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Are engineering programs meeting the 2035 professional and personal requirements?

Zachery Quince, Catherine Hills & Andrew Maxwell
University of Southern Queensland (UniSQ), School of Engineering, Springfield, 4300.
Corresponding Author Email: Zach.quince@usq.edu.au

CONTEXT
The Australian Council of Engineering Deans Engineering Futures 2035 report has shown that "professional skills are certainly as important as technical skills" and that contemporary graduates require these skills now more than ever. As such, a shift in the education trends towards non-technical skills are paramount. It is even more important to begin this development in first year education to allow students to being to develop their professional and personal attributes from their first day. The engineers Australia (EA) stage 1 graduate competencies are made up of 16 skills and attributes, only 6 are "technical". There are 3 elements in the stage 1 competencies, and they are 'knowledge and skill', 'engineering application ability' and 'professional and personal attributes'.

PURPOSE OR GOAL
This study provides a critical review of the professional and personal learning outcomes of the first-year engineering subjects taught in Queensland universities. The learning outcomes from each course were mapped to the 16 stage 1 competencies to determine if there is a balance between the 3 element areas. Part of this study investigated the differences in learning outcomes between a common and non-common first year engineering program.

APPROACH OR METHODOLOGY/METHODS
Each university in Queensland that offers a Bachelor of Engineering in the three main areas of engineering (electrical, mechanical and civil) had their first-year units learning outcomes mapped against the stage 1 competencies. A comparison between the universities, majors and difference between a common and non-common first year was investigated. A comment on how these learning outcomes are derived and implemented will be made, alongside an overall statement regarding if Queensland universities are currently meeting the requirement set by the 2035 report.

ACTUAL OR ANTICIPATED OUTCOMES
The results of this study showed that Queensland universities are not meeting the mark (personal and professional development) of the 2035 report in first year education as technical learning outcomes are still being prioritized over non-technical by a ratio of 2:1. Most institutions are currently omitting the project and professional graduate competencies for first-year education, with some core competencies not examined in first year. This review shows which core competencies need to be delivered and that a common first year is currently not designed to meet the 2035 reports requirements.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
This study showed the areas of weakness in first year tertiary engineering education in Queensland with respect to the 2035 report requirements. This study is transferable across the country and shows that educators are missing the mark in first year education. It provides a comprehensive evaluation and strategic path forward to fix it.

KEYWORDS
Learning outcomes, stage 1 competencies, first year education

Introduction

The Australian Council of Engineering Deans Engineering Futures 2035 report (Crosthwaite, 2021; Crosthwaite et al., 2018) has found that "Industry wants to see a re-balancing of the theory-practice components of professional engineering education, with a greater emphasis on practice, including the human dimensions of engineering" and "Potential students are motivated to solve "real-world" problems and want to see that engineering practice addresses societal needs". As such, there needs to be a shift towards more project-based learning outcomes (LO) from graduates and professional development that is taught in-conjunction with the technical side of a typical engineering degree.

Learning outcomes are comprised of a list of objectives that an individual course aims to instil in students at successful completion. At the end of the program of study the graduate should have a pool of verified competencies for use in respective areas of employment. Each university generally has their own list of prospective graduate competences that a program of study should develop, however, there may also be industry/accreditation-based competencies that graduates must meet to allow them to practice in their field. This is specified for engineering and forms the "Stage 1 competencies and elements of competency" which is governed by Engineers Australia (EA). The stage 1 competencies are segmented into a set of (16) core competencies that a graduate engineer must obtain at the successful completion of their undergraduate degree. These stage 1 competencies are categorized into three sub-categories or elements which are '*knowledge and skill', 'engineering application ability' and 'professional and personal attributes'.* For a graduate to become a practicing engineer they must meet the stage 1 competencies that are examined by the individual institution. As such, each program of study is required to be accredited by EA. Every 5 years EA will audit the degrees offered and award accreditation where they deem successful.

Each course/unit will have a list of learning outcomes that are available to students. These learning outcomes are linked back to the assessment items that are undertaken. For example, if a student is to write a report, then a LO could be communication skills. If a student passes the unit, then it is assumed that they have attained said LO. The LO are typically written by the coordinator of the unit with supervision/approval by heads of learning and teaching. These LO are then mapped to the graduate attributes of the institution and what is becoming more common is that they will be mapped to the EA stage 1 competencies. This is typically seen as a list where the competencies are marked. This mapping can be external or internal, meaning that student may not see this. If it is visible, the LOs do not describe how they are mapped for the level of attainment.

