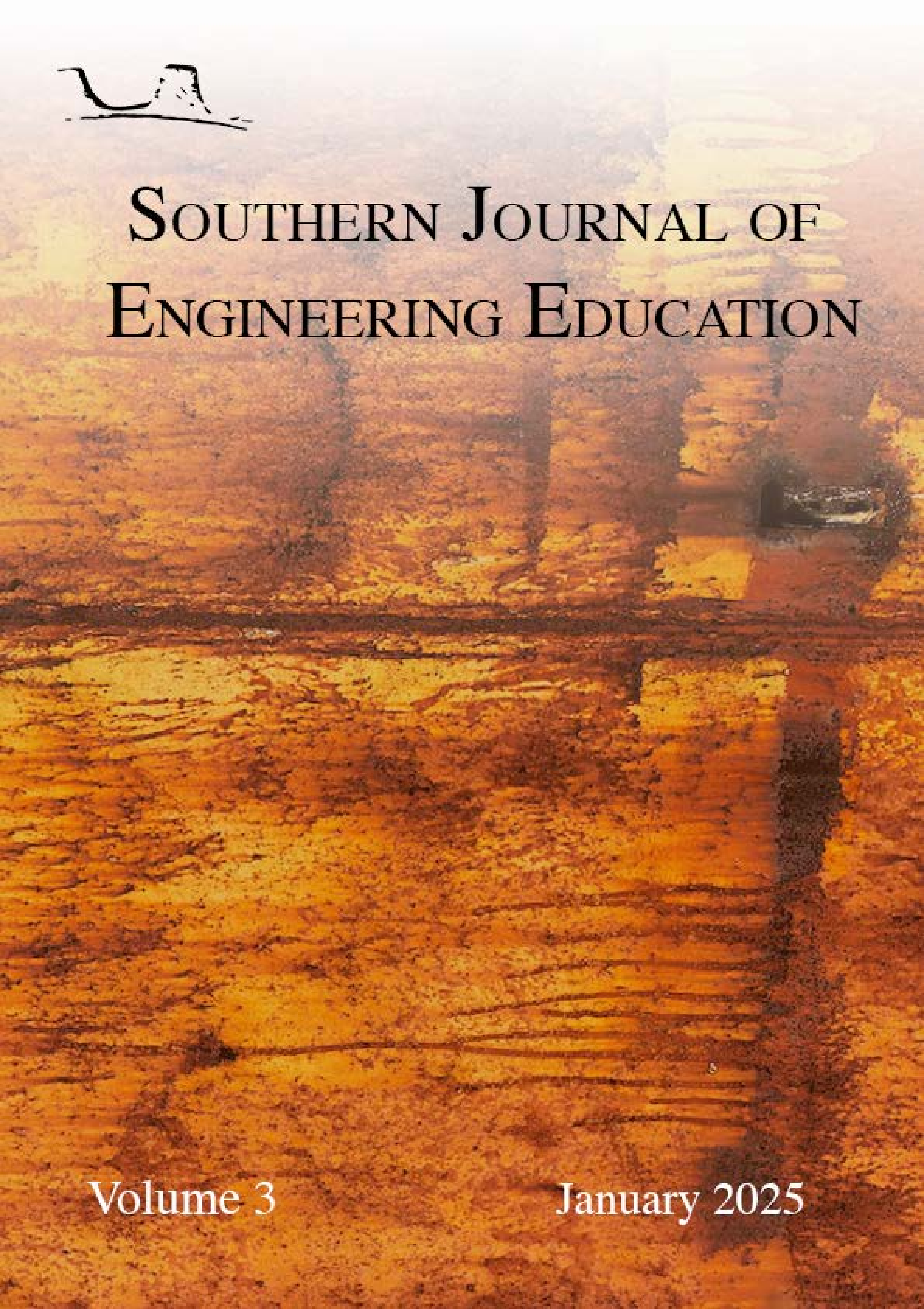

Southern Journal of Engineering Education

Volume 3 January 2025

SOUTHERN JOURNAL OF ENGINEERING EDUCATION

Volume 3 **2024**

(published January 2025)

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Editorial

This third issue of the Southern Journal of Engineering Education is exciting for several reasons. The variety of topics covered by the articles contained in this issue – discussed in more detail below – is certainly inspiring. Another exciting aspect is the collaborations involved in the production of these article. Only one article is sole authored while the others bring together authors from different institutions, countries and continents. The variety of the types of articles is also notable, from empirical articles and shorter research pieces to a conceptual article and an article focusing on curriculum that relies mainly on document analysis.

But this issue is especially exciting because it marks the point at which the SJEE is being submitted to the Directory of Open Access Journals (DOAJ) for accreditation. The DOAJ is, according to their website, ‘a unique and extensive index of diverse open access journals from around the world, driven by a growing community, committed to ensuring quality content is openly available online for everyone.’ After publishing three issues containing a total of 15 articles, we meet the criteria for assessment and are hopeful for a positive outcome, something that will improve our impact and reach, and expand the niche that we fill in the Engineering Education Research (EER) ecosystem.

Turning to consider the quality pieces in this issue, the first article by **Ashish Agrawal and colleagues** from various universities in South Africa, Lancaster University in the UK and Virginia Tech in the USA, compares six chemical engineering programmes across three Washington Accord countries. The article shows that despite the homogenisation of requirements by an agreement like the Washington Accord, there remains significant variation in the day-to-day structuring of engineering curricula both within and across national boundaries. The ‘day-to-day structuring’ refers to the defined parameters of contact hours, curricular rigidity, and first year of the degree. The variation *within* countries is fascinating, as is the variation *across* national boundaries. It also opens some intriguing questions about the supposed ‘substantial equivalence’ between curricula of universities in the vastly different countries that are signatories of the Washington Accord.

The second article by **Halkiyo, Halkiyu and Kellam** explores the experiences of women students in engineering in Ethiopia, focusing on their sense of belonging and its impact on motivation, persistence and performance. This is a detailed, sensitive study that draws on the narratives of four women engineering students at a mid-sized public university in Ethiopian. The findings show that while some participants felt a sense of belonging, engineering can be an alienating and even hostile space for women engineering students in Ethiopia. Importantly, this piece brings to light how sexual harassment in Ethiopia is, according to the literature, 'rampant, normalised and persistent… especially in STEM institutions' (p. 32). The findings of this study allow the authors to make some important recommendations for policy revision in Ethiopia in the hope of improving women engineering students' autonomy and agency regarding their choice of major and career path and improving their sense of belonging, not least by helping to combat the pervasive threat of sexual violence in Ethiopian universities.

The third article by **Smit and Pietersen** is a timely conceptual piece that delves into the potential benefits and challenges of accommodating of artificial intelligence (AI) tools, in particular, large language models (LLMs), in engineering education. Using the subject of embedded systems as a case study, the authors advocate for the 'thoughtful inclusion' of LLMs in the curriculum to give students the opportunity to engage responsibly with this technology in carefully designed learning activities (p. 76). It is suggested that educators dynamically assess the degree to which the course outcomes are met as they implement learning activities that incorporate LLMs.

There are two short research pieces in this issue that are authored by **Jessica Versfeld**. The first is sole-authored and explores the strategic refinement of the Student Success Reflection (SSR) module and its impact on at-risk students in engineering at a South African university. The adjustments to the support module are shown to improve students' time management, mental health, and social integration, and increase the chances of success of at-risk students in engineering. The second article, with co-authors **Talia da Silva Burke** and **Reginald Kanyane**, explores how a peer-led tutoring initiative in a high-impact engineering course (in mechanics) fosters resilience and creates a supportive learning environment for students. Both of these pieces make important contributions in terms of the design of organisational strategies within engineering schools to support students who are academically vulnerable. Their findings 'underscore the need for reimagined educational strategies that move beyond academic instruction to incorporate emotional and psychosocial resilience' (Versfeld et al., 2024, p. 129).

The sixth article in this issue, by **Theunissen et al.**, explores a stream of engineering that is relatively unfamiliar – naval architecture and marine engineering (NAME). Using a qualitative content analysis methodology of relevant documentation and drawing on personal communication with experts in the field, the authors review various aspects of NAME curriculum at internationally recognised institutions. They provide a compelling argument and put forward a proposal for a marine engineering curriculum that is unique to the South African higher education environment and will enable graduates to apply mathematical and scientific principles to the design, development and operational evaluation of marine craft.

Some news from 'back room' of the journal: in 2024 we expanded our Editorial Team and welcomed on board Esther Matemba who is very involved in Engineering Education Research internationally – her heart is in Africa but she is grounded in Australia! This is exciting for us because it represents our desired move towards working together with international colleagues rather than confining ourselves to South Africa, even though the SJEE is the official journal of the South African Society for Engineering Education (SASEE). We hope to welcome other international colleagues to the Editorial Team as we grow.

At this point I would like to extend my thanks to the incredible colleagues who make up the Editorial Team, and who worked tirelessly in shepherding the manuscripts through the review cycles and providing the necessary recommendations for me to make decisions. The support we received from Reggie Raju and his team at the University of Cape Town Libraries, the unit that is hosting the SJEE, is also gratefully acknowledged.

Looking forward, we are anticipating hosting a special issue on Problem Based Learning (PBL) after presentations at the 10th International Research Symposium on Problem Based Learning (IRSPBL) 2025 conference that is being held in Pretoria, South Africa from 17–21 November. This event is a joint venture with SASEE (as the 7th SASEE conference), as well as the 5th 'SoTL in the South' conference. The theme is *Anchoring Conversations: Connection, Collaboration, and Co-Creation for the Future*. As engineering education research in the Global South grows, the SJEE is privileged to be part of a thriving ecosystem made up of amazing people.

Bruce Kloot
Editor-in-chief
SJEE

Southern Journal of Engineering Education, 2024
Vol 3, 4–28

Impact of curricula on student learning: a comparison of six chemical engineering programmes in three Washington Accord countries

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Despite homogenisation due to accreditation requirements, there remain significant variations in day-to-day structuring of engineering curricula. This article shows these variations, and their influence on students' learning experiences, in three Washington Accord countries – England, South Africa, and the United States. The curricular parameters that we focus on include weekly contact hours, curricular rigidity, and the structure of the first year of the degree. Findings obtained through an analysis of undergraduate handbooks, weekly timetables of the different courses, and student interviews suggest considerable differences across the engineering programmes along these parameters, both within and across national boundaries. A high contact time, particularly in the South African programmes we studied, limits students' capacity to self-study and participate in extra-curricular activities. In contrast, programmes that we studied in the US and England, which offer more opportunity for electives, allow students to diversify their skillsets but potentially prevent them from acquiring discipline-specific engineering competency. Finally, we noted variations in the structuring of the first year of the degree. Where a programme introduces a significant number of courses specific to chemical engineering from the first year, students tend to build an early understanding of the discipline, while limiting their capacity to change majors.

Keywords: ABET accreditation criteria; chemical engineering; curricular differences; outcome-based education; student experiences with curriculum; Washington Accord

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Introduction

The connection between advancement in engineering, innovation, and economic growth is well established in both developed and developing countries (Centre for Economics and Business Research, 2016; Matthews et al., 2012). In the debates on engineering education, curriculum occupies an important place. It is generally agreed that engineering curricula are in need of reform to address several issues, including attracting and retaining more students; improving diversity in engineering; and enhancing graduate preparedness by better training engineering students to serve the needs of the industry (Graham, 2022; Jamieson & Lohmann, 2012; Morgan & Ion, 2014; Scott et al., 2013). The links between engineering curricula and how they influence students' experiences and choices has been previously studied. Stevens et al. (2005, 2008) note that students' experiences of navigating through an engineering degree is closely related to what they call 'navigational flexibility' at a university. Through examples of different students, they highlight that at institutions where there was limited flexibility in the curriculum in taking courses outside engineering, students either struggled to complete the engineering coursework while also taking courses based on personal interest, or followed a pre-determined plan of study as recommended by their departments. Similarly, Lichtenstein et al. (2009) highlight that a curricular structure that affords students flexibility in choosing majors and taking courses outside of the chosen major allows them not only to explore other majors, but also to easily shift majors by leaving engineering. However, it is important that a greater flexibility in curricula is balanced with the need to retain a sufficient core of engineering content.

Several other studies have highlighted the role of specific curricular features in shaping engineering students' experiences. For example, Mann et al. (2009) show that project-based learning in curricula can help students better learn professional engineering skills such as teamwork and project management. Kotys-Schwartz et al. (2011) note that service-learning can lead to an increased knowledge of the subject matter and improvements in critical thinking, problem-solving skills, teamwork, and communication among students. Along similar lines, internships and cooperative learning projects can help students better understand theoretical concepts by seeing their practical implementation (Mann et al., 2009). They can also help students self-evaluate their interest in pursuing an engineering career (Matusovich et al., 2010) and competence in being a successful engineer (Matusovich et al., 2008).

One significant facet of the ongoing discussions on curricular reform is the facilitation of movement of engineering graduates between countries. This need has led to the creation of global accreditation requirements (Case, 2017) which have been achieved through, for example, the mechanism of the Washington Accord. Established in 1989, the Washington Accord initially aimed at mutual recognition of undergraduate engineering programmes in the participating countries. The initial signatories to the Washington Accord included Australia, Canada, the Republic of Ireland, New Zealand, the UK, and the US. Since 1989, the Washington Accord has spread across the globe. However, the European Union, most of Latin America, and most African countries are still not signatories (Lucena et al., 2008). In the European Union, the alignment of curricula across countries facilitating international movement of engineering graduates is achieved through the Bologna agreement signed in 1999 (Adelman, 2009; Case, 2017). In recent years, there have been increased efforts to link more countries to global accreditation, with Peru joining the Washington Accord in 2018, Costa Rica in 2020, and Chile gaining provisional signatory status in 2018 (Washington Accord, 2022). In Africa, substantial differences remain in engineering programmes with Anglophone and Francophone nations reflecting the degree structures of their former colonisers (Case, 2017). To date, South Africa, which joined in 1999, remains the only signatory from Africa (Washington Accord, 2020).

The Washington Accord is closely based on the accreditation criteria of the Accreditation Board for Engineering and Technology (ABET). Membership to the Accord requires the participating countries to accredit their engineering degrees to a similar set of criteria (Case, 2017). ABET's own accreditation criteria have changed over the years. The initial ABET criteria focused on inputs; the emphasis has shifted to an outcome-based approach through the adoption of the Engineering Criteria 2000 (ABET, 2002). The Engineering Criteria put more emphasis on clearly articulating programme objectives and learning outcomes while reducing detailed specifications on the content of engineering curricula (Prados et al., 2005). As a result, the accreditation requirements for engineering programmes, which are being adopted by an increasing number of countries across the world, have adopted an outcome-based model since 2000.

This focus on learning outcomes has considerably influenced the design of curricula across undergraduate engineering programmes at different universities in countries that are signatories to the Washington Accord. These programmes have deliberately incorporated various elements into the curricular structure to meet the accreditation requirements, for example ensuring appropriate coverage of engineering topics such as engineering science and design, including modules on mathematics, science, and general education, and incorporating a capstone project that requires students to use the knowledge and skills from the previous coursework (e.g., Buyurgan & Kiassat, 2017; Chandrasekaran et al., 2013; Meah et al., 2020).

As a result of adopting outcome-based approaches through accreditation requirements, there has been some homogenisation of undergraduate engineering curricula across national boundaries. However, this homogenisation has generally been at a level of the overarching structure of the whole degree rather than the specifics of particular course curricula. For example, most Washington Accord programmes are four-year degrees allowing similar development towards the outcomes. There is some variation: in England, the Washington Accord equivalent is a three-year bachelor's plus a one-year master's programme, or an integrated four-year master's degree. South African Washington Accord programmes are typically four-year bachelor's degrees despite the national norm of three-year bachelor's degrees. Additionally, most degrees incorporate various practice-related elements such as capstone projects in the curriculum, and assessment of these tends to aim to directly demonstrate outcome achievement. Accreditation requirements have also ensured that curricula meet the requirements of incorporating certain disciplinary content, i.e., courses on mathematics, science, or humanities (Chandrasekaran et al., 2013; Jawitz et al., 2001). The reason for homogenisation of engineering curricula at a degree level is that the Engineering Criteria 2000, which was a significant starting point for the formulation of these global accreditation criteria, 'emphasise[s] learning outcomes, assessment, and continuous improvement rather than detailed curricular specifications' (Prados et al., 2005, p. 165).

Nonetheless, the adoption of outcome-based approaches has allowed undergraduate engineering programmes to meet the global standards while preserving institutional autonomy and alignment with national requirements and engineering cultures, as illustrated by Klassen and Sá (2020) in their study of three Canadian schools of engineering. Similarly, Downey et al. (2006) highlight how engineering problem solving varies between countries, which in turn influences the design of engineering curricula. They note that engineering curricula in the UK emphasise the use of engineering knowledge in solving practical problems, while those in France focus on using first principles and curricula in Germany on the attainment of a high degree of precision. In the US, engineering curricula have been significantly influenced by the technical needs of the country during the Cold War period, and consequently incorporated a high level of mathematics and engineering science to produce cutting-edge technologies such as computers, jets, and rockets to meet the needs of the military (Seely, 1999). Along similar lines, given the diversity of the student population in terms of backgrounds and preparedness for university education, the Council on Higher Education (Scott et al., 2013) in South Africa has also advocated for a flexible curriculum for higher education (including engineering education) in the country. This flexible curriculum is intended to suit the needs of a diverse set of students with different levels of preparedness by allowing them to complete the degree requirements at different speeds according to their needs and preferences. This flexibility remains in tension with the push to get students through the system in regulation time.

It is thus clear that accreditation requirements allow universities considerable scope for the incorporation of particular needs while maintaining institutional autonomy. It follows then that there could be considerable differences in how undergraduate engineering curricula are structured at the micro level in terms of credit requirements, contact time, experiential learning activities, and the incorporation of interdisciplinary courses across institutional and national lines.

While prior studies have highlighted how engineering curricula meet both local and national requirements (e.g., Downey et al., 2006; Klassen & Sá, 2020) and accreditation requirements (e.g., Buyurgan & Kiassat, 2017; Chandrasekaran et al., 2013; Meah et al., 2020), this literature highlights the structuring of and the variation in engineering curricula at the macro level, i.e., at the level of the entire degree. Within chemical engineering specifically, comparative studies have been done to highlight the different ways of teaching certain aspects of the degree and an increased or reduced emphasis on some topics (Voronov et al., 2017; Yao et al., 2022). Our study expands this literature by exploring the structures of undergraduate engineering degrees at the micro level that concerns students' day-to-day involvement with classes and their ability to make decisions in terms of choosing courses and specialisations within the degree. The reason for our focus in this article is that these elements do shape the students' perception of their experience of the programme. Usually these are simply taken as a given: 'this is how we do things here'. The purpose of this article is to show that there is a wide variation in these structures. This information may help educators and institutions make more informed decisions in the design of engineering curricula with respect to aspects of curriculum design that are often overlooked. The research questions that guide this study are:

> **RQ1**: How do chemical engineering curricula vary at a micro level that influences students' day-to-day experiences?
>
> **RQ2**: How do these variations shape students' experiences?

This article focuses on the structures of six chemical engineering programmes in three different countries, two each in England, South Africa, and the United States, all of which are four-year degrees accredited under the Washington Accord. It highlights the similarities and differences across these programmes in terms of contact hours, flexibility in the curricula, and the structure of the first year of the degree; and their influence on students' experiences. The reason for choosing chemical engineering for this study is that it is both a traditional and an important engineering discipline. It was formally established as a discipline more than a century ago (van Antwerpen, 1980). It is also notable that although the participation of women in chemical engineering remains lower than that of men, the discipline does tend to greater diversity in gender than other engineering programmes (Brawner et al., 2015).

Theoretical framework

The work of the sociologist Basil Bernstein (2000) on recontextualisation of disciplinary knowledge into curriculum provides the theoretical underpinning for this work. Bernstein distinguishes disciplinary knowledge from the curriculum in any field and argues that the disciplinary knowledge is converted into the disciplinary curriculum through a process of recontextualisation. Bernstein (2003) makes a distinction between regulative and instructional discourse. The instructional discourse entails the academic content of the curriculum and involves choices of what is included in the curriculum and its pacing and sequencing. In a discipline such as chemical engineering, there is core knowledge content that must be covered despite the language of outcome-based education used by the Washington Accord. The use of textbooks for core content may also shape pacing and sequencing to some extent. The main interest here is on factors which fall under the regulative discourse and the ways in which those elements influence student experience. Regulative discourse refers to the structures within which the content of the curriculum is communicated. In the context of this study the 'curriculum' is broadly understood as the instructional discourse, and the regulative discourse is the structure in terms of time and flexibility. It has been noted in several studies that the way the student interacts with the regulative discourse can have a significant impact on their perceived experience (Bertram, 2012; Blackie, 2021).

Given different histories and different social and cultural contexts, it follows that there will be differences in the day-to-day structuring of the curricula across national and institutional contexts. This exploration of curricular differences across contexts, along with their influences on students' experiences, is the focus of this article. This exploration and elucidation will provide engineering educators with empirical examples of different ways of structuring curricula, thus helping them make more informed decisions about curricular design.

Methods

Data for this study were collected from six universities across three countries. [3] All institutions are publicly funded and have been given pseudonyms of chemical elements to reflect the focus of the study. Table 1 provides the details about these six universities in terms of their locations.

Table 1: *Details of research sites*

Country	England		South Africa		USA	
University pseudonym	Erbium	Europium	Sodium	Samarium	Argon	Astatine

The data analysed for this article were drawn from two sources: 1) curricular documents such as undergraduate handbooks that detailed the degree requirements in terms of core and elective courses and weekly contact times of the different courses that students needed to take to complete the degree requirements; and 2) annual semi-structured interviews with up to ten students per research site conducted throughout the course of their degree, which captured students' experiences with their courses and assessment practices, relationship with the discipline, engagement in co- and extra-curricular activities, and future plans after the completion of their degrees. Student interviews were carried out between 2017 and 2021.

A preliminary analysis of the curriculum data from each institution and wide-ranging discussions among the authors about possible curricular variations led to a variety of potentially

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[3] These data were collected as part of a larger international project that seeks to understand how STEM students engage with disciplinary knowledge in two different STEM disciplines – chemistry and chemical engineering (for details, see here. The longitudinal research design for the larger project drew from McLean et al. (2018). The overarching interest of the broader project is the development of student agency and knowledge gain. Thus, the focus of this article is on elements of the curricula which can be directly linked to student experience. The analysis herein is an important component of interpretation of the larger project, but the variation discovered is of sufficient interest to be a useful contribution to the engineering education literature.

significant curricular features. Through iteratively focusing on and refining the definitions, three features of the chemical engineering programmes were identified that clearly illustrate the links between curriculum and its influence on students' academic experiences. These curricular features included contact hours, curricular rigidity, and first year of the degree. While these features are not exhaustive, they are illustrative of the distinctions between programmes and serve to illustrate the significance of the regulative discourse on student experience.

The next step of analysis included preparing weekly timetables and the four-year degree plans, considering the different elective and specialisation options, which was primarily done by the second author in close consultation with the first author. Reference was made to university handbooks to obtain details about compulsory, elective, and specialisation courses and their weekly contact times. The decisions made by the first two authors to quantify contact hours or elective and specialisation requirements or first-year credit requirements in cases of ambiguities were achieved through discussion. The final set of decisions were then considered by all the five authors and any disagreements were resolved through conversation with referral to curriculum documents.

To compute contact hours, average weekly contact time was calculated for each year of study and each programme. Sessions scheduled in alternate or intermittent weeks alongside regular contact time were averaged across the term or semester. Atypical weeks (such as examination periods or field trips) were excluded, as were any sessions without a specified schedule. The latter exclusion is often evident in the third and fourth years of study when students may be completing projects and other assignments during unscheduled laboratory work. The reason for choosing weekly contact hours as opposed to the total contact time over an entire semester or an academic year is that we wanted to choose a criterion that relates to students' day-to-day academic experiences and interaction with the academic timetable. A cumulative measure over an entire semester or an academic year may hinder this understanding, as it is the weekly contact time that can either enable or inhibit choices of electives, part-time employment or extracurricular activities, and can also drive different approaches to teaching and learning. Semester and year totals can disguise these variations over the course of the programme.

For curricular rigidity, we wanted to explore the extent to which the degree is constrained by compulsory courses that must be completed by all students, and the extent to which students have some freedom of choice. All institutions use the notion of credits to designate workload.

Hence the unit of measure used here was the course credit. Since the definition of a credit varies across institutions, we quantified fractions of a curriculum in terms of the university's own allocations of credits. It is noted that credits may not be a reliable indicator of workload but, as they are linked to notional hours of work, is the most accurate measure that can be attained from course documentation. We therefore define the rigidity of a curriculum in terms of the fraction of course credits that are compulsory for all students in the programme. We chose curricular rigidity as a construct to analyse the curricula as opposed to curricular flexibility, because all institutions have a similar conception of compulsory courses, making rigidity an easily measurable construct. By contrast, the non-compulsory features that provide curricular flexibility take various forms, making flexibility more difficult to quantify consistently across curricula.

To analyse the degree to which students are exposed to the discipline-specific content in the first year, we compared the first year of the chemical engineering programmes to another engineering programme: mechanical engineering. Mechanical engineering was chosen as it was common across all the six institutions. By calculating the proportion of first-year course credits that each chemical engineering curriculum shares with another discipline, we quantified how much of the first year of the engineering degree in each programme is discipline-specific and how much is common.

Once we identified the three curricular features and quantified the curricular differences across the programmes under study, the next step involved reading through the interview transcripts to identify instances that connected student experiences with these three features. The initial identification of relevant interview excerpts was done by the first author, which was then cross-checked by the third author.[4] It should be noted that since the interview questions explored students' broader curricular experiences, there was ample scope for students to recount experiences that challenged our findings. It should also be noted that not all students talked about the influence of all three curricular features on their experiences, and hence the findings from the qualitative analysis of interviews provide exemplars of experiences rather than establishing prevalence among all students. Moreover, the article does not use student data

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[4] Interviews included a range of questions related to students' course and assessment experiences, engagement with disciplinary knowledge, experiences with diversity, extra-curricular activities, and expectations from the university. These interview topics were shaped by the broader project of which this article is a small product, therefore not all interview questions were relevant to this particular study.

to strengthen the analysis of curricular differences; rather the interviews are used to illustrate the patterns that were found in the analysis of curricular data.

Findings

Our investigation of curriculum documents highlights three themes that were common across institutions and national contexts. We saw evidence of difference between these contexts as well. In this section we will discuss these themes: contact hours, curricular rigidity, and first year of the degree, in terms of how they were illustrated across institutions and countries. Following the discussion of each theme, we describe how the curricular feature shaped students' experiences using interview quotes as evidence. Pseudonyms are used to refer to individual students.

