33rd Annual Conference of the Australasian Association for Engineering Education (AAEE 2022)
4 - 7 December 2022 – Sydney, NSW

Identifying Effective Strategies for Integrating Emerging Technical Concepts in a First-year Engineering Course

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ABSTRACT

CONTEXT

With the advent of Industry 4.0, curriculum renewal in engineering disciplines should ensure that the teaching content is up to date with the current industry expectations. Incorporating emerging technical concepts together with authentic applications in different courses equips students with the desired knowledge and problem-solving skills and contributes to the students' competency throughout the program. However, selecting and integrating appropriate technical concepts into the course content for first-year engineering students is particularly challenging because of the limited knowledge base, which clashes with the complexity of real-world applications.

PURPOSE

This paper addresses how real-world applications using emerging technical concepts can be converted into a tutorial-laboratory (tute-lab) so that first-year students can acquire up-to-date hands-on skills while reflecting on associated theoretical knowledge. In particular, the paper aims to identify the effectiveness of using tute-labs for integrating emerging technical concepts in a first-year engineering course.

METHODS

This paper uses a case study to investigate the effectiveness of using tute-labs to integrate renewable energy concepts into the electrical engineering program. Tute-labs using emerging technical concepts (e.g., photovoltaics system modelling) were implemented in a first-year course with 373 students enrolled. The perceptions of the students and the teaching staff involved are collected via online surveys. The participants are asked to complete the survey voluntarily at the end of the term. After the data collection, the responses are analysed using both quantitative and qualitative approaches. For quantitative data, statistical analysis is performed to address the research questions. Open-ended questions at the end of the survey are used to understand how tute-labs can be improved in future iterations.

ACTUAL OUTCOMES

By introducing emerging concepts in a first-year course, students are able to recognise and understand these concepts properly to achieve a basic level of learning outcomes. This benefits the students' future learning when they are exposed to similar concepts in other courses within the program. As discussed in Bruner's spiral curriculum, the students gain a more profound understanding when the course content returns to the same concepts over time. To this end, they can progressively apply, analyse, and evaluate the concepts throughout the program.

CONCLUSIONS

To renew the curriculum of engineering programs in a well-planned and resource-effective way, tute-labs are adapted and validated in a large first-year engineering course to ensure that up-to-date technical concepts are appropriately integrated. With the industry poised for further modernisation and development, the proposed approach can be tailored and implemented in other areas considering the effectiveness and further impact on students' learning and engineering endeavours.

KEYWORDS

Curriculum renewal, integrated curriculum, electrical engineering education.

Introduction

The need to introduce emerging concepts and technologies to engineering students is acknowledged to be increasingly significant by industry stakeholders and tertiary educators (Bosman & Phillips, 2021; Li & Jin, 2018). Engineering students need to gain theoretical knowledge and technical skills which align with the modern engineering practice in the industry throughout their program in higher education. In the modern energy sector, renewable-dominated power systems have been emerging for years and considered as the future of electricity generation. This is not only facilitating the transition of the energy infrastructure, but also changing the workforce requirement of power system professions. The Australian Energy Market Operator (AEMO) released the Integrated System Plan (ISP) in June 2022, which maps the expansion of the energy system for the next 30 years. The report underlines the significance of future workforce demand in the electric power industry, which will be doubled in 5 years (Briggs et al., 2021). Also, the energy industry is currently facing a shortage of skilled engineers who can investigate how renewables impact on the bulk electricity network at a system level. However, power engineering graduates are not technically proficient in this area due to the lack of awareness of renewable integration (Rutovitz et al., 2021), which reveals the mismatch between the curriculum and industry demand. It is imperative that higher education institutions track the industry trend and offer advanced and specialised engineering programs so that graduates can be job-ready for the contemporary industry. However, the associated teaching content and curriculum framework have not experienced a commensurate level of progress, which means that the emerging concepts are not timely incorporated into the teaching and learning activities at the program level.