As such, this review will map the LOs of Queensland universities first-year engineering programs against the stage 1 graduate competencies from EA. Both common and non-common first year programs will be mapped. A common first-year is when all subjects remain the same regardless of major selection. A non-common first-year is when the program is split between core (must undertake regardless of major) and major based courses. The focus will be on first-year programs as this is where students decide if they will continue with the program (Shcheglova et al., 2020) and where they begin to develop their professional skills (Yusof et al., 2016) and sense of belonging (Boles & Whelan, 2017; Hoffman et al., 2002; Morrow & Ackermann, 2012). As part of this review, a comparison will also be made between the common vs non-common first year, and by a product, the differences between civil (CE), mechanical (ME) and electrical (EE) engineering education both internally and between institutions. This mapping will examine if the LOs are robust enough for an individual (student, academic (internal and external) or industry) to determine what stage 1 competencies are being met in hopes to identify gaps where competencies are being missed with respect to the 2035 report. From this, the following two research questions aim to be answered.

Research Questions

Are there differences in LOs between common and non-common programs?

Are there current programs still focusing on the technical knowledge transfer in first-year education?

Methods

Selected Universities

This research looked to map the learning outcomes of the first-year engineering degree at Queensland universities against the EA stage 1 competencies. All university units provide the learning outcomes as part of the unit outline that is accessible by the public. Due to the large number of universities that offer a Bachelor of Engineering in Australia, this study was restricted to Queensland due to the authors familiarity with the institutions reviewed. Further to this, as this paper was to compare and contrast the learning experience between different majors the university must offer civil, mechanical and electrical engineering. They must also be able to be taken in-person due to the abundance of online learning experiences post COVID. Finally, the learning outcomes are required to be not mapped specifically to the engineering stage 1 competences and must directly relate to the assessment items examined in each unit.

After reviewing all of the universities in Queensland there were six identified as meeting all of the criteria to be reviewed as part of this paper; University of Southern Queensland (UniSQ), Griffith University (GU), James Cook University (JCU), Queensland University of Technology (QUT), University of Queensland (UQ) and University of Sunshine Coast (UniSC). Table 1 shows the universities identified and the number of available first year units and whether they offer a common first year experience.

Table 1: Comparison of first year course offerings from selected Queensland Universities

University	Number of core subjects	Total first year subjects offered	Common First Year
UniSQ	4/5^	13	N
GU	6	10	N
QUT	5/6*	11	N
JCU	8	8	Y
UQ	4	16	Y
UniSC	8	8	Y

^Whilst UniSQ offer only offer 4 core subjects, there is one subject that is common to all 3 majors * whilst QUT only offers 5 core subjects, there is one subject that is common to all 3 majors.

It should be noted that UQ offer a first-year engineering degree that does offer a non-common program based on major. Whilst this is offered, there is also an option to undertake a common first year. Given the structure of the non-common degree and the amount of flexibility, the common first year will be reviewed. First year programs can also vary based on the individual's student's entry level. There are various institutions that do not have a mathematics pre-requisite or have a minimum level of attainment. As such, to allow students to have the same entry level knowledge an extra mathematics subject is offered in the first-year program. All program structures examined in this study assume that the student has not completed any of the pre-requisites with exception of GU. This GU university program utilises a trimester-based semester model where if the incoming student does not meet the mathematics pre-requisites, then they must undertake nine subjects instead of the standard eight. Due to the methods of this review, this would bias this program due to the extra courses LOs being added to the program.

Learning Outcome Mapping

The EA stage 1 competencies (Engineers Australia, 2019) are divided into three (3) subsets: *'Knowledge and skill base'; 'engineering application ability';* and *'professional and personal attributes'*. To further compartmentalise, *'knowledge and skill base'* have six (6) areas of competency which then cover:

(1.1). Comprehensive, theory-based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.

(1.2). Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline

(1.3). In-depth understanding of specialist bodies of knowledge within the engineering discipline.

(1.4). Discernment of knowledge development and research directions within the engineering discipline

(1.5). Knowledge of engineering design practice and contextual factors impacting the engineering discipline

(1.6). Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline

'E*ngineering application ability'* which can be further broken into the four (4) sub categories.

