which was made explicit in the findings of this study. The instructors in the study also spoke about the importance of being flexible in their teaching practices and having flexible policies for students. There is some research that talks about flexible teaching, and this has been linked with what is termed 'open learning'. Open learning, similar to what instructors in our study have mentioned, refers to having flexible policies in the classroom as well as through online measures, which means that students have increased access and choices in their learning (Lundin, 1999). These flexible policies for university students specifically have been researched to mimic the work patterns and professional needs of adult learners (Lundin, 1999).

Clear communication was another strategy instructors talked about in relation to responsibility. They specifically explained the importance of communicating assignments, announcements, and updates as well as the relation of all the in-class activities to the learning outcomes of the course with students. Clearly communicating expectations around assignments, for example, helps students manage the time they spend on important educational tasks (Hunt, 2003). Literature, also shows that the lack of clear communication decreases students' motivation to do well (Hunt, 2003). Along with communicating expectations, to clearly communicate and explain how the class activities are related to the learning outcomes of the course, was also stressed by the instructors. Currently, literature supports the idea of not only having well-defined goals and learning outcomes, but also making sure these are clearly expressed to the students. Redelius et al. (2015) explain how when the learning outcomes of the course are both well-defined and expressed to the students, the clarity of this practice motivates students to talk about what they are learning and to make better sense of it.

With regard to student feedback, the instructors spoke specifically about the implementation of this feedback; not just simply taking or giving feedback. The instructors in our study mentioned they liked to address this via a 'common themes slide', and to make sure the feedback was implemented in a timely manner. Leckey & Neill (2001) indicate that there are many instructors who do not view student feedback as being very valuable and are sceptical of the process. One of the reasons for this is that students are not assessors and, in spite of the fact that the lecturer has much more experience than them, if the students' opinions goes against the lecturer, the students' responses can usually not be challenged (Leckey & Neill, 2001). Literature has shown this to be troublesome since there are many benefits to implementing student feedback that include increased student self-esteem, motivation and personal satisfaction (Clynes & Raftery, 2008). Additionally, multiple studies show that students, for the most part, are willing and appreciate the opportunity to participate in a process of course revision and evaluation (Brew, 2008; Carless & Boud, 2018).

The final strategy of the responsibility element was instructors providing a well-planned and organised system of learning. One of the approaches employed to do this was to align the in-class activities with the course learning outcomes. There is extensive literature that deals with the importance of instructors providing well-organised and planned systems of learning in their classrooms, since this establishes an effective learning environment and also prevents most conduct problems (Brophy, 1983). Furthermore, Biggs (2001) emphasises the importance of making sure learning activities and assessments are aligned with the intended learning outcomes of the course.

Competence

It was mentioned in the theoretical framework section that it is ultimately important to understand whether the student's caring needs have been met or not. In the context of the classroom, this relates to whether students were achieving the learning outcomes of the course, and hence, one strategy mentioned to satisfy this element was to assess the students. This was through approaches involving assessing the learning outcomes (formal assessments), talking to students generally (informal assessments), as well as seeing if anything stood out in the comments in student evaluations. In order to understand whether students are achieving these learning outcomes, general assessment is a vital tool (Suskie, 2008). The instructors however, along with the literature, mentioned just talking to students as an approach to assess them. Saphier et al. (1997), who was cited earlier in this section, explained that as instructors talk to students in and out of class, they get the chance to ask them any relevant questions about the course which is a good way to assess their understanding.

When it comes to competence generally, literature currently does not explicitly mention many strategies in relation to being a competent instructor. Literature states that to be competent involves actions like ensuring instructors can communicate with a diverse range of learners, and being able to involve and include as many of the class as possible (Hollins, 1993). Where this differs from the findings in our study is in the definition of Tronto's element of competence, as opposed to the general definition of competence. This is because the competence element in Tronto's framework highlights the importance of understanding whether the need for care has been met or not. Most of the actions that literature recommends instructors can do to be generally 'competent' fall under the responsibility element in the framework guiding our study. In other words, these are specific actions that instructors might take to positively influence a situation (in the context of study, this is to effectively implement care in the classroom).

Responsiveness

Responsiveness centres around the idea that instructors need to find a way to understand how students are responding to the care being provided to them. This is different to the responsibility and competence elements since Tronto mentions how it is not enough to take responsibility for providing the care or even to ensure that the care needs are met; it is equally important to understand the students' receptivity to the care being provided. The main strategy mentioned here was obtaining student feedback about the instructor and the course experience. Some approaches mentioned were peer evaluation tools. Other methods such as giving general class reflections, exit surveys, or just talking to students were also discussed. When comparing these approaches to the literature on obtaining student feedback, Richardson (2005) explains how surveys that use formal instruments are typically quite effective. This is because these instruments can document student experiences in a systematic manner and are able to gather information from the entire student population. However, Richardson (2005) also mentions that feedback can be obtained through casual comments in the classroom with the students, and meeting groups of students. This is interesting as it relates to the findings of this study where instructors mentioned how they like to generally talk to students in and out of class.

Conclusion

Engineering education faces significant challenges, particularly regarding first-year students' sense of belonging. Research highlights that the prevailing engineering culture often makes newcomers feel excluded and doubt their place in the field (Pearson et al., 2018). This exclusionary environment is further exacerbated by the attitudes of some instructors. Hong & Shull (2010) found that students frequently feel demotivated when they perceive their professors as indifferent.

However, implementing care in teaching can mitigate these issues by fostering a supportive and motivating learning environment. Our case study explored how three instructors incorporated care into their teaching practices within a first-year general engineering programme. This study utilised Tronto's political ethic of care framework, adapted for educational settings, which includes four key ethical elements: attentiveness, responsibility, competence, and responsiveness.

In terms of attentiveness, instructors should be consistently available and accessible to students, maintaining close contact. Regular 'check-ins' with students or groups ensure their well-being and provide an opportunity for addressing questions or concerns. For the responsibility element, course content must be relevant and engaging for students. Promoting active student participation and verbal interactions within the classroom is essential. Clear communication is crucial, including explaining how assignments relate to learning outcomes. Flexibility and responsiveness to student feedback are essential, along with maintaining an organised learning environment. To fulfil the competence element, regular assessments, both formal and informal, help gauge student progress and address their needs effectively. For responsiveness, instructors should seek and act on student feedback to understand their perspectives on the teaching and the course overall.

The study demonstrated that these strategies are effective in a first-year team-based engineering course with about 72 students. It can be seen from the findings however that these strategies are general and can be employed in any teaching context, and not only in a first-year team-based engineering course. Furthermore, while this study was conducted in the US, the approaches seem more widely relevant. While some adjustments might be necessary for different class sizes or more theoretical courses, the core principle of caring for students remains applicable and beneficial. It is notable that it is Global South scholars such as Vivienne Bozalek led the way in bringing Tronto's work into the tertiary classroom.

In conclusion, incorporating care into teaching practices creates a positive atmosphere conducive to learning. This approach fosters student motivation and engagement, addressing the sense of exclusion often experienced in engineering education. By implementing the outlined strategies, instructors can significantly improve the educational experience and outcomes for their students.

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