Contact hours

One notable difference between the curricula among all the sites is the amount of contact time required of students. Though all programmes are four-year programmes, the time that students must spend in a classroom or laboratory varies significantly. To illustrate differences in contact hours, we chose to focus on average weekly contact time as the indicative measure.

There are two ways in which student choice impacts the contact hours (discussed in detail in the section on curricular rigidity). Firstly, some universities offer explicit variations on the chemical engineering programme in the form of specialisations, such as environmental science or biochemistry, that include different courses. The averages presented here exclude these options and focus on the traditional or mainstream chemical engineering curricula. It is acknowledged that some courses in the specialisations could be considered core elements within the specialisation. Secondly, some of the chemical engineering programmes incorporate electives: courses that students can select from a range of options. Where an explicit list of options was provided in the university documentation, the option with the least contact time was used. Where elective requirements were more open (e.g., allowing students to select from any qualifying course offered at the university), values were chosen based on a brief survey of qualifying courses. For example, if the university required students to take a three-credit course, we chose contact time for a typical three-credit course at the university. Additionally, some institutions allowed students to apply to pursue self-study courses in lieu of some course credits, usually meeting with a lecturer on an ad hoc basis. These self-study options were also excluded from the averages.

Figure 1 shows the variation across the research sites in terms of weekly contact hours. There is a surprising variety of contact time both among institutions and across years of study. The South African universities exhibit the most contact time, particularly in the first and the second year, while the programmes at the English universities have the lowest overall contact time requirements. The US institutions show the most consistency across the four years. Two institutions (Erbium and Samarium) show a substantial difference in contact time between the initial years of study and later years. This difference is due to the project and dissertation work that students are required to undertake in the later years. At Erbium especially, the weekly contact time dips quite significantly in the third year, as students spend significant time on their dissertations in that year. It is important to note here that a change in weekly contact time does not necessarily indicate a change in the amount of time a student is expected to spend on their studies. All of the programmes maintain a reasonably even distribution of expected workload across the curriculum as indicated by course credits, despite the clear differences in contact time. Course credits are usually calculated on the basis of notional hours that a student is expected to spend on the course, and these hours include both the structured contact time and the time a student is expected to spend on the course requirements on their own. All curricula show a general decrease in contact time as the programme progresses, likely indicative of a transition to more self-directed learning and project work.

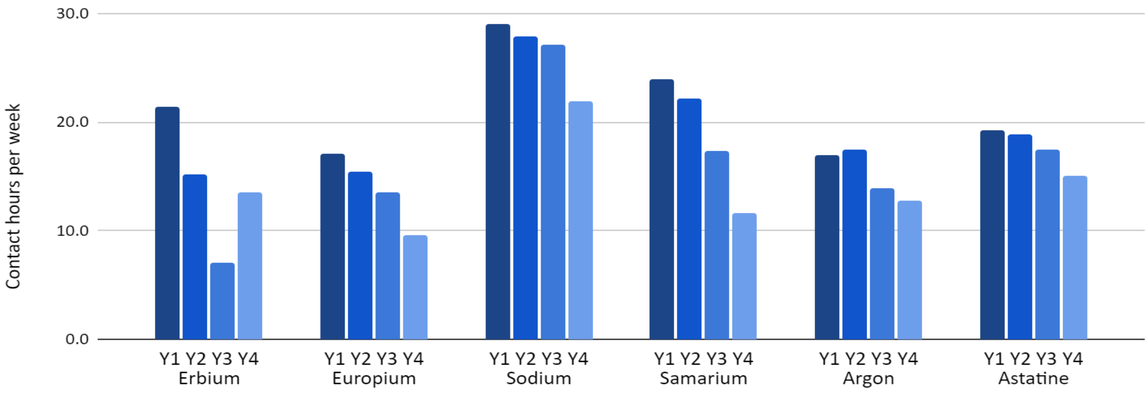

Figure 1: *Contact hours per week across the four years of study*

A relatively packed schedule, especially in the initial years of the degree, was highlighted by several students in their first-year interviews. As Nina from Samarium University notes:

> I start at 9:00 with Maths and then I go to my second lecture, which is chemical engineering. After that I go to chemistry and then my final lecture at 12:00 is stats until 1:00. Monday afternoons I have off or we use our time to do project work or practicals in chemical engineering or catch up on any work that you have. Tuesday I have the same morning from 9:00 to 1:00, and then afternoons I have chemical engineering from 2–5 pm, which is usually used for the project work, group work. Wednesday I have the same morning again and then I have a Maths tut from 2–4 pm and then Thursday the same morning and from 2–5 pm I have a chemistry prac. Friday is the same morning and then I have chemical engineering again from 2–5 pm, project work. (Nina, Samarium, Year 1)

Similarly, Lawrence from Erbium University highlights that some of his weekdays are very tightly packed with lectures, labs, and tutorials.

> Monday, we usually have a few lectures, two or three, and then a little bit of a break. Then, we'll have a lab for three hours. Monday is quite busy. Then, Tuesday and Wednesday, we just have lectures. We'll probably have two lectures on both those days. On Tuesday, we also have a tutorial with a personal tutor, and we just talk over work that we can set for the week before. Then Thursday, we have three more lectures and a lab. Then on Friday, we have a Maths workshop and another lecture. It's quite packed in, especially on Mondays and Thursdays. (Lawrence, Erbium, Year 1)

It is important to note that Lawrence experiences a day with 5–6 hours of contact time as packed even though this schedule is less demanding than a typical day's schedule for Nina. The student's perceived experience of this aspect of the regulative discourse is likely to be influenced by what is taken to be the norm.

A relatively light schedule allows students to engage in self-study and co- and extra-curricular activities. Sameer describes how his schedule allows this:

> Mondays and Wednesdays I have three classes… on Tuesdays I have two classes. I have like an early morning 8 am class and then I have one that's more in the afternoon. Then during then I'll either be working on stuff for those classes or studying for those classes or I'll be working on homework for... if I have any work due further that week, later that week, then I'll be working on that as well. Thursdays are a bit busier. I have four classes that day and two of them are like... and one of them is a lab so it's like a three-hour, two-and-a-half hour block I think. Then I also have seminar later that day so those days are usually pretty busy. I'm kind of going between classes the whole day. Then Fridays are pretty light. I only have two classes which like my morning class and my afternoon class. Those days I'll either be working and then I'm also researching under two professors so

> I'll have like a meeting with the professors that I'm researching under and then kind of go over what I've been working on that week for the research. (Sameer, Argon, Year 2)

As can be specifically seen in Sameer's case, due to a lighter timetable, he is already able to engage in undergraduate research in the second year of the degree. Other students from the two US institutions also note how a lighter timetable means that they spend more time learning the materials outside the class than during the scheduled contact time:

> Yeah, I definitely feel like there's definitely a lot more time outside of class, just in general. For most of my classes, we meet twice a week, so definitely a lot more time on my own with that kind of material. (Drew, Argon, Year 2)

> I definitely spend more time outside of class than in class because we have classes for three hours per class a week. So I end up spending like fifteen, twenty hours for that one class outside of it. So definitely more outside of class. (Liliana, Astatine, Year 2)

Conversely, the South African students struggle to find time for self study.

> I think that maybe if they could give us more time to actually go through the things that they are teaching us. I think we would do better. (Tawanda, Sodium, Year 2)

> It's a lot of things in a short period of time. That's, like, the measure. Some of the concepts I realise that I could've understood better, but because of time I just tend to rush over things. (Ndodzo, Samarium, Year 2)

As can be seen from the student quotes, the weekly contact time significantly influences students' perceived learning experiences. A low contact time gives students ample opportunities to engage in self-study, and importantly, creates extra-curricular learning avenues for themselves. On the other hand, a relatively high contact time leads to students' perceptions of being occupied and not having enough time to study on their own. It is debatable whether such opportunities would actually be taken up. Nonetheless, the fact that students perceive this as being a constraint on their learning experience should be considered.

Curricular rigidity

Another type of curricular variety is whether and to what extent students can control the direction and breadth of their own studies. The structures of the curriculum that allow students to choose what they will study is most usefully considered at the level of the entire curriculum.

As noted earlier, we refer to curricular rigidity as the fraction of course credits that is required by all students in the programme. We distinguish between two aspects affecting curricular rigidity: degree specialisations and elective courses. Elective courses are allocated credits within the curriculum that the student can choose how to fulfil. Some elective credits come from a short list of specified courses chosen to meet particular requirements, such as advanced chemical engineering or science courses. Some fulfil credit requirements in broad categories such as humanities or writing. And some allow the student to select any courses of an appropriate level. We acknowledge that this allows greater possibility for students to influence their day-to-day schedule in terms of the order in which they take different compulsory and elective courses, the way they create their weekly schedule during a particular semester, or the time of the day when they take a particular course. However, that fine-grained analysis is beyond the scope of this article.

Degree specialisations allow students to select a particular area of chemical engineering (e.g., environmental science or biochemistry) within the programme and take a fixed sequence of courses focused on that area. Specialisations are often presented as alternative degree plans or structural choices that are specified within a programme.

Although specialisations reduce the curricular rigidity for students by giving them options to take courses from a focused area of their choice, they complicate the understanding of curricular rigidity. Firstly, specialisations, typically chosen by students during the second or the third year of their degree, may require students to take some prerequisites, thereby constraining the freedom of choice. Secondly, prerequisite requirements or specialisation rules often make it difficult for students to change to another specialisation once they start taking courses for a particular specialisation. Thirdly, once a specialisation is chosen, further opportunities for the student to direct their studies can be limited by the structure of the specialisation.

In order to give some measure of course rigidity, we compared the number of credits of elective or specialisation-linked courses to the total number of credits in the programme. Where an elective was only offered to students who were pursuing a certain specialisation, it was counted under specialisation; otherwise, it was counted under the elective category. Note that the percentages given are an approximate estimate rather than an absolute value. Table 2 depicts the variations across the six universities in terms of the curricular rigidity in the chemical engineering programmes they offer.

Table 2: *Variation of curricular rigidity expressed as percentages of course credits*

Institution	**Specialisation**	**Elective**	**Combined Choice**	**Curricular Rigidity**
Erbium	0.0%	0.0%	0.0%	100.0%
Europium	0.0%	0.0%	0.0%	100.0%
Sodium	0.0%	0.0%	0.0%	100.0%
Samarium	7.5%	14.3%	21.8%	78.2%
Argon	0.0%	20.3%	20.3%	79.7%
Astatine	18.6%	24.0%	42.6%	57.4%

As can be seen from Table 2, Erbium, Europium, and Sodium, have an entirely rigid curriculum structure without any electives or explicit specialisation options. In contrast, Samarium and Argon each have slightly less than four-fifths of their degree requirements determined by a rigid degree structure; and at Astatine, chemical engineering students can choose to have less than two-thirds of their coursework in common. The internal variation in rigidity between the two US and the two South African institutions suggest that rigidity may be more determined by institutional culture rather than national context. It would be necessary to use this measure across more institutions in each national context to draw any substantial conclusion on this observation. It should be noted that electives, especially non-engineering electives, come at the cost of specialised engineering content. This may benefit the student's sense of a well-rounded education but may not be desirable to potential employers. Nonetheless, this is an aspect of the regulative discourse that will influence student experience and is most likely to be aligned with the culture and values of the university.

The ability to choose courses according to their interests allowed students to explore different disciplines, thereby expanding their knowledge and worldview. For example, Adrian from Argon University notes that taking electives will help him with his minor in addition to expanding his knowledge base.

> For my ceiling classes or my electives, I've taken two science-related classes. The first one was Global Science and Technology Policy, and this one I'm taking this semester is Leading Global Sustainability. And I picked this one because it helps me with pursuing a green engineering minor. (Adrian, Argon, Year 1)

Similarly, Nicholas reflects during the first-year interview how taking a humanities elective is shaping him into a person who is more considerate of diversity and differences.

> I am very accepting of people. I do realise that [prejudice and discrimination against people] happen and [it is important] to be able to look out for that and to check myself. I think doing gender studies is also helping a lot in this regard. (Nicholas, Samarium, Year 1)

Ndodzo describes how her elective adds a different dimension to her development as a professional engineer in that she recognises the importance of planning and executing engineering work in a way that prioritises the need of the community.

> It [a humanities elective course] talks about social infrastructures, infrastructures that are meant to bring communities together. The course is about … discussing and actually exploring how it really would be when you are dealing with projects in the community ... Sometimes you do projects trying to improve people's lives, but that is not their first need. And when they see you guys doing that, they might destroy your work. And then money's down the drain because you didn't communicate with the community to see first what they actually need. (Ndodzo, Samarium, Year 3)

These student experiences suggest that curricular rigidity can affect students in two significant ways. Firstly, it can prevent students from pursuing different minors and specialisations based on their interests and career aspirations. Secondly, it can also deny students the opportunity to explore disciplines other than engineering, which may prevent them from developing a diverse worldview and considering an engineering problem from different perspectives.

First year of the degree

A third way in which the chemical engineering programmes under consideration differ from one another is in the design of the first year of study. The first year of the degree varies across the six institutions in two ways: 1) admission of the students into the major; and 2) exposure of students to the discipline-specific course content, i.e., courses required only of students who are pursuing a chemical engineering degree.

In terms of admission of students into the major, four out of the six programmes (Europium, Sodium, Samarium, and Astatine) admit students directly into the chemical engineering degree. At the other two, Erbium and Argon, students join a general engineering programme in the first year of the degree. It is only at the end of the first year that they choose their engineering major based on their interest and performance in the general engineering courses taken in the first year.

In terms of exposure of students to the discipline-specific course content, some engineering programmes present a common first year, allowing – and sometimes requiring – students to learn about different engineering disciplines before choosing a course of study. Others incorporate substantial discipline-specific (i.e., chemical engineering) content from the first year. Again, this is an important aspect of the regulative discourse. The design may be driven by factors individual to each institution. For example, at Samarium there is intentional fostering of chemical engineering student identity which includes building social connections between students. At Sodium, the common first year is favoured to allow students to switch between programmes.

Table 3 presents these variations in the first-year curricula across the six institutions under study in terms of exposure of students to the discipline-specific content. To provide further insight into the first-year curricular differences, we also provide in Table 3 a categorisation of the discipline-specific courses taken by chemical engineering students, identified by the department that offers the course.

As can be seen from Table 3, the six programmes present a wide variety of approaches to the first year. For instance, Europium and Samarium introduce a significant number of courses related to chemical engineering in their curricula from the first year of the degree, with some courses from the field of chemical engineering itself. Sodium and Argon offer a very small number of courses specific to chemical engineering in the first year; the majority of their first-year courses are common across all engineering disciplines. Students at all four of these universities study a course in chemistry as a discipline-specific course requirement.

Erbium and Astatine have the first year of the degree as entirely common across all engineering disciplines. Common first year courses at the six universities generally include introductory courses in engineering problem solving and design, mathematics, and science. At Astatine, students can opt for a specialisation in biotechnology during the course of their chemical engineering degree. Those who do so are required to take one-discipline specific course in biology during their first year instead of taking all common first-year courses. Although students are admitted to a general engineering programme in the first year at Argon, they are encouraged to take more courses in chemistry if they plan to pursue chemical engineering. It is these chemistry courses that lead to a first-year curriculum at Argon that is not entirely common across all engineering disciplines.

Table 3: *Structure of the first-year curricula across the six chemical engineering programmes*

Institution	Erbium	Europium	Sodium	Samarium	Argon	Astatine
Common credit requirements	100.0%	16.7%	96.0%	37.0%	87.9%	100.0% (91.2%)
Discipline-specific credit requirements	0.0%	83.3%	4.0%	63.0%	12.1%	0.0% (8.8%)
Discipline-specific subjects	—	Chemistry, Chemical Engineering	Chemistry	Chemistry, Chemical Engineering, Statistics	Chemistry	— (Biology)

Note: The first-year curriculum is slightly different at Astatine for students who want to specialise in biotechnology, as indicated by the parenthesis in the table.

Another point to note here is that a higher common credit requirement in the first year does not necessarily mean higher curricular rigidity. It is possible that students, while pursuing the common first-year curriculum, have an option to choose electives within the common courses. This is why Astatine, with a very high common credit requirement in the first year, still has the lowest curricular rigidity.

Further, as Table 3 shows, the variation within countries is also significant, with dramatically different structures from different institutions within England and South Africa. As with curricular rigidity, further study in each national context would be necessary to determine the influence of national engineering culture on these choices.

The differences in the first-year curricular structures significantly influenced students' experiences in terms of identifying with their major of study. An early exposure to chemical engineering through their specialised first-year courses helped students relate better to their discipline. For example, as Rabeea from Europium University notes:

> I have for certain lab experiments, for example, fluid flow which is another subtopic of one of my modules, heat transfer and fluid flow. Yes, so maybe because I've done the lecture now and I've done the lab practical for it now and I was interested, so yes, maybe I would

> want to go and see how other big chemical engineering companies use it in action or how it actually worked in society. (Rabeea, Europium, Year 1)

As evident in this quote, an early exposure to both laboratory and theory work in chemical engineering ignited her interest in the discipline. Similarly, Nisha from Samarium University highlights how she has already started to learn about the work of a chemical engineer through her first-year chemical engineering course.

> In our chemical engineering course … we have guest speakers who come back and tell us what they do and what opportunities are out there and what their careers were like; so we learn from that. We are also doing this assignment… to find a chemical engineer and correspond with them through email about what their job is like. [Through these activities] you get a better idea of what is expected of us [when we graduate]. (Nisha, Samarium, Year 1)

Thus, a more discipline-focused first year has helped both Rabeea and Nisha gain a better understanding of chemical engineering. Conversely, when students have not found their first year directly related to their major of study, they not only struggle to develop an understanding of the discipline, but also do not recognise the value of the courses.

> The first year is all common for all engineers. It's just something you're learning things and you think, 'Okay, I don't really think I'm going to use this in my degree'. (Lucas, Erbium, Year 1)

> I don't think my Intro to Engineering class was a very useful class. I don't think it really taught me anything. I think that class could be more specialised towards each of the different engineering disciplines. (Marley, Astatine, Year 1)

While a common first year posed difficulties for students in understanding the relevance of the courses they studied, it also afforded some advantages. Specifically, a common first year gave students the option of changing majors should they not find chemical engineering to be a good fit. As Luke from Erbium University notes:

> I don't like it [my common first-year electronics course], and I don't see when I am going to use it. I will be surprised if I get over 60% in the final exam for electronics. But it has also benefited me because if I had gone straight into nuclear [chemical] engineering, I doubt I would be able to change [my major if I didn't like it]. It is a mixture. But I have benefited from it so I shouldn't complain too much. (Luke, Erbium, Year 1)

The student experiences show that a discipline-specific first year can play an important role in helping students learn about professional practice, which may lead to an increased interest in the discipline. Conversely, a first-year curriculum more generic in nature may feel a bit irrelevant to students and also prevent them from seeing the value in what they are studying. Once again, this simply illustrates the way in which the regulative discourse frames student experiences.

Discussion and conclusion

The findings show that there is a lot of variation in the ways in which chemical engineering courses are structured not only across countries, but also within the same national context in terms of the three parameters: contact hours, curricular rigidity, and first year of the degree. In Bernsteinian terms, this shows that the manner in which the recontextualisation of the disciplinary knowledge into the curriculum is done may be divergent, but it can still be perceived to fulfil a common goal. Nonetheless, the choices made with respect to the regulative discourse will have an impact on the students' perception of their experience. In this article we have shown the different ways chemical engineering curricula can be structured while meeting the accreditation requirements of the Washington Accord. Thus, our findings add to the existing literature (e.g., Downey et al., 2006; Klassen & Sá, 2020) on how engineering curricula differ from one another based on the local and the national requirements while maintaining the accreditation goals. However, the unique contribution of our work is the exploration of curricular differences at the micro level that concerns students' ability to attend classes and choose electives and degree specialisations. Through this article we hope to alert engineering educators to the influence of these aspects, in an attempt to ensure that they are at least considered when undergoing curriculum review or curriculum renewal. Note though that the elements discussed in this article should be considered a small subset of regulative factors.

The variations in the day-to-day structuring of the curriculum may have significant implications for the formation of students as engineers. For example, the degree to which the first-year courses overlap with courses in other engineering programmes (most pronounced at Erbium) determines how easy it is for a student to switch into another engineering programme before the commencement of the second year, as also highlighted by Luke. Where the first-year requirements are very similar between disciplines, students are more likely to be able to change to another discipline without substantial delays in their overall degree completion time. The same flexibility is afforded to students who enter a general engineering programme and choose chemical engineering as their major only at the beginning of the second year, a feature of curricula at Erbium and Argon. However, the advantage of this capacity to switch between engineering programmes is balanced by the advantage of developing a clear identity for chemical engineers early in the programme. At Samarium, for example, there are several elements in the first year which are clearly aimed at community building and early identification with the discipline and the profession. Through an early exposure to the discipline through these curricular elements, students start to build an understanding of the discipline sooner rather than later, which has implications for the formation of professional identity and student retention in the major (Mann et al., 2009; Matusovich et al., 2010).

The possibility of different degree streams in terms of specialisations, which are present at Astatine and Samarium, give leeway for students to follow a path that inclines more towards their particular interests. However, the retention of a substantial commonality between different streams suggests that there may still be strong coherence in the training of the students who come through different streams. Along similar lines, the ability to choose elective courses (often across a diverse range of academic disciplines), present at Samarium, Argon, and Astatine, allows students to study and be exposed to a diverse range of subjects. This allows students not only to pursue different interests leading to the development of diverse skills, but also to develop alternate worldviews. A curriculum that offers alternatives for technical coursework has been shown also to enable students to shift their majors and sometimes to leave engineering (Lichtenstein et al., 2009). An exploration of diverse interests and exposure to different worldviews is also enabled by a curriculum that has a relatively low number of weekly contact hours. Fewer weekly contact hours allow students more flexibility to structure their day-to-day schedule, thus enabling them to engage in extra-curricular and co-curricular activities. However, these aspects of divergence of experience must be balanced against adequately covering the core content for the cohort of students, given their educational backgrounds and the capacity of academic staff to deliver specialised courses.

Given that all of these institutions have accredited chemical engineering degrees, it is evident that there are multiple ways to achieve the outcomes determined by the Washington Accord. The substantial variation in structure presented here should give engineering educators and institutions pause for thought. Just because a course has been currently structured in a particular way does not mean that it is necessarily the best way. For example, are the relatively high contact times found at Sodium actually necessary? Does the low contact time in the third year at Erbium provide adequate teaching conditions? Likewise, is the rigidity of curricula at Erbium, Europium and Sodium essential? And is something lost in terms of engineering identity by allowing enormous flexibility at Astatine? The national academic context does indeed determine some of these salient features of the engineering curriculum (Case et al., 2016), but our analysis also provides examples of significant differences between the universities situated within the same national context. Nonetheless, educators should be mindful of the fact that the regulative discourse is operational, whether it is actively considered and chosen, or unintentionally overlooked.

Acknowledgements

This article is from the Centre for Global Higher Education (CGHE) Understanding Knowledge, Curriculum and Student Agency Project. We acknowledge the contribution of the other project team members: Paul Ashwin, Jenni Case, Jan McArthur, Reneé Smit, Janja Komljenovic, Alaa Abdalla, and Benjamin Goldschneider. The support of the Economic and Social Research Council and Research England (grant references: ES/M010082/1, ES/M010082/2 and ES/T014768/1) and National Research Foundation, South Africa (grant reference: 105856) are gratefully acknowledged along with support from CGHE.

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Southern Journal of Engineering Education, 2024
Vol 3, 29–61

Exploring how Ethiopian women students perceive a sense of belonging in engineering higher education

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In this study, we explored four undergraduate engineering women students' sense of belonging in their engineering major, engineering college, and university in Ethiopia. Specifically, we explored how engineering women students perceived their sense of belonging in the engineering programme and how the perceived sense of belonging impacted their academic participation and experience. We conducted an exploratory qualitative study through narrative interviews, thematic analysis, and a 'sense of belonging' lens to guide the study. Findings indicated that two participants who chose the engineering major themselves felt a sense of belonging in engineering, while one who was assigned to engineering by the government did not feel a sense of belonging in her major, and one experienced a partial sense of belonging. The students indicated that having the autonomy to choose majors of their interest affected them in many ways: their motivation, persistence, performance, experience, sense of belonging, and whether to stay in the profession after graduation or not. The Ethiopian government may need to prioritise making engineering a safer and more inclusive space where students of all genders feel they belong before forcing more women into the major. Furthermore, findings suggest the Ethiopian Ministry of Education might consider allowing the autonomy and agency of women students in choosing their major and/or university whereby they can make pragmatic decisions of what to study, where, and for what purpose.

Keywords: sense of belonging; women students; engineering; Ethiopia; qualitative research

Introduction

A sense of belonging is a fundamental human need for individuals to belong and be accepted, respected, and encouraged by a group or community of people (Goodenow, 1993; Marshall et al., 2012). The concept of sense of belonging has broader definitions in the literature but was

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introduced as a way of indicating 'students' integration within their academic unit … and serves as a measure of the perceived degree of inclusion within that unit' (Lee et al., 2019, p. 2). Some of the common aspects that sense of belonging covers includes school-based relationships, student-teacher relationships, experiences with peers, and students' general feelings about the school (Lee et al., 2019; Strayhorn, 2019). In addition, a sense of belonging is related to self-perceptions of fit within a given context, including classroom environment, campus community, and affinity groups (Hagerty & Patusky, 1995; Smith et al., 2012).

In engineering learning contexts, a sense of belonging is a perception of acceptance, inclusion in learning environments, and willingness of diverse student groups to engage with peers, teachers, and learning materials in academic settings (Smith et al., 2012; Wilson et al., 2015). For example, Rainey and colleagues' (2021) findings showed that classroom practices and faculty efforts could support minoritised engineering students' sense of belonging in learning environments. Further, a sense of belonging is crucial for students who are minoritised in the institutions they attend and/or in the major they pursue due to gender, race, ethnicity, or sexual identity. For instance, a sense of belonging could be more important for Black students who attend predominantly white institutions (PWIs), international students attending US universities, and Black women students pursuing engineering fields (Johnson et al., 2007; Tate & Linn, 2005). One such student group in Ethiopia is women students majoring in engineering.

In Ethiopia, society has lower expectations of women, especially in engineering, a discipline stereotypically coded as a man's profession (EqualEngineers, 2019; Tadesse, 2021; Yossi, 2017), and women have historically had less access to higher education, particularly in engineering (Asfaw, 2012). While under-representation is problematic in higher education in Ethiopia in general, it is worse in the science and engineering fields (Kassie, 2018). However, the Ethiopian government has recently increased women students' access to higher education and engineering (Kassie, 2018). Although access is an important step, it does not alone guarantee better participation, performance, persistence, and experience. In Ethiopia, women students' graduation rates, performance, and participation in university education are low, and their educational attainment, especially in science and engineering, is lower than that of men students (Kassie, 2018). Several factors affect women students' academic participation and experience in engineering, and a sense of belonging might be one of them.