(2.1). Application of established engineering methods to complex engineering problem solving.

(2.2). Fluent application of engineering techniques, tools and resources.

(2.3). Application of systematic engineering synthesis and design processes.

(2.4). Application of systematic approaches to the conduct and management of engineering projects.

Finally, '*professional and personal attributes'* which cover the following.

(3.1). Ethical conduct and professional accountability.

(3.2). Effective oral and written communication in professional and lay domains.

(3.3). Creative, innovative and pro-active demeanour.

(3.4). Professional use and management of information.

(3.5). Orderly management of self, and professional conduct.

(3.6). Effective team membership and team leadership.

Each of these competencies have at least one indicator of attainment (but typically more). These indicators of attainment allow self, and peer, review of the competency. To map each of the learning outcomes to the relevant competencies, the indicator of attainment was used to determine if there was a match. The mapping was performed by two researchers to reduce the potential bias and mismatch between LOs and indicator of attainment. Where there was a discrepancy, the learning outcome would be remapped until a consensus was met. Due to the overlapping nature of the of the indicators of attainment, the learning outcomes were mapped to multiple indicators if applicable. If there was seen to be the same indicator of attainment in the same unit, then it would only be mapped once. For example, if a unit described two specialist bodies of knowledge, which is competency 1.3, then it would only be mapped once. Given that the units were first year, and the stage one competencies are graduate outcomes, if there was an indication of attainment the competency was mapped. For example, an indicator of attainment for 1.1 states "complex problems". In first year a complex problem may take many forms, as such if the LO state a multidisciplinary nature, specific major or industry knowledge then it would be mapped. Each major was mapped as its own first year program. As such there was a total of 12 first year programs mapped across the six (6) Queensland universities. The date of the review took place between

January 2023 and February 2023. Wherever possible the latest iteration of the unit and program was selected for review. Where the course had generic LOs but were subsequently mapped to the stage 1 competencies, they were not used as reference so as to not introduce additional bias from the authors.

Results and Discussion

Table 2 shows the full LO mapping table for all programs.

Table 2: Mapped LOs for all university split into each of the 16 competency elements.

University	Major	Element 1						Element 2				Element 3					
		1	2	3	4	5	6	1	2	3	4	1	2	3	4	5	6
UniSQ	CE	5	7	3	1	4	3	0	3	3	2	3	4	1	1	0	2
	ME	5	8	5	0	3	2	0	5	3	2	1	5	1	0	0	2
	EE	6	8	5	0	3	2	1	4	2	2	1	7	1	1	1	2
GU	CE	6	6	3	1	2	3	3	4	2	2	0	5	1	0	1	6
	ME	6	6	4	1	2	3	3	4	2	2	0	4	1	0	1	6
	EE	6	6	4	1	2	3	3	3	2	2	0	4	1	0	1	5
QUT	CE	8	7	5	0	2	4	1	5	1	0	1	7	1	0	0	3
	ME	8	8	5	0	1	3	0	7	1	0	1	6	1	0	0	1
	EE	8	8	5	0	1	4	0	7	1	0	1	5	1	0	0	1
JCU		5	7	6	0	1	1	1	2	3	0	1	5	0	1	1	1
UQ		5	7	5	0	2	1	2	3	1	2	2	5	0	1	1	5
UniSC		5	7	4	0	1	2	3	5	1	1	1	1	0	1	1	2

Comparison of common and non-common programs including different majors

Between the common and non-common first-year programs and those universities that offered it, there were significant differences between university offerings. Table 3 shows the combined learning outcome mapping for each of the 3 competency elements. JCU and USC have a lower amount of learning outcomes than the other programs that offer common and non-common programs. UQ has a higher amount of element 3 and in fact the highest mapped across all programs. A distinction can be made from the lower amount of element 1 competencies mapped. This is to be expected in programs that do not specialise as competency 1.3 is not able to be mapped. It was identified that there were small differences present between the number of competencies in the majors for each institution, where these differences typically reduced to one or two LOs.

For example, UniSQ's civil engineering did indicate that there was less presence of competency 1.3, relating to subject specific knowledge. This is explained by the civil engineering discipline being quite broad and tendency to house a shallow level of knowledge to allow students to experience a wider array of subject areas within that discipline. Whilst the other institutions did not necessarily show this trend it is assumed that the different demographic of the institution played a part in the topics and by association, learning outcome differences.