In traditional electrical engineering programs, students have limited exposure to renewable energy concepts before taking senior (e.g., third and fourth year) elective courses in the energy systems discipline. Even if the students follow the energy systems pathway, the updated content is incorporated into the courses as add-ons after the students have gained all the associated knowledge background in the first two years of the program. In this regard, students who are not specialised in energy systems may not have a chance to become familiar with renewable-related concepts, which potentially reduces the volume of the workforce for the future energy sector.

Students might be more inclined to persist and study specific subfields of engineering if they are exposed to the emerging concepts in a particular discipline in the early stage of their study (Xu et al., 2014). To expand the student's knowledge base in a staggered manner, it is more appropriate to integrate renewable-related concepts in a range of courses within the program at different levels. The percept of renewable generation can start from circuit modelling and analysis in Years 1 and 2, which could potentially stimulate the students' interest and curiosity in this field and motivate them to delve into the area later in their study. However, selecting and integrating appropriate technical concepts into the course content for first-year engineering students is particularly challenging because of the limited knowledge base, which clashes with the complexity of real-world applications.

This paper aims to find an effective strategy to integrate renewable energy concepts into a first-year course. More specifically, it explores how emerging concepts (i.e., renewables) were integrated into an introductory course in electrical engineering using contextualised tutorial-laboratories (tute-labs). It also provides a guide to others creating similar course development at the first-year level. The research questions addressed in this paper are:

1. *How can real-world applications using emerging technical concepts be converted into a tutorial-laboratory (tute-lab)?*
2. *Are tutorial-laboratories (tute-labs) an effective approach to integrating emerging technical concepts in a first-year engineering course?*

The manuscript is structured as follows: In section II (Literature Review), a review of strategies for integrating new content in engineering courses is presented. Section III (Case study) describes how real-world applications with emerging technical concepts can be converted into tute-labs and integrated into the course. Section IV (Data Collection) and Section V (Results and Discussion) present how the perceptions of students and teaching staff to the tute-labs are collected and analysed. Finally, the contribution concludes with the implications of the course redesign with respect to future recommendations on curriculum development in engineering courses.

Literature Review

Educators have adopted a variety of strategies to integrate emerging concepts and authentic content into the engineering curriculum, including project-based learning (PBL) and practice-based learning. These strategies expose students to scenarios that typically happen in real-world settings, which helps them to make successful transitions into professional environments. However, the limited knowledge base of first-year engineering students, clashes with the complexity of real-world applications. Gray et al. (2017) used PBL to introduce the concept of “costing” in two junior level engineering courses to improve the performance of students in economic analysis when designing their capstone project. Results show that students could understand the process of performing cost analysis and reconciling the difference between their estimation and the actual costs despite their limited background knowledge in this area. While students did not necessarily understand the reasons behind it, they could perform the analysis as long as sufficient supporting material was provided. In the field of electrical engineering, Cross et al. (2019) also used PBL in a first-year course to get students to design a spectrophotometer. The study suggests that connecting a project to a real-world context (e.g., spectrophotometer) plays a vital role in promoting a thorough understanding and improving students’ motivation and commitment. Yet, circuit design projects require advanced level knowledge and skills, so it is difficult to achieve high-level functionality at the end of a first-year project. To overcome this, the authors recommend expanding the project across different first-year courses so that students can gain a more complete design experience to facilitate the industrial linkages with the courses. Yang (2021) describes how emerging industry needs (e.g., knowledge and technical skills in demand) can be covered in an integrated circuit course by implementing PBL. The design project was blended in the laboratory sessions, where students were required to design and test an authentic industry standard circuit progressively to scaffold the theory. In the energy systems discipline, Joos (2008) outlined how industrial concepts (e.g., energy conversion) can be effectively integrated by involving industry partners and manufacturers in the laboratory exercises. The practice-based learning allows students to apply concepts presented in the lectures in a workplace environment when implementing hardware setup and developing measurement skills. The improvement of students’ hands-on skills was validated in the last two cases (Yang, 2021; Joos, 2008), but the theoretical aspect of the experiments was potentially overlooked and the approaches would be very difficult to implement in first-year courses.