Exploring a sense of belonging of Ethiopian women students in engineering is particularly important for three reasons: (1) the study setting: Ethiopia is a patriarchal society that historically has discriminated against women (Jebessa et al., 2015); (2) the discipline: engineering is a stereotypically masculine-coded profession (Cheryan et al., 2020; Jagacinski, 1987); and (3) the admission system: the Ethiopian Ministry of Education (MOE) uses a centralised admission system to assign students to universities and study programmes. Through the following specific research questions, this study explored factors hindering and facilitating women students' sense of belonging in engineering and how the perceived sense of belonging impacted their academic participation and experiences. The study addresses these two questions: (1) How do women students studying engineering in Ethiopian universities perceive a sense of belonging in their major, engineering college, and university? and (2) How does women engineering students' perceived sense of belonging influence their academic participation and experiences?

Literature review

Globally, more women are enrolling in universities than men. In 2019, 54% of students awarded a degree were women (Zahidi, 2022). Despite this trend, gender disparities in tertiary education have been a topic of concern for many years (Saadat et al., 2022). Women face more discrimination regarding access to education (Hurtado, 2021; Zahidi, 2022). However, the gender gap in education has decreased significantly, especially in primary education (Hurtado, 2021). According to the Global Gender Gap Report (Zahidi, 2022), in 2020, 88% of females worldwide had primary education compared to 91% of males; the gender gap is most prevalent in STEM fields, with women being under-represented, and women's participation in health and welfare fields decreased while it increased in education. The distribution of learners by field in 2019 showed that tertiary education continued to be segregated by gender; for example, between 2013 and 2019, the gender gap in ICT and engineering and manufacturing remained mostly intact (Hurtado, 2021; Zahidi, 2022).

The Ethiopian context, however, is different. Women's access to higher education has improved, but their attrition has continued to be a challenge (Tamrat, 2022), resulting in the 'worse female under-representation in science and engineering fields' (Kassie, 2018, p. 1). In his study that assessed the student attrition rates in 15 Ethiopian public universities, Tamrat (2022) observed an alarming rate of consistent loss of female students across all 15 universities. He identified that 'more than half of female students enrolled in most universities do not progress to the final year' (Tamrat, 2022, p. 7). He thus concluded that men's graduation rates are higher than women's graduation rates. In research conducted in 2018 at Addis Ababa University, the Ethiopian flagship university, Kassie (2018) identified that:

> The gender gap in enrolments, graduates, and honors lists in the last five years remains wide in favor of males. Females' under-representation was worse in science and engineering … females' educational attainment was lower as compared to males, and their attainment in science and engineering fields was lower than that in the social sciences (2018, p. 1).

The above quote demonstrates wide and apparent gender gaps in engineering (compared to social sciences), honours, and the persistence of the gender gaps over time.

According to Asfaw (2012), there are three significant factors hindering women in education and gender disparity in Ethiopia: '(1) the challenge of translating policies into practice, (2) gender factors outside of education, and (3) favoritism of boys' (p. 2). Additionally, gender equity in education is affected by socio-psychological, academic guidance and counselling, and financial challenges (Tamrat, 2022).

Further, sexual violence is also one of the common challenges for women students in Ethiopian higher education institutions (Mamaru et al., 2015; Sidelil et al., 2022; Hassen & Mohammed 2021), and most do not share what happened to them. For instance, Hassen & Mohammed (2021) assessed the prevalence of sexual violence and associated factors among female students at Debre Berhan University—a public university in Ethiopia in 2016. In their findings, out of a total of 627 undergraduate female students selected via multistage sampling technique and surveyed, 51.8% experienced sexual violence, 12.8% experienced attempted rape, 9.8% experienced rape, and "more than half of the rape victims (35, 57.3%) did not share their experiences with anyone" (Hassen & Mohammed, 2021, p. 1). Sidelil et al. (2022) conducted a study with women students and found that sexual harassment such as staring, insults of a sexual nature, unwanted and persistent requests for dates and sexual relationships, and threatening students with grades to advance the sexual interests of the perpetrators 'is rampant, normalised, and persistent within universities, especially in STEM institutions' (p. 4). Consequently, the learning environment is often hostile for women: 'Women's restricted and inequitable use of space on the campus is directly attributable to the pervasiveness of sexual harassment as a manifestation of hostile gender relations enabled by institutional culture' (Sidelil et al., 2022, p. 7). Some universities have a zero-tolerance policy for sexual harassment (Bezabeh, 2016; Marsh et al., 2009). Unfortunately, they do not enforce this policy due to 'absence of clear policy directions, widespread denial, misrecognition and inaction about this prevalence, which leads to institutional neglect and inaction' (Sidelil et al., 2022, p. 12).

Based on available places and the acceptance capacity of each university, Ethiopia has a centralised admissions system in which all institutions are set undergraduate admissions by the Ethiopian MOE (Trines, 2018). In theory, prospective students indicate a prioritised/ordered list of majors they want to pursue and/or universities they wish to attend. Thus, in principle, while some students prioritise getting a major of choice (over the learning institutions), others prioritise attending the university of their preference (whatever the major is). A very few outstanding students are fortunate to major in the field of choice in their first-choice learning institutions. The majority, however, including engineering students, are assigned to their study majors and universities largely decided by quota, with little consideration of students' interests, based on Ethiopian Higher Education entrance examination results (Halkiyo et al., 2023; Trines, 2018). This means, 'students are admitted to the programme after scoring above a centrally determined admission cut-off point on a pre-college entrance exam' (Gofere, 2022, p. 2). This indicates a student's admission process is less likely to include their interest in their assignment to learning institutions and/or their study majors (Halkiyo et al., 2023). That is, many students of all genders, especially those who score less on university entrance exams, have limited autonomy and agency to choose what to study (their majors) and/or where to study (their universities) (Trines, 2018), hence the career they want to pursue after graduation. Thus, except for some outstanding students who may be assigned to the major of choice, the central admissions system plays an important part for most of the students in determining whether they do the courses they want, also hindering their sense of belonging in the major.

Given the national interest of the country to produce as many engineers as possible to help with the transformation of the country into a middle-income one, the likelihood of students assigned to STEM fields against their interest, especially in engineering, is very high in Ethiopia.

Because of this admissions policy, we expect that women students' admission experiences might be one factor that impacts their motivation and ability to develop a sense of belonging in an assigned university and major.

Globally, many countries are increasingly adopting centralized student admission systems (Kutscher et al., 2023). In centralized student admission systems, a single body oversees the admission process across multiple institutions. Proponents of these centralized admission systems claim that these processes make enrolment processes more transparent, efficient, and equitable (Elacqua, 2021; Kutscher et al., 2023). However, there is growing concern that these centralized admission systems might not make enrolment processes more equitable and could unintentionally lead to more segregation (e.g., they can lead to less socio-economic diversity in schools (Kutscher et al., 2023)). In decentralized student admission systems, student admission processes are overseen by an individual institution or program. Decentralized student admission systems can be a strength as the criteria for admission could be better aligned with the institution's values. A weakness of decentralized student admission systems is that it can be difficult for potential students to navigate many different admission systems.

In Ethiopia, there is a centralized student admission system, where the government selects the institution that a student will study within. Institutions place these selected students into academic units, but are required by the government to place 70% of students into science and engineering and 30% in social science, humanities, and education (Mekonnen et al., 2021). The administrators have no autonomy in decision-making over admissions and little autonomy over academic unit placement, and students have even less autonomy or agency in these decisions. Because students have little control over these placements in their institution or academic unit, they likely feel a loss of agency and feel disempowered, which would easily lead to a loss of sense of belonging. In a United Nations Research Institute for Social Development discussion paper (Kabeer, 1999), there is a discussion about the importance of empowering women through policy choices. These centralized student admission systems and requirements for placement of students in academic units may claim to encourage more gender equity, but because they strip the power of women in their countries even more by forcing them into specific universities and majors, may instead be reproducing gender inequality. Kabeer (1999) explains that 'one way of thinking about power is in terms of ability to make choices: to be disempowered, therefore, implies to be denied choice'

(1999, p. 8). In the case of these centralized student admission systems and restrictions on placement of students in academic units, governments are disempowering women, thus denying them their choice.

Theoretical framework

This study's theoretical framework is anchored in the concept of a sense of belonging, emphasizing the human need for both social and academic integration. Strayhorn (2019) posits that a sense of belonging is a core motivator, with social identities intersecting to influence college students' belonging. McLaren (2009) further defines a sense of belonging as "personal involvement and integration within a system or environment, wherein individuals feel they hold a unique role" (p.3). Building on Maslow's (1943) perspective of a sense of belonging as the need for interpersonal connections and acceptance, Strayhorn highlights how individuals seek relationships to fulfill this need. The conceptualization of a sense of belonging within educational settings encompasses perceptions of acceptance, membership, and sharing of lived experiences, thus fostering intentional connections and learning opportunities. Strayhorn (2019) underscores how belonging informs students' affiliation with disciplines, peers, and institutions, impacting their academic engagement and outcomes.

Previous research, exemplified by Xu and Lastrapes (2022), Abrica et al. (2022), and Cwik & Singh (2022), demonstrate the significance of a sense of belonging in various contexts, such as STEM career interest, community building, and academic performance. For instance, in studying the impact of a STEM-related sense of belonging on career interest, Xu and Lastrapes (2022) found that 'female students' STEM sense of belonging had an indirect impact on their career interest via its correlation with STEM attitudes' (p. 1). Abrica et al. (2022) also used a sense of belonging in study community building within a STEM intervention programme with a focus on Latinx male undergraduates' experiences. Similarly, in studying students' sense of belonging in introductory physics courses for bioscience majors, Cwik & Singh (2022) found that 'women had a lower sense of belonging and grade than men in the course and that the student's sense of belonging played a major role in predicting students' grade in the course' (p.1). Moreover, in studying how Latinx dual credit earners describe their sense of belonging in engineering programmes, Allen et al. (2018) concluded that while the interactions (with faculty, advisors, and peers) facilitated a strong sense of belonging, 'the size and rigor of classes, distance to campus, outside responsibilities, and feeling like an outsider' hindered students' sense of belonging at the institution (p. 1). These studies show the importance of understanding sense of belonging within different contexts.

This study positions a sense of belonging as a crucial lens for understanding and enhancing students' experiences within academic environments. We conceptualise a sense of belonging in learning environments as students' perceptions of acceptance, of being a member, and claiming lived experiences within academic settings, for instance, sharing personal differences with peers, classmates, or faculty. The above conceptual definition is adopted to understand and examine what helps students feel belonging within a university, or engineering discipline, to create intentional connections and learning experiences.

Methodology

Research context

This study was conducted in Ethiopia – a patriarchal society where men hold dominant positions in the economy, politics, leadership, socio-cultural domain, the university professoriate, and certain majors and professions, such as engineering (EqualEngineers, 2019; Tadesse, 2021; Yossi, 2017). Historically, women in Ethiopia have faced discrimination, with limited representation in influential social, cultural, and political roles. For example, there has been no woman prime minister or speaker in the parliament, and leadership roles in major religions have been exclusively held by men. Household headship has traditionally been assigned to husbands. Men have dominated tertiary education. University leadership roles (e.g., board directors, university presidents and vice presidents, college deans, school directors, and department heads) have always been dominated by men. Society has largely preferred daughters to marry at an early age, be 'good/submissive' wives, and have children rather than, for instance, pursue higher education and become professors, engineers, or scientists. Thus historically, fewer women students have been admitted to universities and non-STEM majors. Women students who do enrol face pervasive gender stereotypes, sexual harassment, and violence (Dea, 2016).

To address these disparities, the Ethiopian government introduced gender-related policies and laws aimed at promoting gender inclusivity across all aspects of life, including education, politics, economy, and leadership. In the government's pursuit of becoming a middle-income country, Ethiopia implemented measures to increase the number of STEM graduates, intentionally including both men and women. While these gender policies are commendable on paper, critics argue that their implementation has been limited due to inadequate infrastructure and resources. It is worth noting, however, that recent efforts by Prime Minister Abiy Ahmed, who assumed office in 2018, have brought about significant changes. These include appointing the first woman president, head of the Supreme Court, and head of the Electoral Board, as well as increasing women's representation in parliament from under 5% to 38% (Bishu, 2022). The Ethiopian cabinet has also achieved gender parity, with women occupying from less than 9%, to '50 % of the government's top ministerial positions' (Belete et al., 2022, p. 72). Despite these circumstances, few women in Ethiopia pursue university studies, including engineering, and most still occupy largely marginalised positions in society.

Research site and participants

This study was conducted at an engineering college at one of the mid-sized public universities in Ethiopia in 2021. Four interviews were conducted with four women students pursuing engineering in diverse majors (see key demographics summarised in Table 1). We used purposive sampling (Tongco, 2007) to recruit study participants based on inclusion criteria such as age (18 years or older), discipline (enrolled in undergraduate engineering), gender (identify as women), seniority (fifth year or above), and willingness to participate in the study. In addition, we considered fifth-year students in the belief that they could provide richer and more detailed responses about their academic experiences due to the longevity of their stay in the university (Tongco, 2007). The recruitment strategies include professional networks, campus postings, emails, and snowball sampling.

Table 1. *Participants' demographics: women students in engineering (n = 4*)*

Participants (pseudonyms)	**Major (discipline)**
Biftu	Civil Engineering
Meto	Electrical and Computer Engineering
Rom	Civil Engineering
Lidia	Construction Technology and Management Engineering

* = Participants are fifth-year students – the normal time span for Ethiopian university students to reach seniority.

Design and data collection methods

We used an exploratory qualitative inquiry using a narrative design emphasising subjective meaning-making (Crotty, 1998). Specifically, we used narrative semi-structured interviews, with an interview protocol composed of ten questions (see appendix for the protocol). The interview protocol began with a question that elicited the respondents' narratives of how they became engineering students. The protocol also included questions about women students' sense of belonging within their engineering programme, the college, and the university, factors hindering and facilitating their sense of belonging, and how their sense of belonging impacted their academic participation and experiences. Some interview questions included:

- How would you describe your education journey?
- Was engineering your first choice?
    - If so, what made you decide to major in engineering?
    - If not, who assigned you and why?
- Do you feel you belong in engineering?
    - If so, why do you feel a sense of belonging in engineering? Could you give me an example of when you do feel a sense of belonging in engineering?
    - If not, why? Could you give me an example of when you do not feel a sense of belonging in engineering?
- What does your interaction look like with your peers and faculty, and how does their gender affect your interaction?

Following the receipt of Institutional Review Board (IRB) approval, we conducted the interviews in English. In cases of participants with low English fluency, we used Afaan Oromoo, one of the widely spoken languages in Ethiopia. The interviewer, the first author of this paper, provided participants with interview questions in advance and gave them a range of ideas about what a sense of belonging means. While we recognise that providing interview questions in advance could hinder data quality (in case the participants artificially prepared possible responses), such an approach benefited the study outcome. It significantly enhanced the efficiency of the data collection process when the interviewer and the participants experienced multiple interruptions due to the weak internet signal. That is, by having the interview questions in advance, participants spent much of their time responding to the questions instead of struggling to hear and understand them. The interviews ranged from 40 to 50 minutes and were conducted remotely via Zoom technology, the preferred data collection platform, as the study was conducted during the Covid-19 pandemic, and the interviewer (Jemal) was in the US with the participants in Ethiopia. We compensated the participants for their time and ideas. Two were compensated 23 USD each for participating in the interview, while the remaining two were compensated 35 USD each for participating in the interview and sending additional data through structured email because of fluctuating communication during interviews due to the poor network connection. Even though there was some risk of biasing participants, it was important to follow best practices around ethical compensation for research participants and to treat our participants fairly and avoid any possibility of taking advantage of them (Gelinas et al., 2018). The compensation was included in the IRB application at our institution and details of compensation were included in the consent form. Further, we obtained consent from participants and collected demographic information via email.

Data coding and analytical approach

All interviews were audio-recorded. Due to the usage of two languages, meaning-based translation and transcription were conducted by Jemal, the first author, who is fluent in both languages. Another PhD holder who was not one of the co-authors checked the accuracy of the translations to help confirm the translations and reduce researcher bias. This independent researcher was Ethiopian-born, trilingual (fluent in the languages used in the study) and had expertise in qualitative inquiries and publications. In addition, this study was considered cross-cultural research, where we used two languages during data collection. Thus, we used meaning-based translation to reduce the possibility of losing the complexity and richness of meanings and potential misinterpretations (Birbili, 2000; Liamputtong, 2010).

Data coding and analysis were conducted in three steps. First, we engaged in inductive–iterative, and ongoing reading and coding of emergent insights, and deductive coding – applying a researcher-developed codebook composed of 15 codes (Creswell & Creswell, 2017). At this stage, we read the transcripts and inserted codes as shown in column three of Table 2. For example, some preliminary codes included *civil engineering as my first choice, MOE assigned to civil engineering, and study at the 5th choice university.* In the second step, we organised the codes by checking the consistency of code names with the research questions across all interview transcripts. Third, we organised codes of similar meaning into categories to form themes (Creswell & Creswell, 2017). For example, the three preliminary codes mentioned earlier in this paragraph were combined into a theme of *student admission systems.* For more examples, refer to column four in Table 2. Further, we solicited feedback from the research team and two qualitative research professors on all study steps to enhance the quality and trustworthiness of the study planning, data collection, analysis, interpretations, and reporting. This included but was not limited to revising the interview protocol and codebook, piloting interviews, and soliciting feedback from co-authors and other colleagues as coding and analysis progressed through the project (Saldaña, 2021).

Table 2. *Example of the analytic process for data excerpts*

Participants	**Interview excerpts**	**Preliminary codes**	**Themes (codes)**
Biftu	… As I grew up, [1] I developed an interest in civil engineering-related jobs like construction works and building diverse roads. Deep inside, I like doing such jobs and activities. I was wishing them. [2] From the very beginning, my interest was not only to major in engineering, [3] but also in civil engineering … I scored a great GPA,[4] chose civil engineering as my first choice, and I got it. Thus … [5] I view the discipline as mine.	[1] Interest in Civil Engineering jobs [2] Interested in Engineering [3] Interested in Civil Engineering	Sense of belonging in Engineering (1, 2, 3, 5, 6, 7)
Rom	... My dad has a high passion for education. He makes a big effort to educate his children. His interest is as I achieve big things in education. I started and completed my primary and secondary education in the countryside, where I was born. Afterward, I attended a preparatory class where my brother works. I have an interest in education, [6] I have a particular interest in studying Health Sciences. [7] I was studying Biology. I have a high grade in it as well. I was studying Biology since I have an interest to join Health Sciences. [8] However, they [MOE] assigned me to a	[5] Civil Engineering is mine [6] Interested in health science majors [7] Like Biology [4] Civil Engineering is my first choice [8] MOE assigned to	Student admission

	discipline, I didn't choose without my interest. [9] They gave me my 5th choice university.	Civil Engineering [9] Study at 5th choice university	systems (4, 8, 9)
Lidia	... In my opinion, [10] men and women peers are more open to each other than women and women ... The relationship I have with women's peers is average ... [11] I easily fit in with men peers … The other reason is that women's peers have jealousy, thus I do not have a great relationship … For me, men peers are more positive. When they help me, they openly discuss their ideas when I ask them questions. [12] Regarding faculty, I more openly relate to my women faculty, than my men faculty, to the extent that the women faculty provides me with advice ...	[10] Had more interactions with men peers [11] Prefer men peer interactions over women [12] Had women faculty interactions [rather] than men's	Interactions with peers and faculty (10, 11, 12)

Limitations

Some participants experienced intermittent communication during the interview due to poor network connection, and additional data were collected through structured email for some sections of interview protocols that were not fully covered during the interviews. A structured email interview is one of the qualitative inquiry and research design approaches used to collect intensive qualitative data when the inadequacy of video data collection is experienced (Fritz & Vandermause, 2018). In future research, it would be helpful to conduct interviews locally and in person so that there is no issue with internet connectivity.

We believe that it would strengthen this study to include Ethiopian women researchers as part of the research team. Because we did not have any connections with Ethiopian women researchers, we leveraged the expertise and experiences of the two US-based women researchers in this study. Yet we acknowledge that the direct experience and nuanced and in-depth understanding and appreciation of the issues faced by the target population as experienced by Ethiopian women researchers/faculty members in engineering education is still missing. In future work, we would like to collaborate with Ethiopian women researchers who are interested in similar research areas.

Positionality, credibility, and trustworthiness

The research team member comprised of two Ethiopian men and one American women. The first author, Jemal, is a Black man is was also a senior doctoral student in engineering education. The second author, Sultan, is also a Black man, specialising in civil engineering, and is a faculty member and department head at Bule Hora University in Ethiopia. The third author, Nadia, is a white woman, an engineering education professor and the advisor of Jemal. She is also a scholar, with her research agenda involving diversity, equity, and inclusion-driven academic research efforts.

All three research team members had studied and/or researched engineering education and shared commitments to equity and justice in education. Each of the research team members also shared elements of identity with the study participants and thus could relate to the research topic, which together provided a starting place for intuitive knowledge, and enhanced understanding and interpretation of the experiences of the study participants (Secules et al., 2021). Accordingly, the woman co-author shared aspects of their gender identity with the participants and could share associated women's experiences in higher education during data analysis, although they had not experienced higher education in Ethiopia. The two Black men shared nationality, ethnicity, trilinguality, and having a major in an engineering discipline. They both had studied engineering, taught engineering, served as engineering department heads, and conducted research at one of the public universities in Ethiopia. They also had a sister who had studied engineering (bachelor's degree) and was pursuing a master's degree in engineering. As siblings who had close contact with their sister in supporting her in her academic pursuit, they were aware of the struggles women in Ethiopia could face in higher education, especially in engineering. Furthermore, the diversity in the researchers' identities, expertise, and experience enhanced the reflectiveness of the research process. For instance, while the two Ethiopian-origin men research team members enhanced the understanding of the Ethiopian context and men's perspectives in patriarchal Ethiopia, the US-based woman researcher facilitated our understanding of women's experience in engineering in the broader global context.

Findings

Women students were asked to discuss their educational experiences to explore their sense of belonging in the engineering major, college, and university; factors hindering and facilitating their sense of belonging; and how their perceived sense of belonging impacted their academic participation and experiences. The four themes that emerged were student admission systems, sense of belonging contexts, women student interactions with peers and faculty, and factors facilitating and hindering a sense of belonging. These themes are described in the following sections.

The impact of the student admission systems

During the interviews, students discussed whether the engineering major was their own choice or assigned by the Ethiopian Ministry of Education. The findings indicate that two of the participants, Biftu and Lidia, had selected their majors; however, Rom and Meto were assigned engineering majors by the Ethiopian MOE.

Biftu, who majored in engineering as her first choice, stated that growing up, she was inspired by engineering-related work and wanted to become a civil engineer one day.

> Growing up, I became interested in civil engineering-related jobs like construction work and building diverse roads. Deep inside, I like doing such jobs. I was wishing for them. From the very beginning, my interest was not only in majoring in engineering but also in civil engineering ... I scored a great GPA, chose civil engineering as my first choice, and got it. Thus … I view the discipline as mine (Biftu).

Here, the data suggested that Biftu had a strong passion for her major and pursued civil engineering with great dedication. Further, pursuing a major that aligned with her interests and goals could certainly offer her a positive sense of belonging regarding her study major.

Rom and Meto, assigned to engineering by the Ethiopian MOE, initially wanted to major in medical fields. Rom, interested in majoring in medicine or health, stated that the government assigned her to her engineering discipline and university.

> No, engineering was not my choice. My choice was to study medicine or health officer. Engineering was my 5th choice. The MoE assigned me to pursue engineering. Additionally, I was assigned to the university by the government (Rom).

Rom and Meto, assigned to engineering by the government, did not have the autonomy and agency to choose a major of their interest, hence, their future careers were selected for them by an external entity, the Ethiopian MOE. For instance, Meto indicated, 'Engineering was not my choice … I wish not to identify with it. The root of engineering is physics, and I did not like physics, and due to that, I do not like engineering either.' The data indicate that Rom felt she had a partial sense of belonging, while Meto did not have a sense of belonging. Therefore, it is not surprising to learn that Rom and Meto struggled in their majors.

The impact of sense of belonging contexts

Students' sense of belonging on campus is crucial for success and persistence in their study programmes. A higher sense of belonging in the learning environment helps students feel respected and welcomed and enhances their confidence. During the interviews, the students discussed whether they felt a sense of belonging in their major, engineering college, and university. Through probing, they also disclosed reasons why they did or did not feel that they belonged in the major, engineering college, or university. This theme consists of three sub-theme contexts based on the student experiences and with which they had reflected their sense of belonging: 1) women students' sense of belonging in an engineering major, 2) women students' sense of belonging in an engineering college, and 3) women students' sense of belonging in the university.

Sense of belonging in the engineering major

Biftu and Lidia explained that they felt that they had a sense of belonging in an engineering major. Meto did not feel a sense of belonging in engineering, while Rom felt that she partially belonged. Biftu, who felt a sense of belonging in engineering, had an interest in the field from an early age, and that explains her sense of belonging in the major:

> I decided to major in engineering since grade 7. I started focusing on courses that incline to have many calculations. Growing up, I became interested in civil engineering-related jobs like construction work and building diverse roads (Biftu).

Biftu, who had a clear interest in engineering from an early age, had a strong passion for civil engineering, and post-graduation engineering jobs. Meto, who felt that she did not belong in engineering, was assigned to the major without her interest and disliked engineering-related subjects, such as physics.

> I do not like electrical and computer engineering. I wish not to identify with it. I was interested in health-related disciplines like biology. I never thought of majoring in engineering. The root of engineering is physics, and I did not like physics (Meto).

Here, Meto was admitted to electrical and computer engineering, a major that did not align with her interests and passions, which limited her sense of belonging.

The data suggest that autonomy and agency in choosing a major, and a sense of belonging in the major, aligned. For instance, Biftu majored in engineering and felt a sense of belonging in engineering. In the quote in the prior section, Biftu stated that she 'was wishing [for] them [civil engineering jobs and activities]' and continued, 'Thus … I view the discipline as mine'. This suggests that Biftu felt that she had autonomy and agency over choosing her major, and thus felt a sense of belonging in her major. On the other hand, Meto, who was assigned to engineering by the government and did not have autonomy and agency over choosing her major, felt that she did not belong in engineering. In the quote provided above, she said that she 'wish[es] not to identify with it [electrical and computer engineering]', indicating that she felt that this major was not her own choice, but was forced upon her. Having the agency to choose one's major seems to have direct implications for having or not having a sense of belonging in the major: those who chose their major felt a sense of belonging in it, and those who were assigned to their major did not.