QUT showed minimal differences between majors. Civil engineering (QUT) showed that it was slightly lower in competency 2.2, which examined application of engineering tools and that it was higher in competency 3.6 relating to teamwork. This again links to a multidisciplinary nature of the civil engineering area.

GU's programs showed consistency across the programs of study. There was a slight difference in element 3 for civil engineering being higher. This can be explained by element 3 containing project management and ethical accountabilities. Due to civil engineering being closely related to environmental engineering, there is a link between the slight increase in these competencies.

Table 3: Learning outcomes for first year programs mapped to the three competency elements of the EA stage 1 competencies.

University	Major	Element			Total
		1	2	3	
UniSQ	CE	23	8	11	42
	ME	23	10	9	42
	EE	24	9	13	46
GU	CE	21	11	13	45
	ME	22	11	12	45
	EE	22	10	11	43
QUT	CE	26	7	12	45
	ME	25	8	9	42
	EE	26	8	8	42
JCU		20	6	9	35
UQ		20	8	14	42
UniSC		19	10	6	35

Figure 1 shows the learning outcomes in a stacked column format, highlighting the difference in the total number of course learning outcomes mapping to competencies, but also the variation in the competencies addressed.

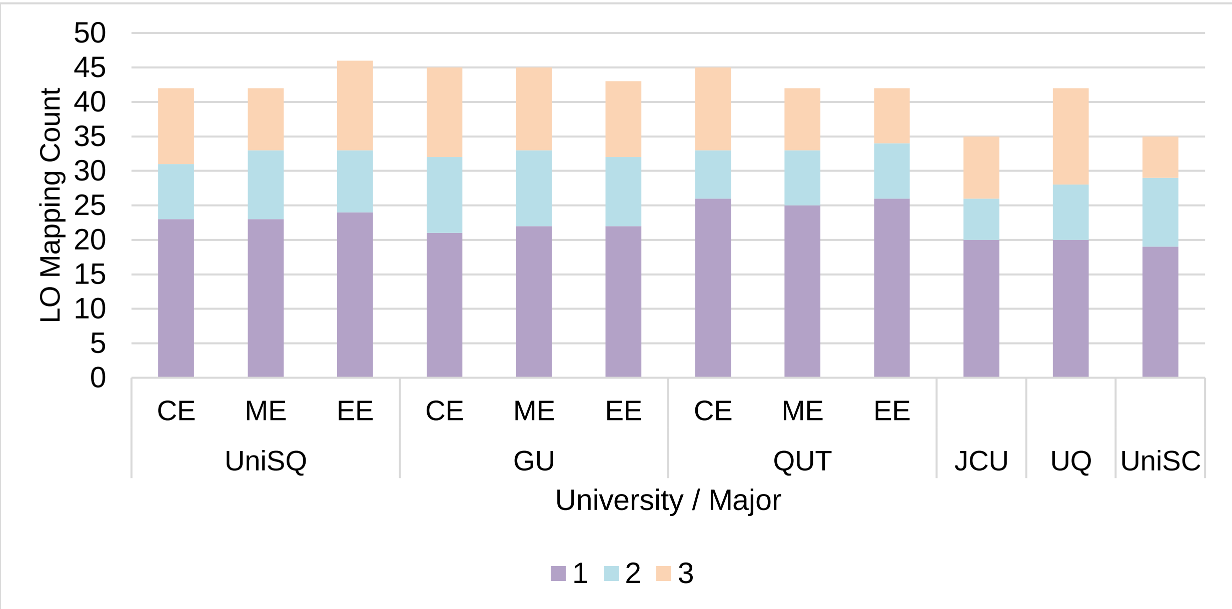

Figure 1: Learning outcomes for the first-year programs mapped to the three competency elements of the EA Stage 1 competencies. The colours indicate the EA Competency.

Figure 1 highlights the situation where within a university the variation across individual competency areas is less than is typically seen between different institutions. That is, the total number of LOs mapped to each competency is roughly the same across majors within a university. It would be interesting to investigate further if this was due to the program structure or the LO mapping process within institutions.

Differences in Learning Objectives

Throughout the review there were several courses from institutions that presented a mismatch between those learning outcomes found in this review from EA compared to the individual institutions own graduate learning outcomes.