In line with the concept of tutorial-laboratories presented in this paper, some researchers have investigated strategies to effectively integrate theory and practice, which shed a light on the importance of fusing “education” and “training” (Swart, 2010). Cielniak et al. (2012) integrated the theoretical and practical aspects of mobile robotics and vision in two computer science undergraduate courses. The lectures covered robotics theory and provided practical examples, while the practical sessions provided access to robotic equipment and strengthened the students’ familiarity with experimentation in the area. Nevertheless, the link between the practical examples and the experiments was not sufficiently addressed, and students found it difficult to reflect on the same concepts from the theoretical and experimental perspectives.

Another important aspect of integrating emerging concepts and authentic applications into the engineering curriculum is the need for whole-of-program approaches, which allow students to return to the same concepts over time and improve their understanding. In (Diaz et al., 2020), a framework was proposed to incorporate computational thinking into the undergraduate curriculum to cultivate students’ computer abilities. The framework consists of five stages, including abstraction, algorithmic thinking, programming, data representation, and decomposition. The use of an instrument called the Engineering Computational Thinking Diagnostic (ECTD) measured the growth in computational thinking in a cohort of engineering students completing the courses throughout the program at different stages. Harris (2015) used Bloom’s and Webb’s Taxonomies (Bloom, 1956; Webb, 1997) to integrate cybersecurity topics into the computing curriculum. The learning outcomes of the courses impacted were redesigned, although the authors did not provide an effective strategy to validate how the topics can be effectively integrated and implemented in practice.

The studies mentioned above indicate a need to investigate an effective strategy to integrate emerging concepts in a growing range of engineering disciplines from early years and throughout the whole program. The strategy needs to take both theory and experimentation into consideration, which results in a holistic approach to improving the students' awareness of the field of interest. Moreover, the effectiveness of the strategy needs to be validated to justify the reliability and acceptance of the approach.

Case study: Use of solar panels in circuit analysis

Strengthening engineering application ability

In the existing curriculum framework in electrical engineering, renewable energy concepts are introduced in third- and fourth-year courses. Students are required to understand and model photovoltaic (PV) modules using simulation software in a third-year course. According to the feedback from the course standardised evaluation, students found that the modelling and analysis of PV systems using circuit theories are highly challenging since they have not been exposed to these concepts before. Although the necessary tools and theories were covered in previous circuit analysis courses, the students' application ability is not well-developed if they are only taught circuit theories instead of circuit applications. Engineering application ability has been acknowledged as a key aspect of engineering education and is one of the competencies of professional engineers according to Engineers Australia (EA). Students are expected to develop such competency through the programs in order to analyse established engineering applications using solid knowledge and skill base. One feasible way to address this is to integrate emerging engineering concepts with real-world applications into engineering programs early in the curriculum. The content needs to be appropriately designed and simplified so that students can perform analysis on the applications (e.g., circuit model) using their knowledge base in mathematics and physics.

Integrated tutorial-laboratories (tute-labs)