Rom felt a partial sense of belonging in civil engineering because her two older brothers had graduated in the major and encouraged her to pursue it. However, she did not feel that she belonged in engineering because she felt that working on remote sites was dangerous for women in Ethiopia.

> The challenges are especially difficult for women in our country. The first reason is that most civil engineering works are in the field, for instance, road construction, bridge, railway engineering, and building engineering. For all these types of work, you have to go to the sites … they are site-based jobs that make women vulnerable to different challenges. The second reason is most engineering works in our country are not supported by machinery … it is done manually, leading to health and safety problems for workers. Thus, my interest in engineering is not that great (Rom).

Although Rom was assigned to engineering by the Ethiopian Ministry of Education, she felt a partial sense of belonging within civil engineering because her siblings encouraged her to persist. Yet she was alienated from civil engineering because, in Ethiopia, engineering jobs are primarily done on site (making women vulnerable), and engineering jobs are dominated by manual work. Thus, Rom believed that expected post-graduation work experiences, job stability, and satisfaction impacted her sense of belonging with regard to her major.

Sense of belonging in engineering college

Biftu and Meto felt they belonged in an engineering college, whereas Rom and Lidia felt a partial sense of belonging. Biftu felt a sense of belonging in the engineering college because of the freedom and social life, lack of discrimination, and conducive and well-equipped library to study in:

> … I see it [engineering college] as my home. The reasons are freedom since it is a government university, the college is equal for all students, the social life in the university, and the rules and regulations equally apply to all, there were no discriminations … The other reason … sufficient books in its library, and no one disturbs you in the library (Biftu).

Thus, for Biftu, some elements of democracy and equality (freedom, absence of discrimination, rules applying equally to all, absence of others who disturbed her) were important determining factors for her sense of belonging in the engineering college.

Rom felt a partial sense of belonging in the engineering college. Lidia did not feel a sense of belonging in the college because of 'weak facilities and lack of technical and laboratory materials'. On the other hand, Rom felt some sense of belonging in the engineering college because of the college's larger goal – 'solving the community's problems'. However, she was alienated from the college because of its limited attitude and efforts towards addressing the quality of education, limited monitoring practices with regard to faculty teaching, and the college's inability to provide sufficient practical aspects of the courses, e.g., laboratory courses.

Sense of belonging in the university

Three of the participants felt a sense of belonging in the university, while Biftu felt a partial sense of belonging. The three participants had a sense of belonging in the university for different reasons.

For Meto, ‘It is where I gained life experience, where I started and completed my university education’. For Lidia, her university was a place with ‘lots of special friends and memories’. For Rom, the university was her first institution after her home high school where she met Ethiopian students from all over the country and from many ethnic groups. Interestingly, Meto was assigned to her major (unsurprisingly, she did not feel a sense of belonging in this regard) but felt a sense of belonging in the engineering college and university. This implies that students may have a different sense of belonging in various aspects of the engineering community; they may feel they belong in a major but not an engineering school or university.

Biftu, who felt a partial sense of belonging in the university, ‘... wanted to go to Addis Ababa University’ – Ethiopia’s most prestigious university – ‘because such big universities have sufficient laboratories and faculties; thus, I could get better quality education. But, unfortunately, this university hasn’t had many engineering materials’. Biftu did not feel a sense of belonging in the university because the university was not her first choice, and it did not have sufficient laboratories.

The impact of interactions with peers and faculty

We explored the interactions of women students with their peers and faculty to see if their interactions and gender mattered to their sense of belonging. This theme consists of two sub-themes: 1) interaction with peers, and 2) interaction with faculty.

Women student interactions with peers

Most of the participants – three out of four women students – had positive interactions and a sense of belonging with men peers. Biftu and Rom preferred interacting with male peers because they thought men were more open to sharing information, providing more support, and being more positive. Further, they believed women were less receptive and exhibited jealousy.

> My relationship with male peers is great … It is easier for men and women to interact; we can easily relate. There is this thing called ‘opposite charge attracts each other’. In my opinion, men and women peers are more open to each other than women and women ... Women too, than for other women, they are more open for men peers … The relationship I have with women peers is average. Naturally, I easily fit in with men peers … The other reason is that women peers have jealousy, thus, I do not have a great relationship … they are not open. If you ask men and women

> peers the same question, who answers for you first? Men. The reason is men are more open. For me, men peers are more positive. When they help me, they openly discuss their ideas when I ask them questions (Biftu).

At this point, Biftu suggests that women students with a high level of interactions with peers demonstrate a stronger sense of belonging, which is directly linked to helping the efforts of students to develop learning experiences in academic settings. While Meto did not have any preference for peer interactions, Lidia had negative interactions with men peers, as they underestimated women and ignored her in group activities, thus she preferred women peers.

> It is very poor, interaction with my male classmates because most underestimate women in educational affairs. This makes me feel sad and embarrassed. … Most males ignore us in participating teams. I prefer belonging to my woman classmates … It makes me feel good and motivated to perform better (Lidia).

Lidia's negative experience with men peers underestimating her intelligence in engineering matches the stereotypes in Ethiopian society; lower expectations for women, especially in engineering (Trines, 2018), which shows the persistence of the same stereotype across time and culture: that engineering is a masculine profession.

Women student interactions with faculty

Biftu and Rom had positive interactions with male faculty. However, Biftu preferred female faculty members as she thought they were more open to help and discuss whatever she wanted without fear because of gender similarity.

> I more openly relate to my women faulty than my men faculty, to the extent that the women faculty provide me with advice. For example, I have a close relationship with Professor Leensee [pseudonym, her favourite women professor] ... My relationship with her goes beyond the classroom and extends to her office, where I ask questions beyond the classroom. I admire the way she taught us. She is often willing to entertain our questions. I prefer women faculty. You can openly ask women faculty whatever you want because we both are the same sex … I am not afraid of talking to them. Men faculty, however, we respect them, but I also fear them …we women students are afraid of talking about whatever we want with them. You have to be cautious when you establish your relationship with men teachers, you have to ask just about academics (Biftu).

In the above quote, Biftu had more open and extended positive experiences with women faculty as they shared more elements of identity. She suggested how she, as a women student, needed to be cautious around men faculty.

In contrast, Rom preferred male faculty members because she thought men took more time to provide support academically, for instance in tutorial classes. 'Men faculty … give us more time to support us. On tutorials for women students, men faculty, most of the time take their time and provide us tutorial classes more than women faculty' (Rom). Rom described more positive experiences with male faculty members, suggesting the subjective experience of women students with faculty of a different gender.

To build a sense of belonging and educational experiences, the sameness in the gender of a faculty member is essential for some students; for instance, Biftu preferred women faculty members to be able to openly communicate even beyond academic matters, while for Rom, the level of support faculty offers mattered more than their gender identity, and she preferred male faculty. On the other hand, Meto could not make any gender preference as she had only had one woman teacher in her five years at the university.

Factors facilitating and hindering a sense of belonging

We also analysed factors that could facilitate or hinder students' perceptions of a sense of belonging. Accordingly, the data suggest that the choice of major by the admission system, the status/prestige of the university, the gender identity of peers and faculty, and the provision of support affect the students' sense of belonging. Selecting a major and pursuing engineering according to one's interest, as was the case with Biftu, who 'decided to major in engineering since grade seven and made it her goal to major in engineering', seemed to enhance her sense of belonging in engineering, in contrast with Meto and Rom, who did not feel they belonged in engineering as they were assigned their majors by the Ethiopian MOE despite medical sciences being their first choice.

The status of the university, its prestige and level of resources, also affected sense of belonging. For instance, Biftu did not feel a sense of belonging in the university because her first choice was Addis Ababa University, the Ethiopian flagship, and a well-resourced university. Not only Biftu – most participants had a limited sense of belonging in the university due to limited facilities, especially laboratories, thus limited ability to facilitate practical aspects of their courses. They were thus obliged to do laboratory applications in other universities.

The preferred gender of faculty depended on the context. With peers, Biftu and Rom preferred to have men peers, but with faculty, Biftu preferred women because she believed she could talk without fear about anything, including advice beyond the academic. In contrast, Rom preferred male faculty because she thought they took more time to support and 'provide tutorial classes more than women faculty' (Rom). It should be noted, however, that most of the women participants indicated that they had to be 'cautious' with men peers and faculty and focus on academics due to the prevalence of sexual violence, the university's limitations in enacting gender violence policies, and instance of advances from some faculty to exchange high grades for sexual favours. That is why Lidia (one of the study participants) recommended that 'there should be strict laws and regulations … preventing…harassments for all university students and workers'.

Discussion

The students were aware of the importance of having autonomy and agency in choosing their major and university and how this affected their sense of belonging in their major, engineering college, university, and academic experience. Our findings align with a study by Murtagh et al. (2011) who found that students feel a greater sense of belonging and satisfaction when they make decisions about major choices and careers based on intrinsic motivations than when being forced by external agencies.

Another insight from the analysis is that the effect of a student feeling a sense of belonging (or not) to an engineering major, college, and university is not necessarily parallel. A student may feel they belong in their major but not in an engineering college or the university. This suggests that students who feels they belong in a major may still have a different feeling of belonging in an engineering college or university and vice versa. Hurtado et al. (2007) similarly found that students' sense of belonging in their major was associated with positive feelings about their learning experiences, even though they did not have a consistent correlation with their sense of belonging in the learning institutions.

Similarly, various students viewed the same thing differently. For instance, Biftu viewed the engineering college as having a conducive and well-equipped library, and this was one of the factors that made her feel a sense of belonging at engineering college. Yet, Lidia viewed the engineering college as having 'weak facilities and lacking technical and laboratory materials'. Thus, among the factors, she did not feel a sense of belonging with regard to the college. At this point, there was a diversity of ideas and preferences around when women students chose a major and university, or on values whereby they prioritised a sense of belonging. If given the agency and freedom to choose a major and/or university, a woman may value different components of the university. Some women students may prefer to join a university that offers an enjoyable student life, while others may want to forgo the student life and instead study a major of their choice. Such freedom and agency may enhance a sense of belonging, inclusivity, and satisfaction. Also, engineering colleges may need to be conscious of variations in students' values and expectations of standards and aim to address the needs of as many students as possible. In doing so, engineering colleges may need to explore and compile common factors, reasons, and values that make many students feel that they do or do not have a sense of belonging within engineering colleges and sustain the elements many students find important for an enhanced sense of belonging (Halkiyo et al., 2023).

Regarding gender preference with regard to building learning experiences, the participants' interactions with peers and faculty were nuanced and pragmatic. Their gender preference seemed to depend on women students' personalities and individual experiences, teachers' enthusiasm and willingness to support students, and gender identity, and these factors had diverse impacts on sense of belonging. This indicates that gender is not static and gender preference differs between peers and faculty, depending on who provides more support in a particular situation and what is important for women students. This is consistent with findings in the literature that an individual's sense of belonging changes based on situations; 'thus, a student with a high sense of belonging in a certain educational context can have a low sense of belonging if they move into a different educational context' (Lee et al., 2019, p. 3).

It should, however, be noted that women students in Ethiopia know that 'sexual harassment is endemic across universities in Ethiopia and affects the psychological, emotional, and physical well-being of women' (Sidelil et al., 2022, p. 2). These students felt they had to be cautious around men students and faculty because sexual violence (e.g., sexual harassment, attempted rape, and rape) is common and persistent in Ethiopian higher education institutions (Adinew & Hagos, 2017). Male instructors engage in sexual advance as an exchange for better grades, or threaten to give bad grades (Bezabeh, 2016), and the universities do not do much to prevent sexual violence. Students also know that 'male academics force female students to comply with their sexual demands … may threaten students with their grades; others bribe students with grades to advance their sexual interests' (Sidelil et al., 2022, p. 208). Despite women students calling for stronger and applicable gender violence-related laws, most universities fail to make violators accountable for their actions. This indifference and lack of action from the university side continue to lead to the persistent and unintended perpetuation of gender violence. Sidelil et al. (2022) argue that 'the high prevalence of sexual harassment in universities is perpetuated by institutional actions and inactions through which universities fail to proactively prevent and effectively respond to sexual harassment' (p. 1).

Implications

The findings of this study have some implications for policy, practice, and research. First, the Ethiopian government and policymakers at the MOE make two contradictory policy assumptions. On the one hand, the Ethiopian MOE is increasing the number of students in engineering disciplines to assist with transforming Ethiopia from an agriculture-oriented to an industry- and manufacturing-oriented middle-income country. At the same time, the government wants to reduce the attrition rate of women students and to have competent engineering graduates who will help transform the country. Against this, however, the Ethiopian MOE is also engaged in assigning some women students to engineering disciplines and universities against their interest. This diminishes women students' sense of belonging in their major and university, which may hinder their participation, experience, and performance, leading to increased attrition. Thus, the government should revise these contradicting policy choices and allow the autonomy and agency of women students to major in the discipline of their choice, hence, in the profession they want to pursue after graduation.

The practitioners, university faculty, and leadership may provide additional academic and social programmes to enhance the sense of belonging of women students in engineering, mainly tailored to those who have been assigned to a discipline and university not of their choice. Moreover, until women students feel safe in the university and do not have to deal with the threats of sexual violence, it will be near impossible for women students to truly experience a sense of belonging. This study confirms prior findings that point to systemic issues of sexual violence in universities.

Conclusion and future work

The importance of allowing Ethiopian women students in engineering to have the autonomy and agency to choose a major and/or the university of their choice is manyfold: it enhances their motivation to learn, helps them to persist, improves their university experience and academic performance, increases the chance of staying in the profession after their graduation, and improves their sense of belonging in their major, engineering college, and university. However, in addition to the agency and freedom to choose one's major and/or university, the students' sense of belonging was also affected by additional factors such as (1) the presence or absence of sufficient engineering resources (e.g., laboratories and library services), (2) gender identity of peers and faculty, and (3) openness and willingness of faculty to support women students.

The Ethiopian government and universities should note that a woman's positive sense of belonging in a major does not necessarily translate to a positive sense of belonging in an engineering college or university. The findings suggested that women students could feel a sense of belonging in their major but not the engineering college. Women students could have the autonomy to major in the discipline of their choice, yet they might not have a positive sense of belonging in the engineering college and/or university. Similarly, just because a woman student does not feel she belongs in her major (if assigned by the government), it does not necessarily mean she also dislikes her engineering college and/or university. The women students were more nuanced and pragmatic; for instance, they might still have a positive sense of belonging in an engineering college and/or university if it was equipped with enhanced engineering resources and a conducive learning environment free of gender violence. A similar situation was true regarding gender preference. While the gender (of peers and faculty) mattered to some, the enthusiasm and willingness to support women (despite their gender) mattered for others.

What is more concerning in this finding was that the government assigned two of the four women students to the discipline and the university against their interests. This was not only damaging in hindering the women's sense of belonging and associated benefits but also it is counterproductive to the effort universities make to increase the retention, persistence, and achievements of female students. Thus, the engineering college, university, and the government of Ethiopia may need to prioritise making engineering a safer and more inclusive space prior to forcing more women into this area of study because making these spaces more inclusive makes women more likely to stay in engineering. Furthermore, in addition to considering hiring more women faculty, Ethiopian universities may want to infuse professional development opportunities that enhance ethics, professionalism, and democratic culture (especially for men students and faculty). Above all, the government of Ethiopia should not infringe on the agency and autonomy of women students in choosing their major and/or university. Ethiopian women students are capable of making pragmatic decisions: what to study, where to study, what values they prioritise, and what they want to forgo.

In future work, we believe that it would be beneficial to consider how sense of belonging impacts Ethiopian women engineering students' future career aspirations and their completion of their undergraduate degrees. Sense of belonging may help us better understand not only their current situations, but also their future conceptions of themselves. It would also be beneficial to have a larger scoped study that considers other possible influences of women students' academic participation, experiences, and successes.

Acknowledgments

We extend our heartfelt gratitude to the Ira A. Fulton Schools of Engineering and Arizona State University, as well as Bule Hora University, for their invaluable financial support and collaboration throughout the data collection phase of this study. The opinions, findings, conclusions, or recommendations expressed in this material solely belong to the authors.

Dedication

On behalf of the researchers, we dedicate this research work to Bedane Halkiyo Anata (father of the first and second authors), who believed in wisdom, and in the power of education in dismantling backwardness and transforming one's life for good. Thank you for affording us (your children) the opportunity you did not get yourself – education!

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Appendix: interview protocol and probing questions

1. How would you describe your education journey?
2. Was engineering your first choice?
    A. If so, what made you decide to major in engineering?
    B. If not, who assigned you and why?
3. Do you feel a sense of belonging in engineering?
    A. If so, why do you feel a sense of belonging in engineering? Could you give me an example of when you do feel a sense of belonging in engineering?
    B. If not, why? Could you give me an example of when you do not feel a sense of belonging in engineering?
4. Do you feel you belong in the engineering college?
    A. If so, can you tell me a time when you felt a sense of belonging in engineering? Why did you feel a sense of belonging in college? Could you give me examples of when you do not feel a sense of belonging in your engineering college?
    B. If not, can you tell me a time when you didn't feel a sense of belonging in engineering? Why didn't you feel a sense of belonging in college? Could you give me examples of when you do not feel like belonging in an engineering college?
5. What does your interaction look like with men peers?
    A. Please explain. Could you give me an example?
6. What does your interaction look like with your female peers?
    A. Please explain. Could you give me an example?
    B. Which gender (men or women classmates) do you feel a good sense of belonging with in engineering? Why?
7. What does your interaction look like with men faculty?
    A. Please describe. Could you give me an example?
    B. What is the number/quantity of faculty/teachers you took engineering courses with? Men teachers: ___________ Women teachers number: ____________
8. What does your interaction look like with women faculty?
    A. Please describe. Could you give me an example?

    B. Which gender (women or men faculty) do you feel a better sense of belonging with in engineering? If women, why? If men, why?

9. Do you feel you belong in [name redacted] University?
    A. If yes, why?
    B. If no, why?
10. How do you think having a sense of belonging impacts your academic participation?
    A. Please describe. Could you give me an example?

Southern Journal of Engineering Education, 2024
Vol 3, 62–83

Transforming embedded systems education: The potential of large language models

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This conceptual article delves into the potential benefits, challenges, and future directions of how educators might adapt practices to accommodate the use of artificial intelligence (AI) tools, in particular large language models (LLMs), with embedded systems education as a case study. Drawing on literature pertaining to embedded systems education and the associated challenges, a new way of approaching embedded systems education is suggested, where students and LLMs work together to solve problems. This article proposes that AI technologies have the potential to improve the productivity of students as they learn to programme and that LLMs can be leveraged as personal tutors, facilitating adaptive tuition. The role of educators remains crucial in this process, as students still require scaffolding and guidance on prompting LLMs. This article suggests that educators have different options when considering how to teach embedded systems with LLMs present, by changing the emphasis of teaching to focus on the process of learning and understanding and using constructive alignment of learning activities and assessment with the new goals. This promises to be an exciting avenue of research and practice going forward.

Keywords: Large language models; embedded systems education; conceptual article; constructive alignment

Introduction

Embedded systems, which form the backbone of various technologies in the modern age, require a unique blend of hardware and software knowledge with cross-domain applications ranging from consumer electronics to industrial machines. The academic subject of embedded systems is regarded as a new and relatively undefined subject that incorporates areas such as computer science, automatic control and electrical engineering (Grimheden & Törngren, 2005a). Teaching embedded systems in higher education is challenging due to interdisciplinary relationships between high-level programming knowledge and low-level hardware interactions. Functional software development hinges on the ability of the student to write programmes to be deployed on hardware systems, with the objective of meeting the design

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brief specifications. If the software has any semantical or syntactical errors, the hardware will not function as expected, if at all. If the hardware has any connection problems, then the software will fail to execute as purposed. Literature abounds with pedagogical strategies suggesting how to better teach this complex cross-domain discipline to deliver quality graduates to industry (Grimheden & Törngren, 2005b; Ibrahim et al., 2014; Nakutis & Saunoris, 2010; Sangiovanni-Vincentelli & Pinto, 2005). As sensors and microcontrollers advance in complexity and capabilities, so too do the demands that industry place on new graduates, requiring workers with more complex knowledge and skills (Ibrahim et al., 2014). The modern era of artificial intelligence (AI) technologies brings with it new opportunities and challenges. There are promising aspects that this technology has to offer education, but uncertainty resides in the method. It might be hard for teachers to work out how to use AI in the classroom and still meet a course's intended learning outcomes (ILOs), and how to assess students to determine if the outcomes are met.

The advent of large language models (LLMs) has ushered a new era filled with possibilities in the field of education, specifically embedded systems education. AI has been present in education for some time but LLMs, such as ChatGPT, have made AI technology readily available to the public. LLMs have the potential to generate both syntactically correct and semantically meaningful code, which is relevant as software development plays a significant role in the development of an embedded system. This raises concern for educators who fear degrading the competency of their students, as LLMs can do the 'heavy lifting' for students as far as code generation goes, resulting in over-reliance on technology (Mahapatra, 2024; Shabunina et al., 2023).

This article proposes that educators should use the opportunity of the potentially disruptive influence of LLMs to reconsider curriculum objectives for embedded systems education. One approach to consider is constructive alignment, a concept that has been used in educational research for many decades. In more recent work, Biggs (2014) emphasised the importance of the behaviour of students to be developed as well as the context in which this behaviour will operate. Embedded systems education in the context of AI requires different student behaviours than those previously taught. At first glance, AI might be seen as posing a threat to the development of proper learning behaviour in students, as they rely on LLMs to perform tasks for them. Issues arise such as academic dishonesty, students not learning to develop code that successfully integrates the software with the hardware and performing debugging procedures.

Even though AI technology comes with its own challenges in terms of integrating LLMs in education at large, and the alignment of LLM output with educational goals should be considered carefully. LLMs certainly have the potential to serve as powerful tools for teaching and learning embedded systems as they can provide real-time feedback, interactive guidance, and debugging assistance (Englhardt et al., 2023). Using constructive alignment to reframe the ILOs, teaching and learning activities, and assessment methods (Biggs, 2014) could benefit educators and students alike, and lead to possible transformation with regards to how embedded systems subjects are presented to students.

This conceptual article aims to delve into the potential benefits, challenges, and future directions of how educators might adapt practices to accommodate the use of AI tools, using LLMs in embedded systems education as a case study. As a conceptual contribution it draws on a framework proposed by Jaakkola (2020), having identified the focal phenomenon and the various concepts that relate to the focal phenomenon as they assist in the conceptualisation of the use of LLMs in embedded systems education. An argument is built using constructive alignment as the backbone, drawing on the concepts covered in literature.

Theoretical considerations for conceptual work in a new field

As mentioned, the focal phenomenon studied in this paper is the use of LLMs in embedded systems education and how educators within this field could adapt their approaches to integrate this technology in the classroom. The *model*-type research design, as proposed by Jaakkola (2020), is used which provides a roadmap for understanding the new possibilities of LLMs in embedded systems education. Literature selected for review is based on the key variables and the association they have with the main idea. These concepts are AI in education, LLMs in education, embedded systems education, and the ability of LLMs to develop embedded systems solutions. This article starts with a review of relevant literature which forms the elements of the conceptual framework. The specific goal of this article is to outline the focal concept, how it is changing, the mechanisms employed and conditions that may affect it (MacInnis, 2011), and an outline of the pitfalls and potentials of LLMs in embedded systems education.

Embedded systems and AI

The literature reviewed in this paper seeks to understand the relationships between the different aspects that play a role in embedded systems education. Before discussing the potential and challenges of large language models in embedded systems, one must understand the concepts involved in embedded systems education. These include, but are not limited to, programming education challenges, and artificial intelligence in education. Understanding the elements that influence the development of an embedded systems engineering graduate will be of use when considering how LLMs could play a role in the process.

AI in education – possibilities and concerns

The application of AI in education (AIED) can be discussed under three overlapping categories: Student-focused, teacher-focused, and institution-focused AIED (Holmes & Tuomi, 2022, p. 550). Table 1 provides a taxonomy of AIED systems that are commonly available and researched. The focus of this article is on student-focused AIED and how LLMs and chatbots support learning.

Table 1: *AIED taxonomy (Holmes & Tuomi, 2022, p. 550)*

Student-focused AIED	**Teacher-focused AIED**	**Institution-focused AIED**
Intelligent tutoring systems	Plagiarism detection	Admissions
Chatbots	Curation of learning materials	Course planning and scheduling
Automatic formative assessment	Automatic summative assessment	Identifying students at risk of dropping out
AI-assisted apps (mathematics, text-to-speech, language learning)	AI teaching assistant	

Benjamin Bloom (1968) argued that all students engage learning activities with varying levels of prior knowledge, with different capabilities to meaningfully engage with the learning activity at hand, and therefore require varied support (Guskey, 2007; Holmes & Tuomi, 2022) to attain the same level of mastery of a topic or aspects of a topic. According to Holmes & Tuomi (2022), Bloom showed that individual tutoring can lead to two standard deviations in learning gain as compared to traditional whole-class teaching. This is perhaps the greatest opportunity for AI in education as it can facilitate individualised learning and tutorage for students. Embedded systems education can be considered fertile soil for the application of AI to provide students with much-needed individual support, depending on their own level of existing knowledge.

Although the potential benefits are promising, researchers warn that educators should approach AIED with caution. Dramatic claims regarding the capabilities of AI have later been found to be inflated and false (Selwyn, 2022). This prompts us to enter the world of AIED with realistic expectations around the limitation of the technology and then to foster discussions with fellow practitioners regarding how to implement it. Not all aspects of education are quantifiable and not all facets of students and the learning process can be captured and represented by data points (Selwyn, 2022). This means that while AIED has great potential, it should be implemented with care. Selwyn (2022) offers the following broad areas that remain points of contention and discussion amongst academics:

1. Hyperbole: exaggerated claims regarding the potential of AI in education.
2. Limitations: the limitation of AI in simulating real world issues within social context. Understanding the difference between ‘technologically smart’ but ‘socially stupid’ systems remain important.
3. Ideology in debates around AIED: acknowledging competing values, interests and agendas that underpin values of only one party (such as computer scientists) in contrast with broader interests that may offer counter arguments, like social justice concerns around privacy of the individual.
4. Environmental and ecological costs of AIED: production, consumption and disposal of digital technologies and acknowledging the impact it could have on the planet.

Selwyn (2022) concludes that the future of AI in education should be approached as contested and subjected to scrutiny prior to its integration in education, and not merely accepted as a neutral agent that will automatically bring about good. This point holds value and should be taken seriously while being realistic about how society is adopting this technology. According to Mahapatra (2024), accuracy and reliability is of concern as students potentially can be exposed to biased data, out-of-date knowledge, and misinformation, all depending on the data sets used for training the LLM.