An example of this mismatch was a unit that only mapped to few (3 in this instance) of the stage one competencies from EA however, however when compared to the institutions LOs, it matched to 12 of the generic graduate attributes and 7 of the engineering specific graduate learning outcomes.

Upon analysis of this situation there are two possibilities for this occurrence. The learning outcomes, typically mapped by the unit coordinator display inconsistency between what the intended outcomes where, to those that were written; and then that the institutions graduate attributes do not align, partially, or fully with those required by EA.

Whilst this mapping is often performed behind the scenes, there is a significant advantage to keeping and publishing this mapping to explicitly inform students of this linkage. This firstly allows tracking of these competencies for accreditation, but also to allow tracking of student competency completion by identifying gaps in the students' abilities.

2035 Competency Requirements

After mapping the learning outcomes to the stage 1 competencies there were several key identified trends. Across the Queensland universities analysed there was more than double the level of element 1 competencies mapped than for element 2 and/or 3. Whilst this is not necessarily cause for concern, this observation can be actioned by incorporating additional element 2 and 3 competencies into the assessments.

As first year engineering education is introductory, and for some students a knowledge catchup, a large number of units should be examining these particular learning outcomes. Although there was a significant amount of these first element competencies, most were competencies 1.1, 1.2 and 1.3 which examine technical engineering knowledge. Alarmingly, competencies 1.4, 1.5 and 1.6 were apparently missing across the universities investigated. Whilst these competencies relate to a higher-level thinking, they can still be examined at an introductory level. For instance, creating an assessment item/s that covered current research and knowledge in engineering design practice and sustainable practice would sufficiently allow for these 3 competencies to be examined.

The professional and personal attributes element (3) was also found to be limited across the board. Most of the programs were able to have the learning outcomes mapped to competency 3.2 and 3.6 however most courses did not map to 3.1, 3.3, 3.4, 3.5 even once. Competencies 3.2 and 3.6, covering communication and team membership, were the most commonly mapped, which is understandable given that the engineering discipline in general is quite multidisciplinary. This is better reflected in Figure 2 where the averages of each of the 16 competencies are shown.

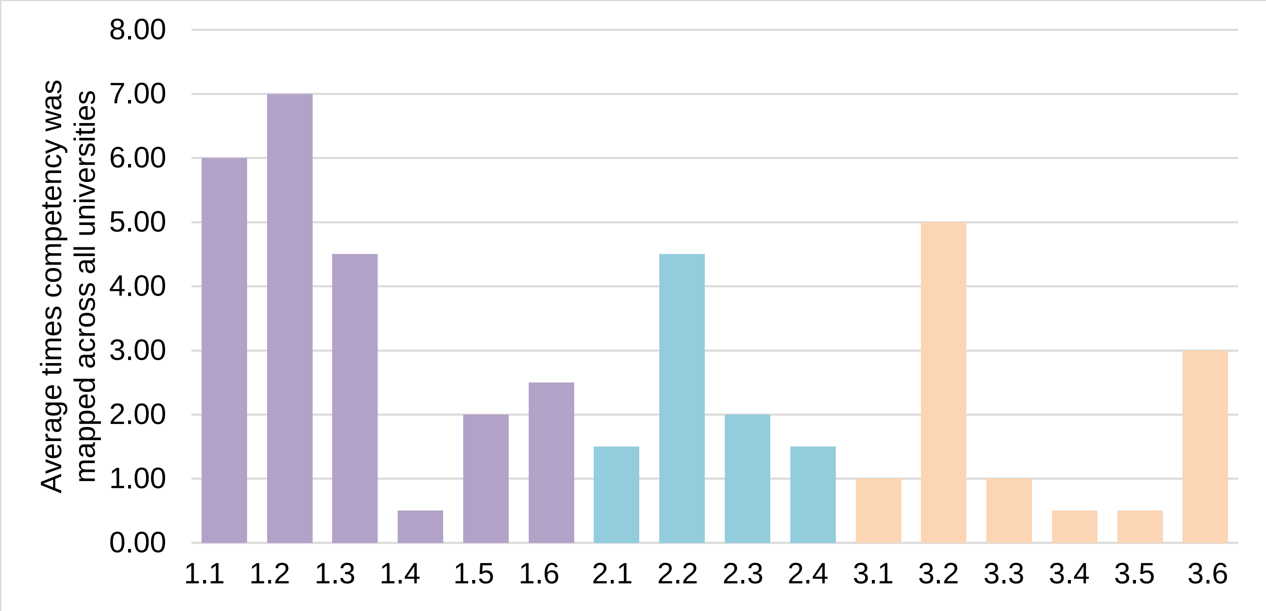

Figure 2: Average times competency was mapped across all universities.