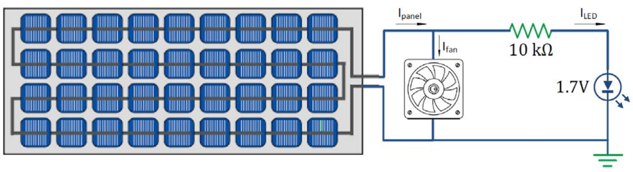
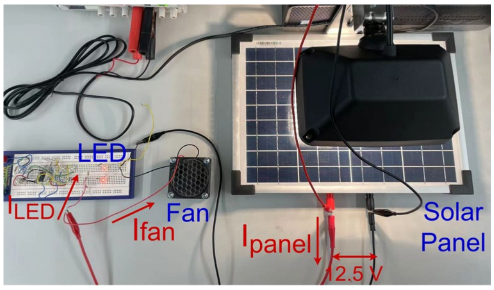
To effectively develop students' application ability, both the theoretical and practical aspects of a course need to be properly integrated in learning activities, so that students can reflect on the theory and align it with the practice within a real-world context. In a traditional course setting, a lecture is followed by a tutorial session, which provides a set of practice questions to consolidate students' theoretical knowledge. Students also perform measurements and interpret experiment results in the laboratory sessions to enhance their hands-on skills, but the context of the tutorial and laboratory activities is normally unrelated, and students find it difficult to make links between theory and practice (Cielniak et al., 2012). Instead, these separated course components can be effectively integrated by using the same real-world application for tutorial questions (theory) and in-lab experiments (practice).

Tute-lab is short for tutorial-laboratory, which encompasses tutorial questions and laboratory experiments that share the same application context in the same session. In the tutorial part, students are given a series of contextualised questions to analyse an authentic circuit/product by applying the theory they have learned in the lectures. Then, students need to set up and perform testing on the circuit/product given in the tutorial and compare the measured results with the calculated results, simulating a real-world engineering process. The tutorial questions strengthen the students' understanding of the concepts covered in the lecture and help them develop problem-solving skills in an authentic context, while the laboratory experiments, more focused on hands-on approaches, help students to gain insight into their future profession as engineers.

Converting real-world applications with renewables to tute-labs

Electrical Circuit Fundamentals is a first-year course that introduces fundamental electrical elements and circuits, as well as the technical skills to analyse and implement such circuits. To integrate renewables into the course content, a solar panel was considered as an appropriate option due to its simple circuit configuration and the nature of its electrical characteristics. First, the topic "Basic elements, basic laws & V-I characteristics" is covered to develop the conceptual understanding of the content. The topic is then contextualised using a solar-powered pet house circuit. In the tutorial part of the tute-lab, the theories and analytical methods introduced in the lecture are revised by asking the students to analyse the solar-powered pet house circuit. The tutorial questions provide detailed information about the solar panel, so that students are aware of its complexity, but they are not required to analyse the solar panel itself or fully understand how PV panels work. Instead, an operation point is provided and students deal with the PV panel as a simple power source. In the laboratory part of the tute-lab, students explore the solar panel by measuring some of its parameters (e.g., open circuit voltage and short circuit current for different irradiances) and examining its V-I characteristic. This helps them better understand the concept of operating point and how PV panels can be used as power sources. Then, the students set up the same circuit presented in the tutorial part, measure the same magnitudes that they have been previously asked to calculate, and think about the reasons that cause the difference between the analytical and experimental values. Table 1 presents an example of how "theory-practice" alignment is achieved in the tute-lab setting.

Table 1: Theoretical and practical aspects of the solar power-based tute-lab.

Theoretical Aspect - Tutorial	Practical Aspect - Laboratory
Calculate the current across the fan, the current across the LED light, and the output current of the solar panel when the output voltage of the solar panel is 12.5 V. 	Connect the lamp to the DC power supply and adjust its value until the output voltage of the solar panel is 12.5 V. Find the current through the solar panel, the fan and the LED light using the multimeter. Record all your results and compare them with the values calculated in the tutorial section. 

Data Collection

Participants

The population of the study is the students enrolled in the first-year course Electrical Circuit Fundamentals, which is included in both electrical and non-electrical engineering majors. To determine the required sample size, 95% confidence level and 5% margin of error are considered to calculate a reasonable sample size for a population of 373 students (course enrollment), ensuring that the survey results are statistically significant. Given the statistical parameters, the ideal sample size of the target population is determined as 190 at a minimum. In this case, 230 out of 373 students responded to the survey, so the number of responses meet the sampling requirement.