Another concern is the prevention of plagiarism. The issues here are, firstly, students using LLMs to plagiarise and submit unoriginal work. Secondly, plagiarism detectors are easily bypassed as to produce similarity scores of 20% or less (Mahapatra, 2024). Working around the issue of plagiarism is challenging and contributes to the workload of educators as it requires that each student submission should be checked for plagiarism as well as AI detection, although AI detection also has a low success rate at this stage. As a sidenote, one might also argue the imperfections of LLMs could potentially be leveraged in learning activities where students must critically evaluate LLM outputs to determine their accuracy. This is not to suggest a default modus operandi, but as an example of how to put even a flawed LLM output to good use.

Students are making use of this technology, whether educators approve of it or not. The era prior to the launch of LLMs was perhaps different in the sense that accessibility to AI was limited, but open-source models such as ChatGPT disrupted the discussion and now require further investigation in terms of, for example, their social impact.

The end of 2022 was a turning point in the discussion around AI in education when generative AI hit the market. Seemingly, the educational sector felt the shockwaves of this disruptive technology the most, with concerns around intellectual property and academic dishonesty in the teaching and learning environment. To date, many still strategize on how to deal with LLMs such as ChatGPT within the context of education. What has become clearer with the passing of time is that their elimination from academic activity seems impossible. So, if they cannot be eliminated, can they be leveraged to promote learning? This remains a discussion for which there are no definitive answers yet.

Large language models in education

ChatGPT, an LLM, is a natural language processing model that was launched by OpenAI in November 2022 (Qadir, 2023). Its architecture is based on that of GPT (Generative Pre-Trained Transformer), originally purposed for language generation and summarisation, and it can generate new content, in a conversational style, in real time. Large data sets from the internet were used to train ChatGPT which is what makes it so fluent in human-like conversation with a vast knowledge base (Qadir, 2023). But where does the term ‘ChatGPT’ come from? Chat refers to the conversation-like nature of the chatbot while GPT refers to the following: **Generative**: ability to generate novel text; **pre-trained**: trained on large datasets from the internet; and **Transformer**: GPT uses the transformer architecture which is a sequence-to-sequence neural network specially adopted for general purpose language modelling (Kamalov et al., 2023).

Preparing students for modern life, one where AI features and where AI literacy could be an advantage to graduates, requires that higher education systems seek the active implementation of approaches that may foster this preparation (Shabunina et al., 2023). If educators wish students to discover their own initiative and creative potential then it is necessary that conditions conducive to these expectations are created, which is possible through the integration of AI technologies in educational programmes (Shabunina et al., 2023). As educators, we must be aware of both the positive and negative aspects of this technology. In Table 2, Shabunina et al. (2023) offer a SWOT analysis as compiled through a review of literature exploring the potential/pitfalls of LLMs in education:

Table 2: *SWOT analysis of ChatGPT in the context of its current (or potential) application in education (Shabunina et al., 2023)*

SWOT Analysis

Strengths	*Weaknesses*
Enhanced learning experience through meaningful interaction with the LLM 24/7 availability. Adaptive learning, meaning the LLM can respond to the level of knowledge of each individual student. Generates plausible and credible responses.	No human element. Limited domain experience due to available training data. Inability to scrutinise credibility of data post 2021. Decline in higher order thinking skills of students.
Opportunities	*Threats*
Supplemental learning tool. Provide challenging learning. Individual learning paths. Quick access to knowledge. Decreasing educator workload by automating various teaching tasks.	Over-dependence on technology. Plagiarism in education. Privacy and security risk.

Table 2 offers an overview of the current position of LLMs in education. This draws attention to the need for realistic expectations and sober vigilance regarding the integration of LLMs in the classroom. Both educators and students can benefit from LLMs (Mahapatra, 2024). For educators, LLMs can assist in creating course outlines, presentations, setting of assessments and formative quizzes, while for students it can be useful for solving questions, writing reports, generating code and obtaining feedback on work they have done (Mahapatra, 2024; Qadir, 2023). LLMs undoubtedly have great potential for students as they have been shown to have utility in both the learning of new material and preparing for assessment (Mahapatra, 2024).

The integration of LLMs in education is clearly a double-edged sword, but there are strategies educators can employ to mitigate the bad while incorporating the good. Table 3 summarises the aspects and strategies suggested to educators (Mahapatra, 2024).

Table 3: *Strategies in response to plagiarism concerns (Mahapatra, 2024)*

Aspect	**Strategies**
Task design	Include questions that require diagrams in the answer as it is difficult for LLMs to generate these diagrams with accuracy. Use questions that require analysis.
Identification of AI writing	Plagiarism detectors could not detect AI originated text, but AI detectors did. Checking references as many references are merely fabricated.
Institutional policy	Establish anti-plagiarism guidelines Provide students with education on academic integrity.

The workaround suggestions are not unrealistic as the strategies are implementable with little extra effort. Changing learning tasks to be more analytic and diagram-based will allow students to incorporate LLMs but make the copy-paste approach more difficult, as LLMs do not perform these tasks well. Although digital-free assessment formats might feel like a step backwards, this is a strategy that can be employed for certain assessments, such as final summative written assessments. Where students submit reports, AI detectors such as Quillbot can be used, as this platform has the capability to detect AI writing (Quillbot, 2024). Spot checking some of the references provided by students in their text can also be done to confirm if the references are real or fabricated, as ChatGPT tends to generate false references. Educating students by providing them with guidelines how to use LLMs and how to present their work can also help reduce plagiarism.

Chatbots can offer valuable support as they provide personalised assistance outside of formal class meetings, providing feedback and formative assessment for each student (Baskara, 2023). An attractive feature of an LLM is its ability to provide feedback in complex areas such as argumentation and critical thinking (Pendy, 2023), two very important skills to any engineering graduate. This kind of interaction will have to be facilitated through well-designed prompting, otherwise the LLM will simply provide answers to student questions, detracting from higher order thinking skills development as mentioned in Table 2.

LLMs and other AI applications can be useful in embedded systems education but not without well thought-out instructional design by the educator. To better understand the potential of LLMs in embedded systems education, the challenges faced by educators and students within the embedded systems education space is explored in the next section.

Embedded systems education

Embedded systems can be described as a subject domain that includes computer science, automatic control and electrical engineering (Grimheden & Törngren, 2005a). A Swedish study found that industry is concerned with functional legitimacy, meaning that engineers working in the field need to be capable of designing and implementing embedded systems (Grimheden & Törngren, 2005a). Industry wants engineers who can solve problems with implementable solutions. Embedded systems design problems are complex, requiring the student to integrate software and hardware to develop a solution for the given design problem (Ibrahim et al., 2014). Figure 1 illustrates the methodology used for embedded system design. So how should embedded systems engineering students be educated to meet the requirements of industry?

Various pedagogical approaches have been developed by educators to facilitate the teaching of embedded systems in higher education institutions to close the divide between the skills taught at academic level and the skills required by industry (Ibrahim et al., 2015). Some of these approaches include software-oriented, hardware-oriented and codesign-oriented approaches, as described by Ibrahim et al. (2015). A large component of embedded systems design is the software development portion, which in itself is a challenge as learning to programme is complex and perceived by students as difficult, fraught with barriers (Becker et al., 2023). Learning to programme requires understanding of various concepts that build on one another. For a student to progress in programming, there are multiple threshold concepts that influence their overall understanding of the subject. These concepts are crucial as they contribute to how students move forward in their learning (Kallia & Sentance, 2017). The consequence of this is that students often tend to avoid programming fields as possible career paths (Suliman & Nazeri, 2024).

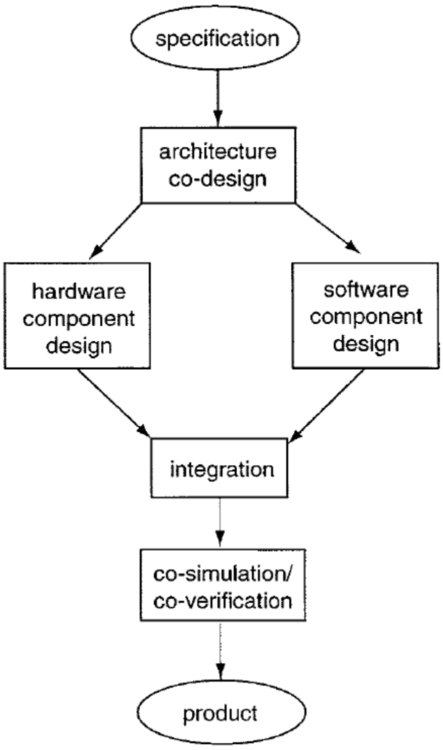

Figure 1: *Methodology for embedded systems design (Wolf & Madsen, 2000)*

The reality is that embedded systems design is far more complex than merely executing software on small computers. At its core, an embedded system has to interact with the physical world which is the main contributor to the complexities of embedded systems design (Fernandes & Machado, 2007). The challenges faced in embedded systems education can be categorised as student-related, lecturer-related and course-related (El-Abd, 2017). Figure 2 (overleaf) provides an overview of the challenges faced in teaching and learning embedded systems.

Embedded systems education has many challenges to overcome. The approach most employed by educators is the do-it-yourself, bottom-up approach. This gradually introduces the concepts of embedded systems in stages, while giving students the opportunity to implement these concepts practically for themselves (Ibrahim et al., 2014). Grimheden & Torngren (2005b) argue for teaching embedded systems courses through in-depth focus on topics. Also, didactic analysis finds that embedded systems have a thematic identity (themes specific to the domain of embedded systems). Grimheden et al. (2005) hold that educators should focus on teaching practical, real-world scenarios, as opposed to focusing on theoretical aspects alone. In other words, embedded systems education should emphasise the unique characteristics of the larger themes (hardware and software selection, real-time computing, specific functionality and real-world applications) that it forms a part of, and students should learn how to design systems that work according to these larger themes. The task for educators and students alike when teaching and learning embedded systems design is no small feat, and the advancement of AI in the current era requires that educators rethink classroom practices.

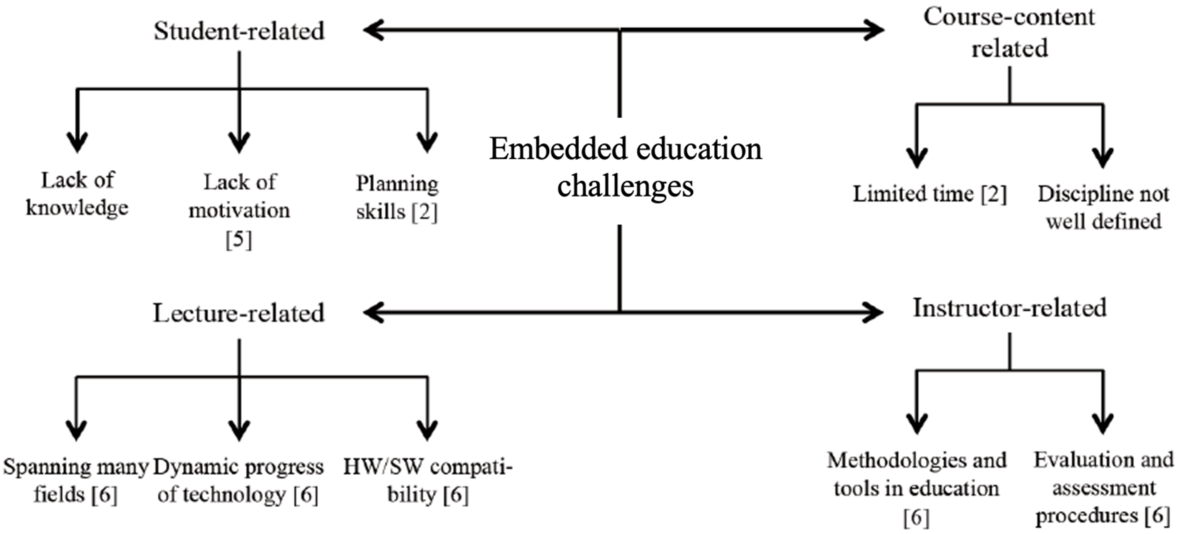

Figure 2: *Embedded education challenges (El-Abd, 2017)*

As educators, it is our responsibility to explore all possible means to better equip future graduates. To refer to the fertile soil metaphor used earlier, Figure 2 indicates the potential for growth. Addressing student related issues, LLMs can be useful in the 'lack of knowledge' area as they provide rapid access to knowledge of hardware and software related to embedded systems applications and the ability to provide in depth explanations on embedded systems-related content (Englhardt et al., 2023). Course-content challenges such as limited time to work through the syllabus and the undefined nature of the discipline can also benefit from the use of LLMs. The time constraints created by an academic semester place pressure on students to work through the course syllabus. Needing to cover complex topics and gain understanding through practical experiments adds to the cognitive load of students. Here LLMs can be of assistance as they have been shown to improve productivity in novice programmers and embedded systems designers (Englhardt et al., 2023). Although the time constraints are not removed, LLMs might assist students in being more productive and perhaps orientating them more quickly in the discipline.

Perhaps it is time to ask a new set of questions regarding what the code development process should look like. Should developers in the new AI era solely rely on their own skills or is AI-augmented development an acceptable way to learn?

The utility of AI in programming and embedded systems education

Of the strategies proposed in Table 3 for implementing LLMs in the classroom, the most productive seems to be task design. To design learning activities that account for the use of LLMs, while being aligned with the goals, assessment methods and outcomes of the subject, can lead to the development of optimal learning environments (Loughlin et al., 2021).

An article published by the University of Reading discusses that when learning environments align learning outcomes, teaching and learning methods and the assessment tasks, students' learning experiences are bolstered, deep learning is promoted, motivation is boosted and mental health improved (Centre for Quality Support & Development, 2024). Thoughtful design of the learning environment will have to be done by educators, if the integration of LLMs in the classroom is to succeed. Teaching embedded systems in conjunction with LLM use by students is hardly known, and when educators rely on the trusted principles of constructive alignment, their new classroom approaches can be implemented with confidence. It need not be a mere knee-jerk reaction to the presence of LLMs, but a thoughtful, deliberate response that assists students to overcome learning barriers through various AI-enabled technologies.

AI code generation tools are fairly accessible to the general public through applications such as OpenAI Codex, DeepMind, AlphaCode and Amazon CodeWhisperer (Becker et al., 2023). These systems have the potential to improve productivity in programming, but they do not come without challenges. Becker et al. (2023) illustrate some of these by asking ChatGPT to elaborate on the opportunities and challenges presented in using automated code generation in education. The response of ChatGPT was:

> There are both educational opportunities and challenges presented by automated code generation tools. On the one hand, these tools can help students learn to code more quickly and efficiently. On the other hand, they can also lead to a false sense of understanding and proficiency, as students may become reliant on the tools to do the heavy lifting for them. Additionally, automated code generation tools can sometimes produce code that is difficult to read and understand, making it more challenging for students to debug and troubleshoot their programs. (Becker et al., 2023, p. 501).

Becker et al. (2023) report that integrating AI code generation tools in programming education simplifies the adoption of new codebases, reduces difficulties with context switching for experienced users, and makes programming more accessible to novices. Specific to learning, AI technologies might provide exemplar solutions to help students assess their own work, provide a variety of solutions to assist students to identify multiple ways to solve a problem, and review code to help find errors in it (Becker et al., 2023). For anyone in programming, regardless of the level of experience, these are helpful resources. The fact that these technologies can generate exercises and explain code while providing examples can greatly assist a new programming student in becoming comfortable with and learning new concepts of coding by reducing the cognitive load (Becker et al., 2023).

To turn to the challenges specific to embedded systems: the key challenge in an embedded system design is the requirement for interaction between the physical and digital environments (Englhardt et al., 2023). Code generated for an embedded system needs to be repeatedly verified through trials. The question is whether LLMs can generate code able to integrate with actual hardware required to interact with a real environment. Hardware knowledge and an understanding of various components are crucial when writing code in embedded systems, as different devices subscribe to different protocols. For example, although the I2C communication protocol has set standards, different devices such as port expanders, real time clocks and RAMs all have very specific procedural requirements to exchange data with the microcontroller. The implication here is that even if LLMs are able to generate code, they should also understand the functional requirements for the specific devices used in the design, or the code becomes meaningless. A study by Englhardt et al. (2023) set out to test the ability of LLMs to develop embedded systems through 450 experiments testing multiple LLMs (GPT-3.5, PaLM2 and GPT-4). Their findings can be summarised as follows:

1. LLMs are able to generate syntactically correct and semantically meaningful code from high level task descriptions.

2. Hardware specifications: they can generate register-level drivers, I2C interfaces and LoRa communication code, showing that they can successfully navigate hardware device requirements.
3. They provide context-specific debugging advice for hardware by providing clarity on wiring.
4. Human-AI co-development works best as GPT-4 could only provide perfect end-to-end code 14% of the time. It is worth noting that the partially correct programmes still contained functional code with detailed comments and explanations on how to design the system.
5. User success rate for complex tasks was improved from 25% to 100%. Users with zero hardware or C/C++ experience could build a fully functional LoRa sensor transmitter and receiver in 40 minutes.
6. LLMs could provide useful suggestions to designers working on building a system (hardware, communication protocols, and coding techniques).
7. Prompting is crucial: prompts should be clear and include key system information to enable the LLM to develop appropriate solutions, taking cognisance of the technical nuances and the intended behavior. This aspect of the findings has clear implications for teaching embedded systems with the use of LLMs, as educators will need to provide scaffolding for students to learn how to prompt the AI effectively to perform learning tasks alongside LLMs.

What Englhardt et al. (2023) found is impressive. However, they highlighted some limitations and concerns: the LLMs can misunderstand tasks due to ambiguous prompts, making assumptions that are incorrect; they can ‘hallucinate’ and, as a result, produce incorrect details in their responses. They were also found to make unprompted modifications to code, which becomes an issue in systems where system resources are limited, and any unnecessary code consumes the limited capacity of the microcontroller. Potentials and pitfalls of LLMs in education need to be well understood if the novel connections made between embedded systems education and LLMs are to be meaningful. The following section discusses how educators might think differently about embedded systems educations as far as LLMs are concerned.

Rethinking embedded systems education

This article aimed to explore some of the potential benefits and challenges of AI technologies in education, and future directions of how educators could respond to the integration of LLMs in embedded systems education. It did this by reviewing literature relating to the focal phenomenon. This section of the article will explore how the different features of these principles can potentially be utilised effectively by educators specializing in embedded systems.

The overarching goal of educators in embedded systems is to produce graduates who are equipped for the complex demands of a growing industry. Using constructively aligned teaching can contribute to this overall goal of embedded systems educators by producing quality learning outcomes (LOs) and student satisfaction (Biggs, 2014). Following the principles of constructive alignment (CA), embedded systems educators need to reassess the goals, learning activities, outcomes and assessment of a given module.

This article does not propose that an entire syllabus should be redesigned, but rather that the focus should be selected learning activities to gradually integrate LLM. While it may still be too early to know exactly how AI will impact knowledge and skills requirement for embedded systems graduates, it seems expedient for educators to pay attention to the possibilities that may open up for graduates with an ability to utilise these new tools. Thoughtful inclusion of LLMs in the curriculum will give students the opportunity to engage responsibly with this technology in carefully designed learning activities. These specific activities can be assessed to measure the degree to which the outcomes are met.

If we are to rethink the teaching and learning process of embedded systems, we must start by being clear about the goals we want to achieve to ensure the teaching and learning of the subject are in alignment. One of the main goals of embedded systems education is to get students to write code that will allow hardware to interact with the external world. It is here where many students struggle, because the process of developing code is complex and presents a formidable barrier (Becker et al., 2023; Ibrahim et al., 2015; Kallia & Sentance, 2017; Suliman & Nazeri, 2024). Englhardt et al. (2023) demonstrate that LLMs are capable of producing code that is matched to the intended hardware of an embedded systems, in the context where it is to be deployed. They can also provide recommendations regarding the connections of the hardware used. This functionality is of great use to students working on an embedded systems design problem.

The main goal of embedded systems education is to teach students how to solve a given problem through the development of software code that will allow hardware platforms to interact with the world in a specific way. The first challenge for embedded systems students is gaining a clear grasp of the problem at hand, and thereafter to break the problem down into sub-components to develop the code for hardware. This requires that students have a thorough grasp on the exact requirements of the hardware and how the sensor interacts with the external world, as the developed code must be specific to the given requirements and specifications of the hardware components used. This is the second challenge for students. They know the basics of programming but fail to cross the bridge where they must apply the coding principles to the specific context of the hardware, addressing the functional requirements of the task at hand. They fail in facilitating interaction between the microcontroller and the peripheral hardware, such as sensors, etc.

The potential application of AI technologies in this regard is notable. LLMs, when applied in the correct way, can contribute to both helping the student to solve the problem at hand and learn coding in the process. This is where thoughtful learning design is crucial.

Using formative learning activities that include LLMs to practice threshold concepts, as defined by Kallia and Sentance (2017) above, allows students to engage with the LLM as with a tutor. The LLM can generate exemplar pieces of code, provide explanations, and generate small tests for the student based on the concept and hardware-specific platform used. This will consider the specific level of knowledge for each individual student and contributes toward one of the main outcomes of embedded systems education: the ability to write syntactically and semantically correct code. The potential lies in that LLMs can support student learning in the specific hardware environment that the student is working in, be it AVR, PIC, etc. This is relevant because through experience of working with students for 20 years in higher education, I have found that this is where they struggle: developing functional, hardware-specific code.

Traditionally, students were given learning activities where the goal was to produce code that, when implemented, would deploy correctly, causing the hardware to function as intended. The artefact would then be assessed through a demonstration where the student presented the work. The focus would be the functionality of the overall system. Due to the adoption and accessibility of LLMs by students, this traditional approach needs to be revisited. Students use LLMs, and the traditional assessment model might not be adequate in measuring the contribution of the student in the learning activity. This article proposes an alternative view by suggesting a more agile process, moving beyond a simplistic view on plagiarism detection and punitive actions during assessment, towards reformulating assessment activities that focus on the entire learning process.

This reformulation starts with the designing of LLM-enhanced embedded systems learning activities. Designing learning activities that include the use of LLMs but shifting the cognitive learning to the higher levels in Bloom's taxonomy, can mitigate some of the concerns around LLMs in the classroom. When the objective of the learning activity is not just an answer, but an exploration, plagiarism and AI generation concerns become less worrisome. The focus needs to shift from assessment alone towards the entire learning process, one that is tailored to respond to the varied learning requirements of individual students. This article proposes alternative approaches to overcome the challenges within embedded systems education in the AI era.

Suggestions of alternative approaches for the embedded systems classroom where LLMs feature

The following examples serve as suggestions regarding how educators can adapt classroom activities.

1. After introducing a topic on microcontroller programming – for example, the use of internal timers – the educator gives students a written piece of code that draws together the elements taught in the completed section of work. The task of each student is then to firstly, identify the portions of the programme that they do not understand and, secondly, to start engaging with an LLM. The focus of the chat with the LLM will be the problematic elements for the individual student. This will be different for each student as each has varying levels of understanding and knowledge. The intended outcome of this learning activity, which is assessed, is for students to reflect and report on how they managed develop a better understanding of the elements that troubled them. The final portion of the learning activity is for the student to implement the given code in hardware.

This recommendation draws on the accepted approaches for teaching and learning embedded systems but revises it through the lens of AI augmentation. In this activity, the student is not assessed for just producing a practical demonstration, but attention is given to the process, which will be different for each student. The student has the unique opportunity to engage in a learning activity that is truly adaptive and matched to him/her, but the goal (practical demonstration) will look the same for the entire class.

2. In a project scenario where students, for instance, are required to develop a system where the microcontroller needs to read data using the I2C protocol and then display the data on a 16x2 liquid crystal display, the same principles can be applied without compromising the ILO. Here the educator can request that students write a detailed explanation of their code, and the role of the LLM in the practical experiment or learning task. Students still need to demonstrate the system in action, but the educator now asks questions regarding challenges they faced and how they overcame these challenges. The educator could require a student to implement a modification in the experiment as this would demonstrate their ability to adapt, indicating the level of their understanding. The assessment rubric could be designed with criteria for both the process and the result, allocating weight to how the student co-created a solution with AI, and demonstrating understanding and the ability to deliver a functional embedded system.

These two short examples are the first steps towards developing a roadmap that educators can use to incorporate LLM-enhanced learning activities, but with emphasis on the process, not only the outcome. It should be noted that the activities should still be constructively-aligned with the outcomes.

Focus assessment on the entire process, rather than just the outcome

Typically, embedded systems students will perform smaller experiments, such as provided in the first example above. They will also design and build a project, as in the second example, and take formative and summative tests through the semester. Triangulation of all three – experiments, project and written tests – has the potential to provide the educator with a portfolio overview of the competence of each student, and if the ILOs have been met, the threat of over-reliance on AI on the part of students will be minimised.

As educators spread the focus across the entire process, a more flexible view is necessary to account for the presence of LLMs while still measuring the understanding of the students. It is part of the responsibility of the embedded systems educator to prepare students for a life where AI features, giving them the tools to improve their productivity by exposing them to AI in the embedded systems domain.

Implementing AI-enhanced learning activities such as these can lean into the strengths of and opportunities offered by AI, while mitigating some of the weaknesses and threats, such as plagiarism and over-reliance on LLMs, as discussed by Shabunina et al. (2023). This confirms the findings of Mahapatra (2024), offering task design as a strategy to work around the concerns regarding LLMs in education. Furthermore, this strategy is accessible to educators where resources, funding and capacity is limited: students merely require access to computers and an internet connection for interacting with open source LLMs such as ChatGPT, Copilot and Gemini, to name a few that have been found capable of embedded systems development and coding.

Embedded systems applications have become more advanced over the years. Exposing students to these increased complexities in technology is challenging due to time constraints in an academic semester. Using exemplifying selection, meaning to identify fewer important topics, allowing for more comprehensive exploration, as suggested by Grimheden and Törngren (2005a), is a good pedagogical approach to teach embedded systems. Using LLMs to assist in this task of teaching a topic in-depth can be beneficial, as the LLM can provide the support to students in times of private study. LLMs have demonstrated excellent ability to navigate the requirements of complex hardware components such as real time calendar clocks, I2C technologies, etc., making them well suited to be study partners and tutors.

The integration of AI technologies, particularly LLMs, in embedded systems education presents a promising avenue for enhancing the learning experience. The potential of these technologies to support students in overcoming complex challenges in teaching and learning in embedded systems is significant. However, it is crucial that educators approach this integration with a clear understanding of the goals they aim to achieve and the student outcomes they seek to measure. By constructively aligning learning activities with these goals and outcomes, educators can ensure that the use of LLMs enhance, rather than detract from, the learning process. Furthermore, the shift in assessment methods, from evaluating the final product to assessing the learning process, can provide a more accurate measure of student understanding and skills development. This approach not only prepares students for a future where AI is ubiquitous, but also equips them with the skills necessary to navigate and contribute to this future effectively. As we move forward, it will be essential to continue exploring and refining these strategies to ensure that the integration of AI technologies in education is done in a way that truly benefits students and educators alike.