As shown by the above figure, the average times that competencies 1.4, 3.1, 3.3, 3.4 and 3.5 were mapped across the programs was 1 or less. This is very alarming as it suggests a mismatch being present between industry needs and what is current curriculum. Moreover, 4 out of 6 of the professional and personal attributes fall into this category. We believe the focus needs to shift towards teaching professional engineering which has a large emphasis on professional skills. There are many compounding factors that have impacted the current pedagogical directives, and they include time and financial resources, different stakeholder viewpoints towards what the degree should prepare students for and what an actual engineer does in a workplace environment. A study by (de Campos et al., 2020) stated that 85% of the desirable skills for employability are related to soft skills, while the remaining 15% are technical. This data was collected from a study in 2015 showing that the development of soft skills has been in need for almost a decade. Key skills required of a graduate engineer include working in teams, managing interdisciplinary groups and understanding society's demands taking into perspective the ecological, ethical and political repercussions of their actions (Gómez et al., 2021; Male et al., 2011).

Conclusions

In this paper, a comparison between first year units (by major) was conducted across a range of Queensland universities. Analysis of these units contrasted and compared both University level graduate capabilities, as well as Engineering Accredited EA stage 1 graduate capabilities. This study has found that there was little to no difference between the LOs of majors but did find a discrepancy between common and non-common first year programs. Whilst this discrepancy is not a significant issue, the recommendation is to try and bolster the LOs with more professional skills. An issue that was identified in this study is that at all universities the knowledge-based competencies are still outweighing personal and professional by almost 2:1. Further to this point, some personal and professional competencies are not being undertaken at all at some universities. This approach shows that cross institution benchmarking obviously allows for identification of perceived gaps in first year engineering education, to allow for corrective action as necessary to help capacity build first year prospective engineers.

References

Boles, W., & Whelan, K. (2017). Barriers to student success in engineering education. *European Journal of Engineering Education*, *42*(4), 368-381.

Crosthwaite, C. (2021). Engineering futures 2035 engineering education programs, priorities & pedagogies. *Australian Council of Engineering Deans, Report*.

Crosthwaite, C., Hargreaves, D., Wilson, J., Lee, P., Foley, B., Burnett, I., Goldfinch, T., & Symes, M. (2018). Engineering futures 2035. 29th Australasian Association for Engineering Education Conference 2018 (AAEE 2018),

de Campos, D. B., de Resende, L. M. M., & Fagundes, A. B. (2020). The importance of soft skills for the engineering. *Creative Education*, *11*(08), 1504.

Engineers Australia. (2019). STAGE 1 COMPETENCY STANDARD FOR PROFESSIONAL ENGINEER. Retrieved June 1, 2023 from https://www.engineersaustralia.org.au/sites/default/files/2022-07/stage-1-competency-standard-professional-engineer.pdf

Gómez, M. Á., Herrera, R. F., Atencio, E., & Munoz-La Rivera, F. C. (2021). Key Management Skills for Integral Civil Engineering Education. *Int. J. Eng. Pedagog.*, *11*(1), 64-77.

Hoffman, M., Richmond, J., Morrow, J., & Salomone, K. (2002). Investigating “sense of belonging” in first-year college students. *Journal of College Student Retention: Research, Theory & Practice*, *4*(3), 227-256.

Male, S. A., Bush, M. B., & Chapman, E. S. (2011). An Australian study of generic competencies required by engineers. *European Journal of Engineering Education*, *36*(2), 151-163.

Morrow, J., & Ackermann, M. (2012). Intention to persist and retention of first-year students: The importance of motivation and sense of belonging. *College student journal*, *46*(3), 483-491.

Shcheglova, I., Gorbunova, E., & Chirikov, I. (2020). The role of the first-year experience in student attrition. *Quality in Higher Education*, *26*(3), 307-322.

Yusof, K. M., Sadikin, A. N., Phang, F. A., & Aziz, A. A. (2016). Instilling professional skills and sustainable development through Problem-Based Learning (PBL) among first year engineering students. *International Journal of Engineering Education*, *32*(1), 333-347.

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