Conclusion

This conceptual article drew on multiple strands of literature pertaining to embedded systems education and its associated challenges. The intention was to provoke the reader to reconsider teaching and learning approaches of embedded systems in the presence of AI technologies such as LLMs. It offered practical examples of how educators in embedded systems education can use LLMs instead of resisting them or constantly policing students for unoriginal work.

Novel connections were identified between LLMs and embedded systems education. Suggestions were developed that could potentially guide educators, offering an alternative view on how to incorporate or manage the disruption caused by LLMs.

The contribution of this article is to challenge educators to apply some flexibility to their teaching and learning approaches, drawing on LLMs as an ally, an instrument that could potentially change the way in which students learn and become competent in embedded systems design. Based on how rapidly AI technologies are evolving, future embedded systems students could simulate complex embedded systems scenarios, allowing for risk-free experimentation in a virtual environment. Future LLMs could potentially analyse vast amounts of industry data to predict emerging trends and technologies, keeping the curriculum relevant. This is indeed an exciting frontier that could transform classrooms and make education more personalised, engaged and effective.

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Southern Journal of Engineering Education, 2024
Vol 3, 84–95

Refinement of the Student Success Reflection (SSR) module: enhancing academic support through informed interventions

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This paper explores the strategic refinement of the Student Success Reflection (SSR) module and its impact on at-risk students in the Faculty of Engineering, Built Environment, and Information Technology at the University of Pretoria. Following a 2023 pilot, the module was refined in 2024 based on a root cause analysis questionnaire to address foundational academic challenges faced by students at risk of academic exclusion. The SSR module, with its mandatory participation, provides structured support to students struggling with foundational courses, particularly calculus. The study examines how this strategic intervention through academic advisory frameworks addresses key themes related to academic resilience, such as time management, university workload adjustment, and escalating mental health challenges. The refined SSR module contributes to improved student success by promoting a culture of support, offering practical resources, and encouraging student engagement with academic advisory services.

Keywords: Academic resilience; academic advising; holistic support strategies; self-regulation in education; student well-being

Introduction

This research was conducted at a leading university in South Africa, where the challenges of supporting at-risk students are becoming increasingly complex. In engineering disciplines, the transition to higher education is particularly tough due to the socio-economic disparities in the Global South (De Klerk, 2021; Tiroyabone & Strydom, 2021). Although South Africa is classified as an upper-middle income country (World Bank, 2018), its high levels of inequality, reflected in its Gini coefficient (OECD, n.d.), intensify the educational barriers many students face, underscoring the need for tailored interventions.

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These students, particularly those struggling with foundational courses such as calculus, face significant barriers to academic progression and success. Five Faculty of Engineering, Built Environment, and Information Technology (EBIT) academic advisors, known as Academic Success Coaches (ASCs) at the University of Pretoria (UP), recognising these challenges, developed a mandatory online Student Success Reflection (SSR) module to provide structured support for such students. The SSR module, piloted in 2023, encompasses a range of topics essential for student success, including time management, study techniques, test-taking skills, mental well-being, and resilience training. Delivered through user-friendly, video-based content, this module seeks to address the specific needs of at-risk students in a comprehensive manner.

The need for targeted academic interventions is especially acute in South Africa, where socio-economic disparities contribute to educational risks (Auerbach et al., 2018; Bailey & Phillips, 2016). The COVID-19 pandemic exacerbated these disparities, causing significant disruptions to traditional classroom-based learning (Doe, 2021). As a result, academic advising has become a critical component in enhancing student success, with a notable shift towards mandatory participation in intervention programmes as a strategy to engage at-risk students more effectively.

Literature review

In the evolving landscape of higher education, especially within the Global South, out-of-class learning experiences have become increasingly critical in shaping the academic journey of students. A socio-ecological perspective, guided by Bronfenbrenner’s ecological systems theory, provides a useful framework for understanding the complex interplay between individual, relational, and environmental factors that influence students’ educational experiences (Mapaling, 2023). This perspective aligns with the multifaceted nature of student development and underscores the importance of examining out-of-class learning from a holistic angle. The framework considers multiple levels of influence – micro-, meso-, exo-, and macrosystems – that impact student outcomes, suggesting that interventions should be equally comprehensive.

Strategic resource allocation, professional development, and policy formulation are crucial components for supporting educational initiatives that focus on out-of-class learning. Global studies emphasise the significance of merging conceptual frameworks with practical applications to foster effective out-of-class learning experiences (Troxel, 2019). Institutional support and recognition are fundamental for these initiatives to thrive. Universities must create environments that not only value out-of-class learning but also integrate it into the broader educational ecosystem to foster a more comprehensive approach to student development (Tiroyabone & Strydom, 2021). This comprehensive approach aims to enhance academic success while contributing to the personal and social development of students, promoting a more equitable and accessible higher education system (Van Der Merwe & Maharaj, 2018).

Additionally, the integration of psychosocial and mental health challenges into the discussion of student success reveals the intricate relationships between internal psychological states, behavioural responses, and the broader social environment (Martikainen et al., 2002; D'Andrea & Heckman, 2008; Patel et al., 2007). Addressing these concerns in higher education involves tackling issues such as academic and enrolment planning, quality assurance, and funding, which have been persistent challenges (StatsSA, 2019). Despite numerous strategic plans and interventions, high student drop-out rates, low completion rates, and limited participation in class activities remain significant hurdles.

The Department of Higher Education and Training (DHET) in South Africa has outlined key medium-term outcomes to address these challenges, including expanded access to post-school education, improved success and efficiency of the system, and enhanced quality of provision (DHET, 2020). However, South African universities continue to face the problem of managing high enrolment rates while also retaining and graduating these large numbers of students (Tiroyabone & Strydom, 2021). Although various funding schemes are intended to increase access to university, graduation rates remain low. According to Statistics South Africa (2019), only 29% of undergraduate degree students who enrolled in 2011 graduated within the required period, and another 29% took between four and six years to complete. This indicates that more than 40% of students either drop out or are still trying to complete their studies after six years.

This broader perspective, informed by a detailed exploration of student psychosocial experiences, highlights the need for educational institutions to adopt holistic support strategies that address both academic and psychosocial challenges to improve student success and well-being. An effective support framework requires a combination of academic advising, mentorship, and psychosocial interventions tailored to the diverse needs of students. This holistic approach aims to create a conducive learning environment that promotes both academic achievement and personal growth, ultimately contributing to a more equitable and accessible higher education system.

Sample and data collection

On 1 February 2023, there were 1514 first-time first-year EBIT students registered at the university. This initial cohort forms the basis of our study, providing a comprehensive representation of the demographic and academic dynamics within the faculty. As of 1 March 2024, following the processing of all appeals, the status of these students was categorised as follows: 961 were active, 129 had been readmitted, 89 transferred to other institutions, 199 were dismissed, and 136 discontinued their studies. Consequently, the overall throughput rate for this cohort is calculated at 78%. This figure represents the portion of the sample population that either continued their education or successfully completed the first year of their programme, providing a baseline for our study's demographic analysis.

Data collection was executed via an online root cause analysis (RCA) questionnaire disseminated to these first-year engineering students at the University of Pretoria. The survey targeted students who had sought academic advising due to academic exclusion, defined as failing to pass 70% of their credits. Featuring open-ended queries, the survey aimed to garner detailed perspectives on out-of-class factors affecting academic resilience. Utilising a digital platform allowed for extensive participation, with 300 students approached and 137 completing the questionnaire. This method ensured a varied collection of student experiences and enhanced the study's depth and breadth of understanding, providing a representative sample of the population in question.

Ethical considerations

Ethical clearance was obtained from the institutional review board to ensure compliance with ethical standards. Participants provided informed consent, were briefed on the research objectives, and assured of confidentiality, anonymity, and the right to withdraw without consequence. Data security was a priority, with access to survey data restricted to the research team, ensuring participant privacy (Resnik, 2011).

Results

The RCA questionnaire provided a detailed understanding of the factors shaping academic resilience among first-year engineering students at the University of Pretoria. Through thematic analysis, responses were examined and coded to identify key ideas, which were then organised into overarching themes that highlight the challenges students face, particularly within the Global South context. These themes reveal the complex interplay of academic, personal, and social factors that impact student success. The findings underscore the need for targeted interventions to address these challenges and enhance academic resilience. By addressing these interconnected issues, universities can implement more effective strategies to support student achievement and well-being.

Theme 1: mastering time management in higher education

Time management emerged as a predominant theme, with students frequently struggling to organise and utilise their time effectively. University-level learning, particularly within engineering disciplines, demands a high degree of autonomy, and students often face difficulties adjusting to this self-directed environment. The findings highlight that organisational skills and self-regulation significantly influence academic performance. The need for enhanced time management strategies became evident, especially as students transition from the more structured learning environment of secondary school to the autonomy of university life.

Subtheme 1.1: organisational skills for advanced time management.

A significant gap in students' organisational abilities was revealed as a prominent challenge. Many struggled with effectively prioritising their academic responsibilities, following study schedules, and managing the balance between coursework and social activities. This inability to plan and organise efficiently often resulted in poor study habits and heightened stress levels. These findings highlight the critical need for structured time management workshops and support systems that can equip students with the necessary skills to thrive in the more self-directed learning environment of university life. This is shown by the following quotes:

> I find it really hard to stay on top of all my assignments. In high school, we had a set schedule, but now I'm responsible for planning everything, and it's overwhelming.

> I create study timetables, but sticking to them is a whole different story. Things come up, and I always fall behind.

Subtheme 1.2: developing self-discipline for effective time management.

Self-discipline, or the ability to manage one's actions to achieve goals, emerged as a key concern. Many students pointed to procrastination and low motivation as major barriers to effective time management, making it difficult to stay focused and maintain discipline, which in turn affected their academic performance. The independence of university life often exacerbates these issues, as students struggle to balance academic responsibilities with social activities without the structured guidance of school. Practical interventions, such as goal-setting and self-regulation training, could help students reduce procrastination and stay motivated. Research by Zimmerman & Moylan (2009) highlights the role of self-regulation in academic success, suggesting that targeted strategies could improve students' ability to manage their workloads effectively. This is illustrated by the following quotes:

> University life is so different from school. There's no one checking up on me, and I need to manage my own time.

> I get distracted so easily. I'll sit down to study, but then I end up scrolling through my phone for hours.

> Some days, I just don't feel motivated to study at all.

Theme 2. Unpreparedness of university workload adjustments

Many students expressed a sense of unpreparedness when faced with the academic workload and social integration challenges at university. This theme emphasises the steep learning curve students encounter as they transition from the structured environment of high school to the more demanding and independent nature of higher education. This adjustment is especially difficult for students from socio-economically disadvantaged backgrounds, who may lack prior exposure to the rigours of tertiary education.

Subtheme 2.1: academic skills for successful university transition.

Adapting to the academic demands of university is a significant hurdle for many students. The shift from high school, where guidance and structure are more prevalent, to the autonomy required in higher education, often leaves students feeling overwhelmed. Many reported struggling with the increased workload and the higher academic expectations, particularly within rigorous programmes such as engineering. This lack of preparedness resulted in difficulties managing time, understanding course content, and maintaining academic performance. This is illustrated by the following quotes:

> The workload in university is so much more intense than in high school. I didn’t expect it to be this overwhelming.
>
> I knew engineering would be challenging, but the level of work is insane.

Subtheme 2.2: social skills for successful university integration.

Alongside academic challenges, students also reported difficulties with social integration. This was especially true for those not living in university accommodation, who found it harder to connect with peers and engage in campus life. Many felt isolated or hesitant to approach new people, making it difficult to form support networks. These challenges highlight the importance of social skills in navigating university life and the need for universities to offer programmes like peer mentoring and social events to help students integrate into the academic community.

> I don’t live on campus, and I’m too scared to approach new people, so I haven’t made many friends in class.
>
> I feel isolated most of the time.

These subthemes reveal the dual challenge of adapting to both academic and social demands in university, underscoring the need for targeted support in both areas to ease students’ transition and promote success.

Theme 3: escalating mental health issues and their effect on academic success

The data highlighted a strong connection between academic pressure and declining mental health. Many students reported that the stress of meeting academic expectations contributed to heightened anxiety and depression, which in turn made it difficult to concentrate and stay on top of their coursework. This vicious cycle between poor mental health and academic performance underscores the need for universities to adopt a holistic approach, integrating mental health interventions with academic support services. This is illustrated by the following student quotes:

> The pressure to keep up with my studies is rough. When I get a bad mark all I can think about is how I am going to disappoint my family.
>
> I've been struggling with stress and depression because of my workload. It feels like no matter how hard I try, I'm always falling behind.

Implementation and enhancement of the SSR module

The SSR module's design targeted at-risk students to mitigate academic exclusion. The module's mandatory nature ensured consistent engagement, particularly among those who might not voluntarily seek help. Following the RCA findings, the 2024 curriculum was adapted to address pressing challenges, including enhanced time management strategies and support for mental well-being.

To illustrate the practical application of these enhancements, the module incorporated a series of videos showcasing its activities and interactive content, designed to engage and motivate students. This strategy aimed to demonstrate the tangible benefits of the module's offerings, fostering student involvement.

Discussion and recommendations

The adaptation of the SSR module's curriculum represents a strategic approach to addressing the root causes of academic exclusion. By focusing on the predominant factors identified through RCA, the module is better positioned to support at-risk students in a challenging educational environment. This approach contributes to improved academic outcomes and student well-being.

Despite various student interventions in higher education, a gap persists between these interventions and students' actual needs. RCA can bridge this gap by revealing common challenges, such as the need for better organisational skills and self-regulation capabilities. Additionally, barriers to academic success include the reluctance to seek help due to a "misplaced sense of self-reliance" (Ryan et al., 2001). To address these challenges, several tailored recommendations are proposed.

To support students more effectively, it is essential to refine existing programmes and implement new strategies that address both academic and mental health needs holistically.

Refine time management workshops. Time management workshops should place greater emphasis on enhancing organisational skills, focusing specifically on cognitive and behavioural strategies for self-regulation. By equipping students with practical tools to prioritise tasks, adhere to schedules, and manage distractions, these workshops can empower students to take control of their academic responsibilities more effectively.

Expand and diversify mental health support. A comprehensive approach to mental health support is critical. Universities should collaborate with their counselling units to broaden and diversify the services available to students. This can be achieved through targeted workshops on stress management, coping skills, and mindfulness, as well as the development of peer support groups that foster shared experiences and offer emotional support. Additionally, reducing the stigma surrounding mental health is essential. Universities must actively engage in awareness campaigns and educational initiatives that normalise help-seeking behaviours, ensuring students feel comfortable accessing services without fear of judgement. Creating an inclusive, supportive campus environment will not only enhance students' mental well-being but also contribute to their overall academic success.

Promote social integration through structured learning communities. To combat feelings of isolation, especially among students not residing on campus, universities should implement structured learning communities that foster social integration. These programmes can provide a sense of belonging, encouraging students to build connections, participate in collaborative learning, and form peer support networks. This focus on social integration will help students feel more connected to the university community, promoting both personal and academic growth.

By addressing time management, mental health, and social integration in a coordinated manner, these recommendations aim to create a more supportive and resilient learning environment for students.

Conclusion

The strategic refinement of the Student Success Reflection (SSR) module represents a pivotal advancement in supporting at-risk students in the Faculty of Engineering, Built Environment, and Information Technology at the University of Pretoria. The SSR module's compulsory participation, following RCA and other data-driven approaches, has proven effective in addressing the root causes of academic struggles. This focused approach has provided students with the necessary tools to overcome challenges and improve academic resilience.

The evolution of this module, from its pilot phase in 2023 to the refined 2024 curriculum, underscores the potential of strategic academic interventions in higher education. By incorporating comprehensive topics such as time management, study techniques, test-taking skills, mental well-being, and resilience, the SSR module engages at-risk students in a meaningful way, fostering both academic and personal growth.

Despite this progress, higher education still faces a gap between intervention efforts and the actual needs of students. RCA has been instrumental in identifying common challenges, particularly those related to organisational skills and self-regulation capabilities. Additionally, the reluctance to seek help due to a 'misplaced sense of self-reliance' remains a barrier to academic success (Ryan et al., 2001). The SSR module addresses these issues by promoting a culture of support and providing practical resources that encourage students to engage with academic advisory services.

The recommendations outlined in this paper aim to further enhance student success. These include refining time management workshops, expanding mental health support, and developing structured learning communities to combat feelings of isolation. By implementing these strategies, universities can create a more inclusive and supportive educational environment.

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Southern Journal of Engineering Education, 2024
Vol 3, 96–118

Strengthening South Africa’s maritime industry through higher education in naval architecture and marine engineering

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The maritime industry is inherently global, with seafarers and skilled expatriate engineering graduates employed worldwide, away from the places where they grew up and obtained their specialist qualifications. Consequently, any higher education qualification in the maritime sector must ensure that graduates are equipped to compete internationally for employment opportunities and be academically prepared for the engineering challenges of the future arising from technological advancements. This paper presents a study on naval architecture and marine engineering (NAME) higher education in South Africa and compares it to three international marine education universities. A qualitative content analysis methodology was employed to analyse the module content of each selected international institution. Patterns that emerged from the analysis were used to compare these with the curriculum of the current Bachelor of Engineering Technology in Marine Engineering degree programme that has been offered by the Nelson Mandela University in South Africa since 2018. This analysis of the international programmes identified 18 themes that a quality NAME programme should encompass to meet the academic requirements for the future engineers in the global maritime sector. The study recommends the addition of a fourth-year Honours degree and a fifth-year taught Master’s degree to the existing three-year undergraduate Bachelor of Engineering Technology in Marine Engineering degree. The proposed curriculum, unique in the South African higher education environment, will enable graduates to apply mathematical and scientific principles to the ‘design, development and operational evaluation of self-propelled, stationary or towed vessels operating on or under the water, including inland, coastal and ocean environments’ (Department of Education, 2008).

Keywords: Academic qualification; naval architect; marine engineer; qualitative analysis

Introduction

The South African government is committed to strengthening the national economy by harnessing opportunities related to the ocean and associated fields. Through the initiative Operation Phakisa (meaning ‘hurry up’ in Sesotho), the government facilitated an Oceans

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Economy Lab from 15 July 2014 to 15 August 2014. The lab, which included over 180 delegates from government, the private sector, civil society and academia, highlighted the need for maritime skills development and the establishment of a maritime educational framework (Findlay, 2018; Department of Planning, Monitoring & Evaluation, 2014).

In South Africa (SA), the broader marine engineering field (naval architecture, ship/vessel design, maintenance, offshore oil rigs), has largely stagnated at higher education (HE) levels (University of Stellenbosch, 2017). From the early 2000s up to 2018, there were no institutions offering any HE qualifications in this field other than seafarer education, which is focused on the operations and management of ships (Cape Peninsula University of Technology, 2017; Durban University of Technology, 2020). As a result, HE in South Africa in naval architecture and marine engineering (NAME), encompassing design, manufacture and development engineering, from the early 2000s to 2018, was non-existent (Heimann et al., 2011). With the focus on ocean economic development, it was identified through Operation Phakisa that NAME is a scarce skill as most of the expertise used in SA is sourced abroad. These are skills that SA once possessed, but the country has lost many of these skills over time and now needs to rebuild them (Funke et al., 2017). Therefore, there is a need for urgent development at the HE level to support the envisioned growth in ship design and building as South Africa begins to invest in the manufacturing and high-value maintenance of ships and vessels.

The purpose of this study was to evaluate if the HE framework in SA can adequately provide the academic foundation needed to develop and build a globally competitive maritime industry in ship design, construction and maintenance, and then propose a framework to address any existing gaps. Using thematic qualitative content analysis, focusing on subjects/modules and content, this study firstly evaluated the current framework of NAME in South African HE. Then a detailed evaluation of three international university NAME qualifications was done to analyse the content and standards of international NAME HE. Various themes of the content that emerged from the international study were compared against the current South African framework. The final analysis highlighted what needed to be added to the South African marine engineering qualifications to ensure that South African graduates would meet the requirements for an internationally recognised qualification in NAME.

Literature review

Marine engineering and naval architecture higher education in South Africa

In SA there are only three universities that have a specialised marine engineering qualification. Durban University of Technology (DUT), Cape Peninsula University of Technology (CPUT) and Nelson Mandela University (NMU) offer accredited three-year seafarer qualifications (NQF 5–7). The South African Maritime Safety Authority (SAMSA) is the accrediting body for seafarer qualifications related to manning and operating ships and related vessels. The (then) Department of Education via its National Qualification Framework (NQF) defines the following levels of education: school exit level = NQF 4; three-year degree = NQF 7; Honours degree = NQF 8; and Master's degree = NQF 9 (Isaacs, 2000).

The Bachelor of Engineering Technology Degree in Marine Engineering from NMU is the only qualification that comprehensively incorporates an academic foundation for design, manufacture and development in NAME, and is accredited by the Engineering Council of South Africa (ECSA). Figure 1 shows the current framework for marine engineering at universities in South Africa, also showing that NMU is accredited by both ECSA and SAMSA.

NAME is an area of study which prepares individuals to apply mathematical and scientific principles to the design, development and operational evaluation of self-propelled, stationary or towed vessels operating on or under water, including inland, coastal and ocean environments; and the analysis of related engineering problems such as corrosion, power transfer, pressure, hull efficiency, stress factors, safety and life support, environmental hazards and factors, and specific use requirements (Department of Education, 2008). There are only a few experts – likely fewer than ten naval architects (Mukandila, 2018) – in the whole of the South African maritime industry. Most are operating independently, with the majority of their projects being for international northern hemisphere clients (Urban Soul Group, 2017). South Africa has also lost many of its expert marine engineers and naval architects to the international market over the last 20 years, and there has been very little investment to maintain these skills (Department of Transport, 2017).

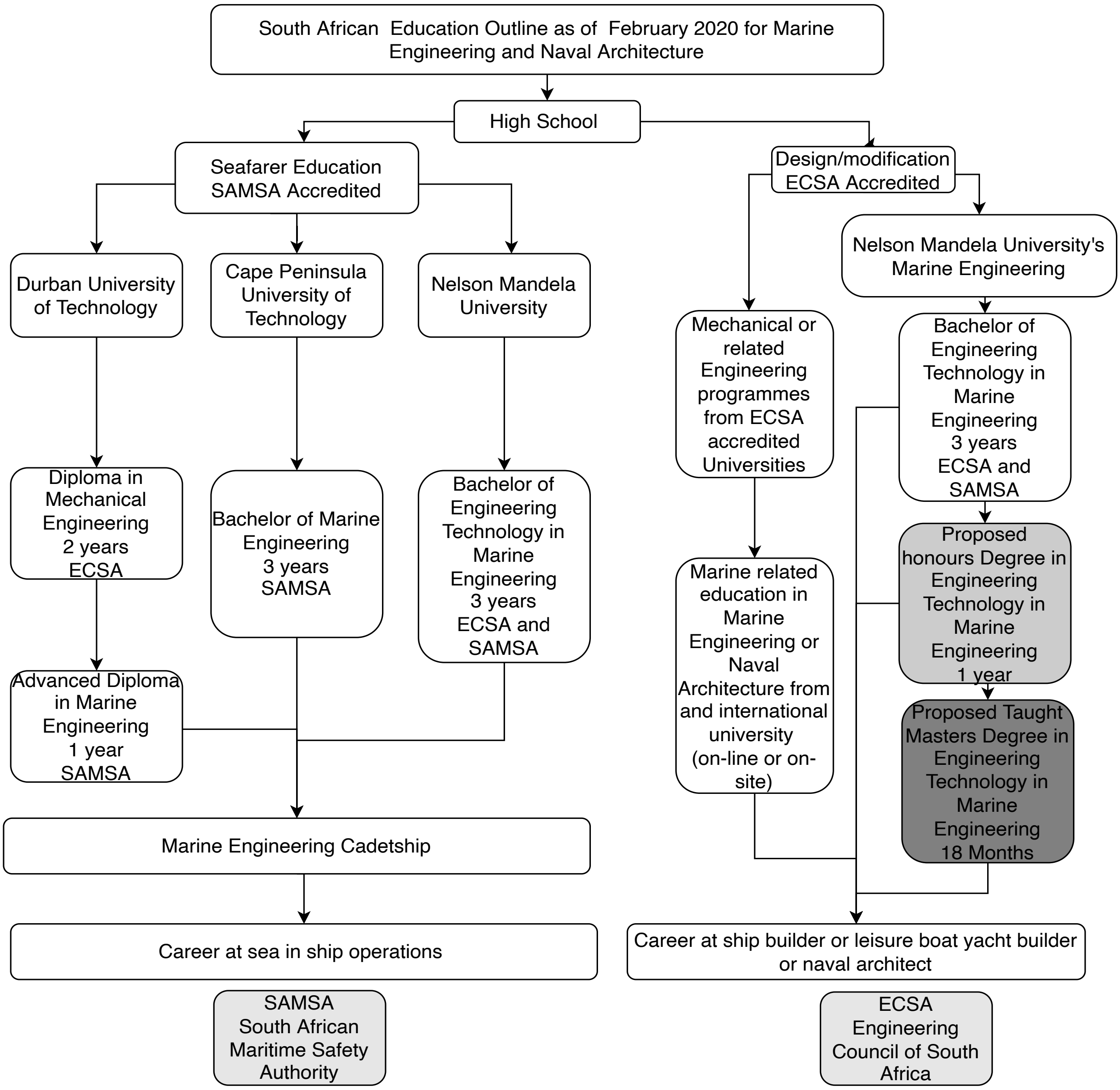


Figure 1*: Flow diagram of marine education in South Africa, February 2021 (Theunissen, 2021).*

Added to the shortage of design skills and expertise in the South African maritime sector is the lack of research related to designing vessels specifically for operation off the South African coastline and in Southern Ocean conditions. Landmass in the northern hemisphere is 68% compared to the 32% in the southern hemisphere (Mendez, 2017), with wave characteristics and frequencies in the latter tending to higher waves with greater gaps between them compared to the former. These wave frequencies impact the sea-keeping and performance of vessels, affecting their comfort, speed, and load capabilities. A vessel designed for northern hemisphere conditions will not operate optimally in southern oceans (MacHutchon, 2006). Potgieter (2014) describes the southern hemisphere operational problems experienced by South African Navy strike craft:

> Owing to operational problems and shortcomings experienced with strike craft, the new ships had to be bigger. Their small size, limited sea-keeping and lack of endurance made strike craft unsuitable for South African conditions. Their endurance is drastically reduced in heavy seas, speed must be reduced and crew fatigue increases. The cramped and often demanding conditions on board were not conducive to attracting and retaining highly-qualified personnel (pp. 183–202).

The sustainability of the maritime industry depends on the skills in the various maritime-related fields. To develop and grow the sector designing and building boats, ships and marine structures in South Africa, there needs to be a focus on the source of the skills, namely the universities. In any given career, the normal flow is mentorship of university-educated graduates by industry professionals, which is an important process in an engineer's career development. ECSA requires that a graduate registers as a Candidate Engineer under mentorship of a professional engineer before applying to be registered as a professional engineer (ECSA, 2020). These professionals pass on their experience to their mentees. As these graduates grow in their skills, they then transfer their skills on to the next generation of professionals. However, as noted in the introduction, there is a critical shortage of skills in South Africa in the design and building of boats, ships and marine structures. In addition, there are no local universities training new graduates in these skills. Therefore, there is limited transfer of NAME skills, and these skills are slowly being lost.

Stellenbosch University has proposed to reintroduce a Master of Engineering in Marine Engineering that was offered from the early 1970s until the late 1990s. The course focused on hydrodynamics, ship stability and sea-keeping. However, this course is still not available (University of Stellenbosch, 2017). Therefore, since the early 2000s and prior to 2018, the only marine engineering higher education in South Africa was for seafarer training and development in the transport sector offered at DUT and CPUT. These qualifications are focused on seafaring, operations and maintenance. There has been no programme that focused on marine design until January 2018, when the Nelson Mandela University introduced the ECSA-accredited Bachelor of Engineering Technology (BEngTech) in Marine Engineering. This paper only focuses on the Bachelor of Engineering Technology in Marine Engineering at NMU and will make recommendations of what modules and content need to be added to the qualification to meet the academic requirements for graduates to register as a recognised naval architect with the professional body, RINA (Royal Institute of Naval Architects).

International standards and requirements for naval architecture and marine engineering

To accomplish this, the authors collaborated with Prof Philip Wilson, who has over 40 years' experience as a lecturer/professor in naval architecture at the University of Southampton. He noted that it was not possible just to add a few marine-related modules to a mechanical engineering qualification to adequately prepare a graduate for a career in NAME. There were fundamental educational concepts and foundations that needed to be established within the curriculum, or additional subjects/modules added to the overall curriculum to ensure that these principles were covered. Mathematics is fundamental to naval architecture. The University of Southampton even allows first degree graduates with a mathematics background to enter its MSc in Marine Engineering. Therefore, for a naval architecture qualification to be relevant, it needs to have a significant mathematical component (Weymouth, 2020).

Wilson (personal communication, May 29, 2020) recommends that the relevant mathematic requirements for naval architecture need to include the following:

- First course in Ship Stability – Marine Engineering
    - Basic integration and differentiation.
    - Ability to integrate linear shapes in 2-D and in 3-D. Integrate parabolas to find areas. Integration for finding moments and volumes of known shapes.
    - Numerical integration using Simpson's Rule.
    - Basic algebraic manipulation.

- Ship Dynamics – Naval Architecture (RINA)
    - Second order linear differential equation methods of solution. This is to apply Newton's Laws and find solutions.
    - Probability theory, including an introduction to probability and various theorems, for example, binomial theorem, introduction to probability density functions using Rayleigh distribution.
    - Setting up coupled differential equations and decoupling where possible.

Further, Wilson (personal communication, May 29, 2020) confirms that to build on the foundation that is laid by the required mathematics, any design-focused NAME qualification will need modules that cover maritime specialities, not just general engineering-related content. For example, (Wilson, 2019) includes:

- Ship Stability – Marine engineering-related speciality modules considering:
    - Marine Hydrodynamics
    - Ship Design and Economics
    - Structural Design and Production
    - Materials and Marine Composites
    - Offshore Engineering for platform specialists

- Ship Dynamics – Marine Engineering, building towards naval architecture-related speciality modules, considering:
    - Marine Hydrodynamics
    - Sea-keeping and Manoeuvring
    - Ship Resistance and Propulsion
    - Advanced Marine Engineering
    - Computational Analysis applied to CFD and FEA
    - Marine Structure

- Further electives for specialities, related to South African industry:
    - Small Craft Performance
    - Renewable Energy and Environmental Flows

Therefore, any qualification that lays the academic foundation for a career as a design-focused marine engineer and RINA-accredited naval architect needs to cover the above content at the Bloom's taxonomic levels of Analyse, Evaluate and Create (Anderson & Sosniak, 1994).

Evaluation of three European universities offering NAME qualifications, in relation to South African higher education

To do a comparative benchmark of the BEngTech at NMU, three international universities were selected for evaluation and comparison. This paper is limited to these three institutions but acknowledges that future research possibilities could include other programmes. These institutions provided a suitable foundation for this paper. The selection of these university programmes was based primarily on the established relationships and contacts with the institutions, supported by the similarity of these institutions' offerings to the South African institutions.

The approach of these institutions to their NAME courses is applicable to the South African context as follows:

- The University of Southampton in Southampton, United Kingdom, offers a four-year Master's in Engineering qualification.
    - The Southampton engineering degree is fully recognised by RINA.
- Chalmers University of Technology, in Göthenberg, Sweden, offers a two-year postgraduate Master's programme that a graduate would consider after completing an undergraduate engineering qualification
    - This institution was chosen as it resembles the programme structure that Stellenbosch University in South Africa proposed to implement for their Naval Architecture Master's degree.
- Solent University, in Southampton, United Kingdom, is an applied engineering university with a three-year Bachelor of Engineering (Honours) and a four-year Master of Science degree.
    - This institution is very similar to the Nelson Mandela University structure with a large focus on applied engineering, although the Solent courses are only partially recognised by RINA.

The University of Southampton undergraduate Bachelor and Master of Engineering

The University of Southampton is one of the top 100 global universities (Quacquarelli Symonds, n.d.) and is a global leader in maritime education with global alumni. The Southampton undergraduate ship science programmes are based on the broad foundation of a mechanical engineering degree with a focus on marine engineering. The programmes aim to provide the students with the necessary academic foundation for a career that covers the design, construction, maintenance and operation of marine vessels and structures (Keane, 2020).

Note that the University of Southampton uses the descriptor 'Ship Science' to broadly describe their naval architecture and marine engineering qualifications. Speciality pathway streams that an undergraduate can elect are as follows:

- Bachelor of Engineering (three years) – BEng (Keane, 2020)
    - Ship Science

- Master of Engineering (four years) – MEng (Keane, 2020)
    - Ship Science
    - Ship Science/Naval Architecture
    - Ship Science/Yacht and High Performance
    - Ship Science/International Naval Architecture
    - Ship Science/Marine Engineering and Autonomy
    - Ship Science/Ocean Energy and Offshore Engineering
    - Ship Science/Advanced Computational Engineering

Table 1: *Modules and structure of the Southampton Naval Architecture Pathway*

	Semester 1	**Semester 2**
Year 1	Basic Naval Architecture	
	Design and Computing	
	Mechanics, Structures and Materials	
	Thermofluids	
	Electrical and Electronic Systems	
	Mathematics for Engineering and the Environment	
Year 2	**Semester 3**	**Semester 4**
	Engineering Management and Law	
	Hydrodynamics & Sea-keeping	
	Mathematics for Engineering & the Environment	Materials and Structures
	Resistance and Propulsion	Ship Structural Design and Production
	Systems Design and Computing for Ships	Ship Design and Economics
Year 3	**Semester 5**	**Semester 6**
	Individual Project (core)	
	Marine Craft Concept Design	Ship Manoeuvring and Control
	Marine Engineering	Marine Hydrodynamics
	Finite Element Analysis in Solid Mechanics	Marine Structures
Year 4	**Semester 7**	**Semester 8**
	Group Design Project (core)	
	Maritime Safety and Law	
	Advances in Resistance and Propulsion	Marine Structures in Fluids
	Composite Engineering, Design and Mechanics (Optional)	Design Search and Optimisation (optional)
	Offshore Engineering and Analysis (optional)	Renewable Energy from Environmental Flows (optional)
	Maritime Robotics (optional)	Failure of Materials and Components (optional)

Southampton's flexible structure, as shown in Table 1, with options in year 4, ensures a core framework of naval architecture and marine engineering while allowing the choice of a specialist pathway. The first two years, common across the specialities, cover the fundamentals of basic engineering and ship science. The programme ensures that design is emphasised throughout all the levels of the academic qualification, both in a general and a marine context. Additionally, there is also a focus on computational methods as a tool for engineering problem analysis.

Southampton Postgraduate MSc in Maritime Engineering Science

The University of Southampton includes a pathway to a postgraduate Master of Science in Maritime Engineering Science for graduates who have engineering, scientific or mathematical backgrounds (University of Southampton, n.d.; Weymouth, 2020). This is a one-year (two semester) Master's degree, which suits postgraduate students who would like to pursue a career in the maritime sector after studying a non-marine related qualification. However, the previous qualification must have been in been in engineering, science or mathematics, for a candidate to be eligible to take the MSc.

Chalmers University of Technology in Sweden – Master in Naval Architecture and Ocean Engineering

Chalmers University in Sweden, ranked globally at 125 (Quacquarelli Symonds, n.d.), offers a Master of Science in Naval Architecture and Ocean Engineering degree taken over two years. Entry into the course requires a bachelor's degree in science, engineering, technology or architecture. As with the University of Southampton, Chalmers notes that mathematics is important and must include linear algebra, multivariable analysis, mathematical statistics and numerical analysis. Additional foci required include mechanics, fluid mechanics and strengths of materials or solid mechanics.

The Naval Architecture and Ocean Engineering course focuses on the 'conception, planning, design and analysis of large marine structures considering hydromechanics and strength through a holistic approach' (Chalmers University, 2020). Table 2 outlines the course content with the optional electives (Chalmers University, 2020).

Table 2: *Two-year postgraduate programme structure and optional modules for Chalmers University Master in Naval Architecture and Ocean Engineering*

Year 1	**Semester 1**	**Semester 2**
	Maritime Transport Studies	Ship Geometry and Hydrostatics
	Marine Structural Engineering	Ship Resistance and CHD
	Marine Propulsion Systems	Elective Course
	Waves Loads and Sea-keeping	Elective Course
Year 2	**Semester 3**	**Semester 4**
	Master's Thesis	
	Design Project (Ship, Offshore, Yacht etc)	Elective Course
	Marine Engineering	Marine Hydrodynamics

Optional modules for electives
Matlab
Composite Mechanics
Finite Element Method - structures
Turbulence Modelling
Reliability Analysis of Marine Structures

Solent University – Southampton

The School of Engineering has a number of programmes related to NAME. However, Solent takes a slightly different approach in that it focuses on selected areas of specialties that directly link to the design and construction of maritime superyacht, yacht and power craft. The following qualifications are offered:

- Bachelor of Engineering (Honours) in Yacht and Power Craft Design (three years)
- Bachelor of Engineering (Honours) in Yacht Design and Production (three years)
- Master of Science in Superyacht Design (four years)

The literature review highlights that the BEngTech in Marine Engineering at NMU does not fully cover the academic foundation required for a NAME qualification in design and development. There is additional content and knowledge required. This will be analysed and addressed in this paper.

Research Methodology

The comparison of the NMU Bachelor Engineering Technology in Marine Engineering against the selected international institutions' NAME qualifications required a systematic evaluation of every subject/module that made up the core curriculum of the qualification. To comprehensively evaluate the data, a qualitative content analysis research methodology was used. Content analysis is the detailed and systematic analysis of the content of a body of material to identify patterns, themes or biases within that material (Leedy et al., 2014) and comprises replicable methods for making interpretations from observed communications to their context (Krippendorff, 1980). All module data (core content text) was imported into and analysed using the qualitative data analysis software, ATLAS.ti. The software highlights and automatically tracks these links and generates reports to view results accurately. To ensure validity, reliability and repeatability, the detailed text of each module from all three international institutions was carefully coded by evaluating every line of text, extracting the subject content keywords and descriptions, and allocating to a theme heading. Initially, a number of theme headings that were commonly related to the NAME field were outlined e.g., Naval Architecture, Mathematics and Principles, Ship Manoeuvring and Control, Resistance and Materials. If there was content not related to any current themes, a new theme was created and all related key words and content linked to the new theme. The themes that emerged from the international content were then evaluated against the NMU BEngTech core content to validate or highlight the gaps. The process followed the seven phases of qualitative data analysis (Marshall & Rossman, 2014). Focusing on the text from the marine modules from the international university programmes, we were able to arrange and reassemble the module text data systematically and establish patterns and networks that emerged from the text study.

Results

Analysis of NAME content covered by the three selected international universities

Once the core content details of the modules were analysed, a pattern emerged showing the content that should be covered in a high-quality marine qualification. These extracts were linked to general headings/themes covering the major sectors for a general (not specialised) NAME qualification. The analysis shows that any qualification aimed at developing the NAME framework in South Africa would need to consider the following content, separated into 18 themes:

1. Codes and Legal Regulations: all legal and regulatory codes and guidelines that an engineer needs to consider and be aware of.
2. Computer Design, Modelling and Software: content related to understanding, operating and producing results assisted by computers.

3. Design: general and specialised design theory and concept theory applied to designing systems, ships and vessels and general related items.
4. Economics, Management and Projects: all themes relating to economics, management and project management, including communication skills and requirements.
5. Electrical, Electronics and Automation: electrical power generation, electronics and automation to control and monitor the systems.
6. Ergonomics and Style: how vessels look and operate, considering comfort, style and seaworthiness
7. Finite Element Analysis (FEA): understanding of fundamental knowledge and techniques of FEA and developing tools to analyse engineering problems.
8. Hydrodynamics and Sea-keeping: the study of fluid dynamics and statistics associated with random processes and integration with a range of marine structures operating on or below the free water surface, for example, how structures interact with the water.
9. Marine Engineering: the principles, design and analysis of ship power plants, drivetrains and auxiliary systems found on board marine vehicles and structures.
10. Materials and Composites: the relationship between composition, microstructure and properties of materials, linked to a deeper understanding of their structural performance. This assessment of structural performance is also developed through more advanced stress and deflection analyses for more complex engineering components and systems used to manufacture the vessels.
11. Mathematics and Principles: laying the mathematical foundation for all engineering modules.
12. Naval Architecture: fundamental properties of floating bodies and insight into the design, construction, management and operation of marine vehicles and an awareness of an engineer's responsibility.
13. Offshore: engineering concepts and analytical techniques that are fundamental to design, operate and decommission offshore fixed, floating and seabed infrastructure in a safe, sustainable way. This includes learning about the different types of sites, platforms and monitoring /decommissioning requirements, an introduction to analytic and numeric methods for predicting the wind, wave and current loads on offshore structures, and the engineering design of different systems to ensure their safety and performance under these expected loads.
14. Renewable Energy and Environment: the atmospheric and gravitational processes present in earth-generated flows of wind and water. This area studies these resources and practical methods/technologies for extracting cost-effective electrical and other energy conversions. The main focus is on wind, wave and tidal energy devices including the use of turbines for low- and high-head hydroelectric schemes. Systems considered include the vital aspect of marine energy in the offshore environment including installation and system survivability.
15. Ship Manoeuvring and Control: fundamental concepts associated with the principles of manoeuvring and control theory, with a focus on vehicles operating on or below the air-water interface.
16. Ship Resistance and Propulsion:
    - Fundamentals of ship resistance to determine the resistance of a ship using traditional experimental and empirical methods, including modern computational methods to analyse the flow around a ship hull.
    - The components of the propulsion system of a ship, from the fuel tanks, through the machinery to the propeller. Systems engineering is introduced as a tool for design of general complex

systems with focus on marine machinery systems. Knowledge of basic hydrodynamic properties of the propeller together with propeller design principles.

17. Structures and Mechanics
    - Knowledge of ship structures and the analysis of their strength. Engineering beam theory and buckling analysis as applied to ship structures and their structural elements.
    - Fatigue design principles.
    - Structural principles and their application to marine-related problems. Fundamental understanding of the methods for the design and analysis of maritime structures and structural components.
    - Fundamentals of mechanics, statics, dynamics and materials.
    - Aspects of design relevant to the longitudinal and transverse strength of ships.
    - Production technology applicable to the shipbuilding industry from the perspective of the shipyard and its management, but also from a design for production viewpoint.
18. Thermofluids: core thermodynamics and fluid mechanics for engineering.

From the extensive ATLAS.ti text analysis, the graph shown in Figure 2 was developed. This shows the total common themes by comparing each university curriculum. For example, ‘Design’ and design-related core content, were featured 16 times over the 25 modules in the four-year MEng (Naval Architecture) at the University of Southampton. It was featured 12 times in the 27 modules at Solent university, also four years, but six times at Chalmers.

This graph shows that the most common topics/themes that have the most overlap of content are in the areas of design and mathematics, with mathematics showing the content most covered by all three universities. Hydrodynamics and sea-keeping and structures are also areas that are covered across the qualifications.

It was noteworthy that Chalmers University constantly had less common content compared to Solent’s MSc and Southampton’s MEng Ship Science/Naval Architecture four-year programmes. The reason for this is that Chalmers is a two-year postgraduate master’s degree and requires a three-year engineering qualification as an entry into the programme. It is therefore expected that Chalmers would have less common content as there would be a significant portion of the content covered in the undergraduate qualifications that are not part of the Master’s content, and therefore were not analysed as part of this research.

Solent and Southampton track against each other closely as they are both four-year qualifications. They accurately reflect the quantity of similar content covered relating to the concepts and themes that a good quality NAME qualification should cover, and therefore should be the focus of that qualification. Noting this, any qualification framework in South

Africa should focus on design, mathematics, hydrodynamics as well as sea-keeping and structures.

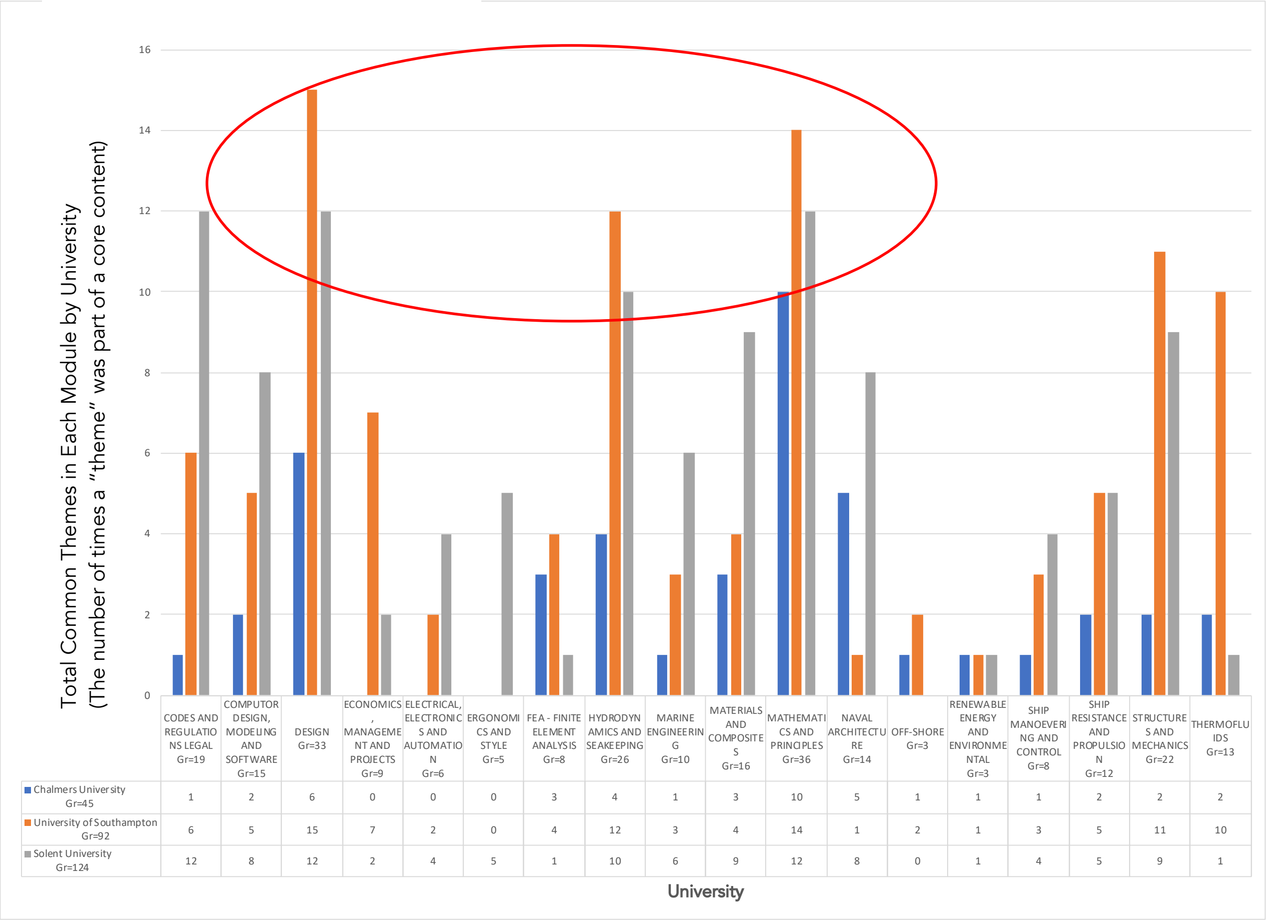


Figure 2: *Total common themes in each university*

The University of Southampton generally leads with more content over Solent owing to its being a science university. The focus of Southampton is the science of engineering, and therefore it approaches problem resolution from a 'first principles' position. Solent is an applied university, and therefore its approach is applied engineering. The understanding of first principles is taught, to ensure that students have a foundational knowledge of the formulae and concepts; however, the general approach is to provide the formulae to solve problems rather than develop the formulae from first principles. Solent takes applied teaching a step further and does not have a separate mathematics module, as is generally expected in an engineering programme. Solent teaches the specific mathematics skills in the modules and applies the mathematics in context (Jonathan Ridley, personal communication, July 14, 2020). Solent also has a focus on codes and regulations and materials, and specifically, composites. Solent's qualifications are further applied to the yachting and leisure craft industry. As a result, Solent focuses on the regulations for this sector as well as the material that the yachting industry uses, rather than the generalisation of marine materials. The next level of content that the programmes are built on are structures and mechanics.

All three institutions apply little focus to the renewable and environmental modules. However, this is a growing knowledge area that is gaining focus. All future programmes must integrate these modules into the programme to remain relevant to modern engineering.

Offshore engineering is only covered by Chalmers and Southampton. However, in a South African context, the offshore industry will continue growing as there is further exploration for oil and gas off the SA coast. Therefore, any South African qualification should incorporate offshore content. The requirement for offshore skills was again highlighted in a News24 article in February 2019 entitled 'What a major offshore gas find means for South Africa's energy future' (Mtshali, 2019).

Results analysis applied to Nelson Mandela University Marine Engineering programme

In late November 2017, the Faculty of Engineering, Built Environment and Information Technology at Nelson Mandela University in Gqeberha (formerly, Port Elizabeth) received approval from the South African Qualifications Authority (SAQA), the Higher Education Quality Framework (HEQF) and Council on Higher Education (CHE) to offer the Bachelor of Engineering Technology degree in Marine Engineering (Louie Swanepoel, personal communication, October 27, 2017).

From the outset, the goal of the Bachelor of Engineering Technology in Marine Engineering was to lay a solid foundation for naval architecture as there was no other institution in South Africa, or even in Africa, that offered a RINA-accredited qualification (or equivalent) in ship engineering, design and naval architecture. One exception was the University of Alexandria in Egypt, which has several NAME programmes from Bachelor up to PhD level (RINA, 2020).

Table 3 shows the framework of the current undergraduate Bachelor of Engineering Technology in Marine Engineering offered at the Nelson Mandela University. The core content of the undergraduate programme was evaluated against the 18 themes listed above in the results section. It was determined that an Honours and taught Master's programme should be developed to fully cover the required content and level to provide an academic foundation for future NAME managers.

Year 1 – NQF 5	**Semester 1**	**Semester 2**
	Mathematics IA	Mathematics IB
	Physics IA	Physics IB
	Engineering Drawing IA	Marine Engineering Knowledge I
	Professional Communication Language IA	Naval Architecture I
	Professional Communication Computers IA	Marine Law
Year 2 – NQF 6	**Semester 3**	**Semester 4**
	Mathematics II	Thermodynamics IIB
	Strength of Materials IIA	Strength of Materials IIB
	Statics and Dynamics IIA	Naval Architecture II
	Marine Engineering Knowledge II	Mechanical Design IIB
	Fluid Mechanics IIA	Marine Electrical Systems II
Year 3 – NQF 7	**Semester 5**	**Semester 6**
	Thermodynamics IIIA	Naval Architecture III
	Marine Electrical Systems III	Marine Engineering Knowledge III
	Marine Research and Project Management III	Marine Advanced Automation IIIB
	Marine Automation and Programming IIIA	Marine Engineering Capstone Project IIIB
	Mechanical Design III	

Table 3: *Bachelor of Engineering Technology in Marine Engineering NFQ 5, 6 and 7*

Nelson Mandela University Department of Marine Engineering Honours framework

To comprehensively address the gaps identified in the analysis of the undergraduate programme, an Honours and a Master’s framework were developed to ensure that necessary NAME core content would be covered.

The framework illustrated in Table 3 was developed at NQF 8 level. This fourth year still did not fully address the NAME requirements, but it built progressively onto the foundation of the BEngTech. This level provided opportunity to introduce more complex marine engineering topics like hydrodynamics, that will still need a subsequent level to complete, Hydrodynamics II.

Year 4 – NQF 8	**Semester 7**	**Semester 8**
	Applied Mathematics	Hydrodynamics
	Ship Design and Economics	Research Project
	Ship Structural Design and Production	
	Off-Shore Engineering I	Design Project
	Marine Materials and Composites I	

Table 4: *Proposed Fourth-year Honours for Nelson Mandela University Marine Engineering*

The fourth-year Honours in Marine Engineering at the Nelson Mandela University was submitted to the SAQA and the CHE for accreditation and registration, and was approved on 3 August 2021 (Julie Reddy, personal communication, November 18, 2021).

Nelson Mandela University Department of Marine Engineering Master's framework

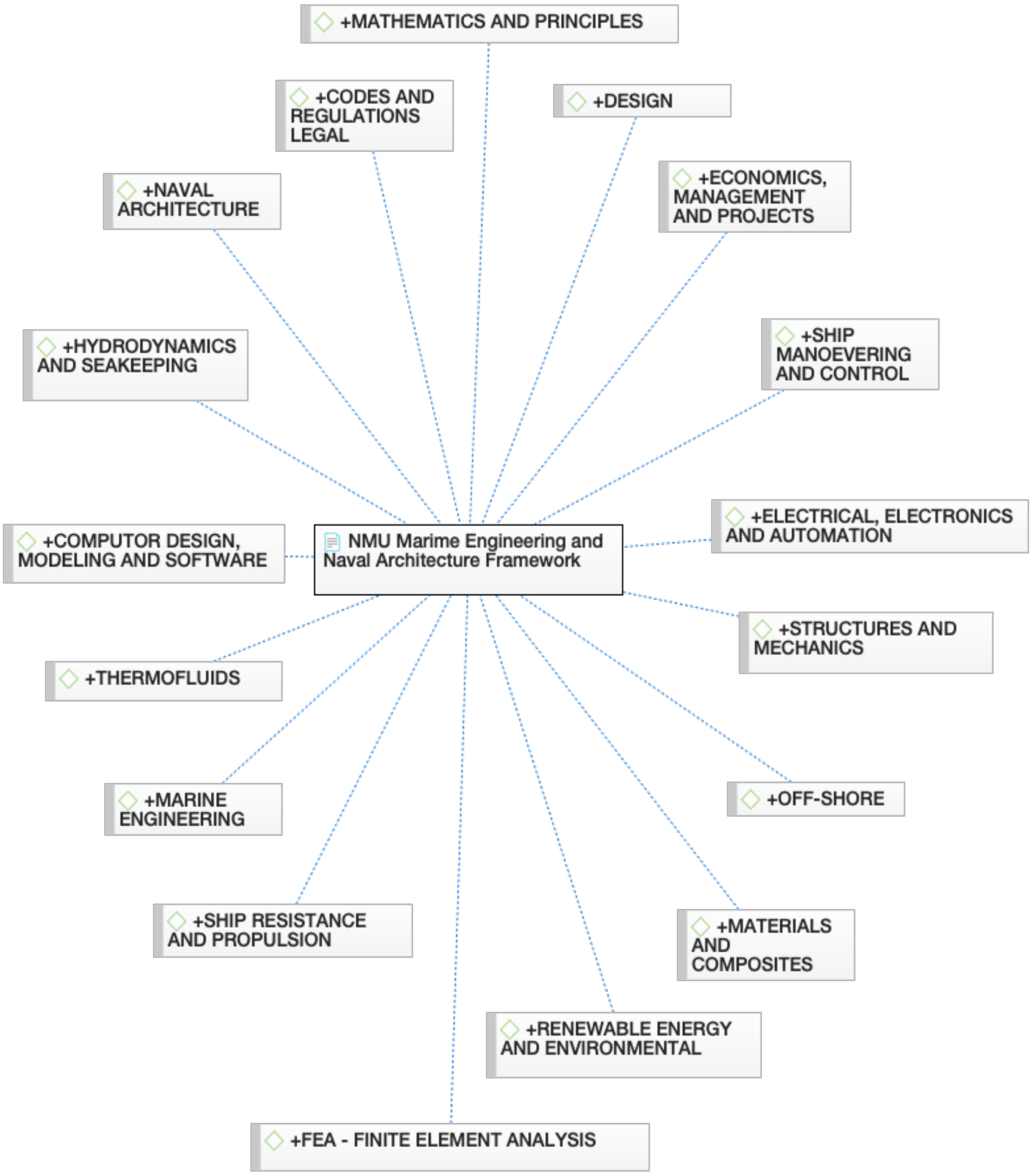
To present the full RINA-accredited qualification in South Africa, the Department of Marine Engineering has developed a Master's qualification framework to address the shortfall that was identified in this research after analysing the international qualifications. Table 5 outlines the modules that the NMU will require to meet full RINA accreditation. This framework still needs to be submitted to SAQA and CHE for approval in South Africa higher education.

Year 5 – NQF 9	**Semester 9**	**Semester 10**
	Sea-keeping and Manoeuvring	Computational Analysis Techniques applied to CFD and FEA
	Ship Resistance and Propulsion	Small Craft Performance
	Marine Hydrodynamics II	Advanced Marine Engineering
	Off-Shore Engineering II	Marine Structures
	Renewable Energy and Environmental Flows	Dissertation Project

Table 5: *Proposed fifth year master's for Nelson Mandela University Marine Engineering*

A final evaluation of the full NMU framework was conducted. The network diagram (Figure 3) shows that, of the 18 themes listed in figure 2, the NMU Framework covers 17, with the only theme not covered being ergonomics and style. This is similar to Southampton's framework, which also does not cover this theme. It is worth noting that Solent University does cover this theme is this qualification specialises in luxury and superyachts. The NMU framework encompasses a general NAME qualification, with additional foci on offshore engineering as well as renewable and environmental energy. Therefore, the decision to exclude ergonomics and style was to make way for the offshore and renewable energy content. However, NMU should consider developing a short course that could focus on ergonomics and style and offer this to students and industry. This would create the opportunity for a guest lecturer to present the short course in South Africa specifically focusing on ergonomics and style (internal and external). This would be particularly beneficial to the luxury yacht and boat industry for all the yacht, catamaran and motorboats manufactured in South Africa.

Figure 3: *Network diagram of NMU Marine Engineering and Naval Architecture framework*



Conclusion

In this article, the academic requirements for an internationally recognised qualification for future engineering managers in NAME were evaluated. The results were used to curriculate an Honours and Master's degree in Marine Engineering for NMU in South Africa, which will need to be added to the current Bachelor of Engineering Technology Degree in Marine Engineering. The educational framework developed for NAME in SA is directly related to the national maritime economy and relevant to the industry needs. These graduates will be able to contribute towards growing the maritime industry in South Africa.

The diversity and current size of the maritime industry in South Africa requires that experts be academically prepared and relevant to the diverse requirements and needs of the industry. While there may be some students who are employed at their first-choice company, many graduates will apply for many different opportunities in the maritime industry, which might mean oil and gas, offshore engineering, ship maintenance or luxury yachts. The NMU framework developed in the article meets the requirement for this diverse academic preparation that will equip and prepare the graduates to enter any sector of the industry.

It is noted that the framework compared in ATLAS.ti did not highlight the practical design and research projects; however, these aspects are included in the individual modules. Research and practical projects are a requirement for ECSA accreditation and are therefore included in all aspects of the curriculum.

The NMU Framework covers 17 of the 18 NAME themes, with ergonomics and style the only theme not academically covered. NMU can use this module to create postgraduate short course opportunities with an international guest lecturer. This will be beneficial to those in the South African industry as the course is integral for internal and external styling.

The NMU NQF level 9 Master’s Framework meets the required academic foundation for graduates to register with RINA. The NQF 9 level also enables the graduate to register with ECSA as a Professional Engineer in terms of the Washington Accord. NQF levels 7 and 8 meet the requirement for Professional Engineering Technologists in terms of the International Engineering Alliance Sydney Accord (ECSA, n.d.).

Graduates with the NMU Bachelor, Honours or the Master's qualifications will be well prepared academically to enter the maritime workplace and contribute meaningfully at these respective levels. With industry experience and mentoring, they will develop into the future engineering managers and leaders of the maritime industry in SA. In time, SA will replace the critical skills lost since the early 2000s, primarily due to the accessibility of an internationally recognised qualification in marine engineering available in South Africa.

Acknowledgements

We would like to extend our gratitude to Prof Philip Wilson for all his advice and contributions towards developing the curriculum framework, and Mr Jonathan Ridley, HOD of Engineering at Solent, for providing insight into the Solent programme.

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Southern Journal of Engineering Education, 2024
Vol 3, 119–131

Fostering Resilience and Learning in Engineering Education through Peer-Led Tutoring in the Global South

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Peer-led study groups have increasingly gained attention as a strategy to enhance student resilience and improve academic outcomes. In the Global South, where socio-economic challenges and limited resources often hinder student success, such interventions are critical. Despite the growing interest in collaborative learning, there is limited research on how these systems influence student resilience, particularly in environments that emphasise Ubuntu values of mutual support and interconnectedness. This study fills that gap by critically examining the role of peer-led study groups in high-impact engineering modules. Focusing on the experiences of students navigating complex academic challenges, it explores how these tutoring systems foster resilience and create supportive learning environments. Drawing on Relationship-Resourced Resilience (RRR) Theory, which highlights the importance of social connections in overcoming adversity, the study employs a qualitative methodology to analyse student feedback from interviews and focus groups. The findings illustrate the transformative potential of peer-led groups in creating an inclusive, supportive educational environment that goes beyond traditional lecture-based approaches.

Keywords: Student success; South Africa; peer-led groups

Introduction

The transition to higher education, particularly in engineering disciplines, poses substantial challenges for students, especially within the unique socio-economic and educational landscapes of the Global South (de Klerk, 2021; Tiroyabone & Strydom, 2021). The Global South is often used as a symbolic term to describe low-income and marginalised societies (Trefzer et al., 2014). While South Africa is classified as an upper-middle-income country (World Bank, 2018), it remains one of the most unequal nations globally, as indicated by its

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Gini coefficient (OECD, n.d.). The country faces stagnant economic growth and rising unemployment rates (Francis & Webster, 2019; World Bank, 2018). In South Africa, as in many other post-colonial contexts, education plays a pivotal role in cultivating the skills, knowledge, and attitudes necessary for ongoing development (Martin et al., 2017).

Engineering students in regions like South Africa often face under preparedness, financial constraints, and a lack of personalised academic support, resulting in low retention and graduation rates (Tiroyabone & Strydom, 2021). While traditional tutorial systems are designed to complement lecture-based learning, they frequently fail to meet the diverse needs of students who grapple with complex engineering concepts in these contexts.

Emerging research underscores the potential of peer teaching and collaborative learning in improving academic outcomes and fostering deeper student engagement (Arruda & Silva, 2021; Christie & De Graaff, 2017). However, there is limited research examining these pedagogical approaches within the Global South, where cultural and material constraints shape the educational experience. This study addresses this gap by investigating how peer-led tutoring systems, grounded in collaborative learning principles, can enhance student resilience and learning outcomes in this unique setting.

The theoretical framework guiding this study is Relationship-Resourced Resilience (RRR) Theory, which posits that students in the Global South, particularly within South African communities, draw on Ubuntu[1] values – emphasising collective well-being, mutual support, and interconnectedness – to navigate adversity (Ebersöhn, 2019). By embedding this cultural ethos within peer-led tutoring models, we explore how such systems can foster resilient learning communities in resource-constrained environments.

This study aims to contribute novel insights by addressing the following research question: How do peer-led tutorial systems in high-impact engineering modules foster student resilience and learning experiences in the Global South? Through a qualitative exploration of student experiences in small peer-led study groups, this research provides evidence-based perspectives on how such models can overcome the limitations of conventional tutorials. Additionally, it highlights the importance of collaborative learning strategies in enhancing both the academic

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[1] Ubuntu is a moral worldview originating from Nguni languages spoken in sub-Saharan region and translates to ‘A human being is a human being because of others’.

and psychosocial dimensions of student life, advocating for a shift toward more inclusive and supportive educational practices.

Implementation of the peer-led study group intervention

The 2022 pilot of the peer-led study group intervention for the mechanics module at the University of Pretoria represented a shift in pedagogical strategy, aimed at revitalising student engagement and fostering deeper comprehension of complex engineering concepts. The pilot introduced small, peer-led groups designed to address existing challenges in traditional tutorial formats, which often failed to meet students' needs in grasping complex engineering concepts. These peer-led groups created an interactive, supportive environment that allowed students to work collaboratively, encouraging active engagement and inquiry rather than passive learning. Based on feedback from the 2022 pilot, the intervention was further refined in 2023 with significant enhancements aimed at improving both the quality of tutoring and the overall learning experience. The key modification in the 2023 implementation was the integration of trained tutors, who provided more detailed conceptual guidance without undermining the collaborative nature of the peer-led groups. This dual approach – maintaining the peer-driven focus while adding targeted academic support – struck a balance between formal instruction and the benefits of collaborative learning, creating an enriched learning environment.

The inclusion of tutors was informed by ongoing feedback from students and lecturers, reflecting a responsive, iterative approach to addressing the specific educational hurdles that engineering students face. These refinements also included the earlier rollout of structured study sessions at the beginning of the academic cycle, allowing students to engage with the material from the outset, thereby reducing the sense of being overwhelmed by difficult content as the semester progressed.

In this evolved model, the role of study leaders was redefined. Rather than acting as traditional tutors who deliver direct instruction, they took on the role of facilitators, guiding group discussions, encouraging peer-to-peer learning, and fostering a supportive, interactive environment. Study leaders were selected not just for their academic ability but for their capacity to lead and support their peers, and they received additional training to equip them with the skills needed to manage group dynamics and facilitate learning effectively.

The expansion of the intervention also included additional tutoring sessions, particularly before major assessments, and the introduction of peer advisors who offered a blend of academic content reteaching and emotional support. This combination of roles further strengthened the collaborative learning environment, creating a space where students could actively engage in problem-solving while receiving guidance when necessary. This intervention model is a distinct departure from traditional tutorials and consultations, which are often underutilised and perceived as formal or rigid.

Methodology

This study employed a qualitative research approach to explore the impact of the peer-led study group intervention that took place in 2023 at the University of Pretoria. The research sought to gain deep insights into how peer-led study groups foster student resilience and learning in high-impact engineering modules. By focusing on student and tutor experiences, the study aimed to uncover the psychosocial and academic dimensions of these peer-led interventions.

Data collection was conducted through semi-structured interviews, focus groups, and online surveys. A total of 24 participants were included in the study, comprising 18 students and 6 tutors. The participants were enrolled in or facilitating a high-impact mechanics module, a subject known for its complexity and high failure rates. Students ranged from second-year to fourth-year engineering students, ensuring a mix of academic levels and experiences with peer-led study groups. Among the students, approximately 60% had no prior experience with structured peer-led tutoring systems, while the remaining 40% had participated in informal peer-learning activities in the past.

The online survey consisted of questions that sought to gauge the students' perception of the benefits of the study groups, the ways in which they benefited, if their grades improved, and their recommendations for improving the study groups. The surveys were distributed to all participants immediately after the intervention concluded, providing additional data on their perceptions and experiences. The focus groups were conducted with two of the study leaders to obtain their feedback on what worked well and their suggestions for enhancing the learning community experience in the future. These lasted approximately 90 minutes each, were conducted with two groups of study leaders, each consisting of three tutors. These sessions facilitated in-depth discussions about the challenges and successes of facilitating peer-led groups. The semi-structured interviews lasted between 30 to 60 minutes and were conducted over a two-month period (April to May 2023). These interviews provided an opportunity for participants to reflect on their experiences with the study groups. The quotations that are provided in the Findings section below are taken only from the semi-structured interviews.

Participation in this study was entirely voluntary, and no academic penalties or rewards were tied to involvement. Informed consent was obtained from all participants, ensuring they understood the purpose of the study and their right to withdraw at any time. Students and tutors were mentored into their roles prior to the intervention, with tutors receiving formal training in group facilitation and study leaders receiving guidance on managing group dynamics. This preparatory phase was critical to ensuring that participants were equipped to maximise the benefits of the peer-led model.

Thematic analysis was employed to identify recurring patterns and themes within the data. This method facilitated the exploration of how peer-led study groups contributed to both academic engagement and psychosocial support, through the lens of Relationship-Resourced Resilience (RRR) Theory. The themes that emerged from the data were coded and organised to highlight key insights into the supportive dynamics, group interactions, and learning processes within these peer-led environments.

Results

Both students and study leaders reported on the positive impact of peer social connection on learning especially for a challenging module like mechanics. Students highlighted several key factors, including the assistance provided by classmates who understood the difficulties of the material and could offer relevant insights. The presence of these classmates created a more comfortable and supportive learning environment, where students felt empowered to ask questions and engage in meaningful learning opportunities. Furthermore, the presence of stronger students in the group provided a valuable opportunity for weaker students to model effective learning techniques and improve their comprehension of challenging concepts.

In addition to these benefits, students also reported that participation in these study groups increased their willingness to participate in future study groups and recommend such groups to friends. This can be attributed to the smaller group size, which fostered students' confidence and aided in comprehending difficult material. The collaborative nature of these groups created a sense of shared experience, which further enhanced students' engagement and motivation to learn.

The post-intervention qualitative data analysis showed that the students who participated in the study group intervention reported an increase in their ability to form bonds within and across peer networks, utilize learning-community networks, and place a higher value on shared experiences with their classmates. Themes are outlined and verbatim quotes given to illustrate participants' experiences of the intervention. The main themes identified from the post-intervention interviews with participating students and study leaders are:

Theme 1: Leveraging social connectivity for enhanced academic resilience

The utilization of resources provided by social ecologies can vary greatly, as it is influenced by the perceived availability of both informal and formal resources (Ebersöhn et al., 2020). Thus, it is crucial for students to understand the value of social connectedness as a protective resource, particularly during times of academic stress related to a challenging course. The collaboration that took place in study groups not only aided in the comprehension of difficult concepts but also highlighted the positive impact of social connection. By promoting the benefits of social connectedness, students could better understand the role of social support in their academic lives, as shown the in the following quotes:

> The study group sessions were very helpful. The groups were fantastic, and it was nice to work with others going through what you are going through and having that support.
>
> The choice of students to run the study groups was great.
>
> It is a good platform to help students help each other.

Studies have demonstrated that peer mentorship can enhance not only motivation, but also provide balance to mitigate stress and burnout. Peer support, whether in the form of guidance or simply a listening ear, may aid in internal stress management or learning coping strategies (Cheetham & Varga-Atkins, 2021). Student-led networks necessitate the establishment and maintenance of productive partnerships among learners within the same peer group. The implementation of study groups facilitated communication and interaction among students, resulting in a heightened level of peer connection and learning as evidenced by the following post-intervention quotes:

> We challenged each other and helped each other.
>
> Working on the problems with my group helped me to grasp the material more easily.

> Coming together and helping each other with the work really helped me.
>
> All the leaders had different approaches and strong points, so we were able to give different ways to look at a problem.

Theme 2: Collective resilience: navigating academic challenges together

In addition to student's appreciation of the benefits of peer connection (working together on the module compared to working alone), students reported that participation in the intervention made them aware of shared experiences students went through. The realisation that other students were facing similar difficulties in the module proved to be a valuable experience for the participants. By acknowledging the struggles of their peers, they gained a sense of support and empowerment.

> You realise that you are not the only struggling so we could comfort and support each other.
>
> Learning from other students who have done the module before was insightful.
>
> Knowing that we weren't the only ones in the class gave us hope and kept us motivated to keep going.

The findings of recent research indicate that engineering students often enter university with a 'STEM-ego', a term used to describe a strong sense of academic self-efficacy. This confidence is particularly common among high-achieving high school graduates who pursue programs in Science, Technology, Engineering, and Mathematics (STEM) – disciplines known for their focus on critical thinking, problem-solving, and technical expertise. These students frequently assume they will not require additional support to succeed, underestimating the challenges posed by the rigorous demands of higher education. Nonetheless, this perspective can have adverse effects on their academic performance and their willingness to seek help. The results from this study highlight that these students are not familiar with failure, as they have been accustomed to receiving good grades in high school. For those students who struggle with this particular module, this can be a novel experience as they confront failure for the first time in their lives. Consequently, sharing similar experiences of difficulty with the module helped students feel less isolated and empowered them to persist in their studies.

> I appreciated the fact that there were other people who found the module a bit tricky and were making an effort to do better.

> For some of these students it was their first time failing so it really made them lose hope, but for the students who stuck with it through with the module, it really helped them to see other students also struggling.

Theme 3: Optimising learning through small group dynamics

Many of the students entering South African universities are in diverse economic, academic, and psychosocial positions. As a result, South African universities try many initiatives to support students holistically. Thus, there has always been an understanding of the need for holistic support (intellectually, ethically, culturally, socially, and even physically) but there appears to be a lack of understanding as to what that support would mean practically. Strydom and Loots (2020) contend that, despite well-intentioned efforts to support students, the practical implementation of such support often fails to incorporate students' perspectives, leaving their voices notably absent from discussions surrounding intervention strategies.

In the engineering department at the University of Pretoria, various types of academic support are offered to students. However, lecture halls and even tutorials are often attended by a more diverse range of students. Students may be reluctant to ask questions in big groups which can interfere with their learning. Because the study groups were small, it was beneficial for students as they felt more comfortable to ask questions between peers.

> Being helped by my classmates, they understand the struggle best and they can relate the most thus making it easy for me to learn from them and as I'm more comfortable around them I can ask as much as I want.

> Learning from other students who also find certain concepts difficult, because the lecturers don't always understand how difficult it is to grasp.

Collaborative learning, defined as a process in which peers assist one another in addressing challenging aspects of a course, is a key characteristic of tutoring (Cheetham & Varga-Atkins, 2021). This approach offers various advantages, such as establishing social connections and complementing lectures, while also providing students with teaching and leadership opportunities. However, students in the Faculty of Engineering, Built Environment, and Information Technology (EBIT) frequently view tutorials differently, as they are often taught in large groups and do not provide an environment where students feel comfortable asking questions. Students reported that smaller study groups were more beneficial, as they felt comfortable asking questions and learning from one another, as shown in the following quotes.

> Working in smaller groups helped us to see different ideas on how to tackle a problem.
>
> I enjoyed how we were all helping each other and giving each other some advice on how to tackle questions. That doesn't always happen in lectures and tutorials because the groups are too big, and you feel shy to ask questions.

Theme 4: Fostering inclusivity and engagement across student communities

In recent years, there has been a broadening of the discourse around student support initiatives to encompass not only the acquisition of academic skills but also the psychosocial dimension (Tiroyabone & Strydom, 2021). As part of orientation, students are frequently encouraged to participate in student communities. However, there are challenges related to the use and accessibility of these communities, particularly for day students. Students in residence tend to have a stronger sense of community, as residences often organise study groups. Conversely, non-residential students may struggle to feel a sense of belonging. Students who were part of the mechanics study group reported an increased understanding of the benefits of these communities, which, in turn, made them more receptive to participating in other student communities, as seen by the following quotes:

> I think the day students benefitted more from the study groups than the res students, because at res we have those study groups. For the day students it helped them a lot to have that support.
>
> It really helped me. It made me realise that working in a group helps you to not feel alone. I wish they had study groups for every module.

Discussion

The current study highlights the crucial role of social connections in fostering academic resilience, reinforcing findings from Rudd, Meissel, and Meyer (2021), who advocate for the importance of peer interactions as a supportive mechanism. However, by embedding these interactions within the socio-cultural context of the Global South and guided by the Ubuntu principles of interconnectedness and collective support, the research introduces a unique and culturally nuanced pathway for resilience. This culturally embedded approach is particularly significant for addressing the adversities faced by engineering students in South Africa, where socio-economic barriers and academic pressures intersect. Peer-led study groups, in this context, go beyond offering mere academic support – they foster a deep sense of community and belonging, which is vital for both academic and emotional well-being. This community-oriented support system not only aligns with Ubuntu values but also provides a profound counterbalance to the traditional, often isolating, academic structures found in higher education. The insights gained from this study resonate with the work of Pointon-Haas et al. (2024), which emphasises the critical role of social connectivity in academic resilience. However, our research contributes a broader perspective by contextualising this within the unique educational landscape of the Global South.

The concept of collective resilience is vital for navigating academic challenges, as echoed by Cheetham & Varga-Atkins (2021). The current study's findings provide a deeper understanding of how peer-led groups foster this collective resilience, particularly within the complex and demanding field of engineering education. By applying Relationship-Resourced Resilience (RRR) Theory (Ebersöhn, 2019), peer-led tutorials show how students draw on the collective strength of their peers to overcome academic struggles. The ability to share academic challenges within a supportive group allows students to view difficulties as shared experiences rather than personal failures. This collective problem-solving process not only enhances academic outcomes but also strengthens students' capacity to cope with the pressures of their courses. Our findings also align with the work of Meuleners, Neuhaus, and Eberle (2023) on the efficacy of peer-led Positive Psychology Interventions, which underscores the power of Ubuntu-driven collectivism in enhancing educational success. The unique feature of the current study is its focus on how culturally grounded, collective resilience contributes to overcoming the specific educational challenges found in the Global South.

The benefits of small group dynamics in improving learning outcomes, as documented by Rudd, Meissel, and Meyer (2021) are reinforced by the results of the current study, which delves into the additional complexities of implementing such dynamics within the Global South's engineering education context. Engineering students in South Africa face diverse socio-economic and academic challenges, and peer-led study groups offer an adaptable solution that is responsive to these varied needs. In smaller, more intimate learning environments, students feel empowered to engage, ask questions, and participate in deeper discussions, which may be less accessible in larger, more formal settings. The smaller group sizes facilitate a more interactive and student-centred learning environment, as well as provide a space for students to build leadership and peer-teaching skills. Additionally, such group dynamics can be adapted to address the unique needs of students in under-resourced, high-pressure educational settings, particularly within the context of the Global South (Sedghi, 2013).

Our findings on fostering inclusivity and engagement through peer-led study groups add a significant contribution to the discourse on educational interventions in the Global South. Our research shows how peer-led study groups offer both psychosocial and academic benefits by creating inclusive, supportive learning communities. These groups are especially beneficial for students from diverse backgrounds, including those who may feel marginalised in traditional educational structures, such as non-residential students or those from underprivileged socio-economic backgrounds. By bridging these diverse student demographics, peer-led groups foster a sense of belonging and encourage active participation in the learning process. This inclusivity is critical in a field like engineering, where students often feel isolated due to the demanding nature of the discipline. The holistic support systems provided by peer-led groups ensure that students receive both academic guidance and emotional support, addressing the full spectrum of their needs and promoting long-term success in their educational journeys.

In synthesising these insights with broader educational literature, the current study not only validates the efficacy of peer-led interventions but also deepens the understanding of their impact within the specific cultural and socio-economic context of South Africa. By advocating for a holistic approach to engineering education that prioritises both academic success and student development, the research contributes a vital perspective to the global conversation on enhancing higher education through peer support. As the demands of the modern educational landscape continue to evolve, our findings underscore the need for reimagined educational strategies that move beyond academic instruction to incorporate emotional and psychosocial resilience. This holistic framework recognises the complex realities of the modern world and advocates for educational models that emphasise collective resilience, peer support, and community-driven success – particularly within the Global South – where resource constraints make such approaches even more critical.

Conclusion

The findings from this study underscore the significant role that peer-led study groups play in fostering not only academic success but also psychosocial resilience. By providing a collaborative, supportive environment, these groups have proven to be more effective than traditional tutorials in facilitating deeper engagement with complex engineering concepts.

The study's emphasis on Ubuntu values and Relationship-Resourced Resilience (RRR) Theory further highlights the importance of social connectivity in academic settings, particularly in regions where socio-economic factors exacerbate the stresses of higher education. The peer-led study groups not only enabled students to navigate academic challenges but also fostered a sense of belonging and collective resilience, which is crucial for their overall development and well-being. This culturally contextualised approach aligns with the unique needs of students in South Africa and other similar environments, demonstrating that educational interventions must be adaptive and sensitive to the broader socio-cultural context. The smaller, more intimate group dynamics fostered by this intervention were particularly beneficial for students who might otherwise struggle in large, impersonal lecture halls or traditional tutorials. The ability to ask questions, engage in discussions, and receive peer support in a non-threatening environment was pivotal in helping students grasp difficult material and gain confidence in their academic abilities.

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