Apart from the students, teaching staff who delivered the tute-labs are also recruited for survey data collection, which contributes to the perception from the educators' point of view. There are 21 (out of 26) responses collected, including 17 (out of 18) responses from laboratory demonstrators, who are in charge of the practical part of the tute-labs, and 4 (out of 8) from tutors, who are in charge of the theoretical part of the tute-labs. Table 2 shows a summary of the number of participants in the data collection.

Table 2: Number of participants in the data collection.

Subgroups		Sample size (N)
Student		230
Teaching staff	Lab demonstrator	17
	Tutor	4

Survey instrument

The survey was disseminated to the students and teaching staff at the end of the course. It is an anonymous survey which consists of closed- and open-ended questions. The questions and scope of the survey are detailed in Table 3, where a 5-point Likert scale has been used for all questions.

Table 3: Details of the survey instrument.

Subgroups	Scope	Survey Question
Students	Familiarity with the concepts	Q1. To what extent were you familiar with the concepts "renewable energy", "circuit modelling of a solar panel" and "V-I characteristics of PV systems" before the course?
		Q2. Now that you are approaching the end of the course, to what extent are you familiar with the concepts "renewable energy", "circuit modelling of a solar panel" and "V-I characteristics of PV systems"?
	Further impact on students in the energy systems pathway	Q3. By incorporating renewable energy context (i.e., solar panel) into the course, are you being motivated to learn and delve deeper into the associated knowledge?
		Q4. How likely will you specialise in the energy systems stream in your further study and engineering career?
Students & Teaching Staff	Appreciation of real-world applications	Q5. Do you think incorporating renewable energy context in a first-year course can improve your (for students)/the students' (for teaching staff) awareness of real-world applications in the area of circuit analysis?
	Future learning and engineering endeavours	Q6. Did you see value in incorporating emerging concepts (i.e., renewable energy) into a first-year course to improve your (for students)/the students' (for teaching staff) learning and future engineering endeavours?

Results and Discussion

Familiarity with the concept

Paired t-test is performed on the responses to Q1 and Q2 to determine if a statistically significant difference exists between the students' self-reported familiarity with the concepts "renewable energy", "circuit modelling of a solar panel" and "V-I characteristics of PV systems" before and after the course. The paired samples statistics is summarised in Table 4. As can be seen in the table, the mean value after the course is greater than the one before the course and the p-value, which indicates whether the difference between "Before the course" and "After the course" is significant, is 0.000 ($p<0.05$ indicates the difference is statistically significant), which means that the students' self-reported familiarity with the concepts is significantly different before and after the course. Considering the increase of the mean value (i.e., from 2.13 to 2.91), it can be inferred that integrating solar-related concepts into the course effectively improves the students' familiarity with the area, as per their own perceptions. The corresponding learning outcome is at a basic level (remember and understand), but it is a good achievement for a first-year course. Additionally, with the scaffolding of the acquired knowledge, it would be easier for students to apply and analyse related concepts in further courses in energy systems.

Table 4: Paired Samples Statistics and Differences.

	Mean	Std. Dev.	t	df	Sig. (p-value)
Before the course	2.13	1.111	-11.489	229	0.000*
After the course	2.91	0.912			

Further impact on students in the energy systems pathway

Among the respondents, 41.3% (95 out of 230) are electrical engineering students, and 48.4% of them (46 out of 95) believe they are likely to continue studying energy systems in the future. A follow-up question was asked to find out if the electrical engineering students were motivated to learn and delve deeper into the associated knowledge of renewable energy after they learned about circuit modelling of the PV panel through the tute-lab. Figure 1 shows the crosstab analysis of the likeliness of being specialised in energy systems in the future and the motivation to learn and delve deeper into the area of renewables. The graph indicates that using solar panels in the tute-lab positively motivates students who intend to move forward to the energy systems pathway in the future, which is consistent with the observation in the literature (Cross et al., 2019). Most of the students who wish to continue their study in energy systems benefit more from the tute-lab than others because they understand the importance of the application of such concepts in their future study and profession.

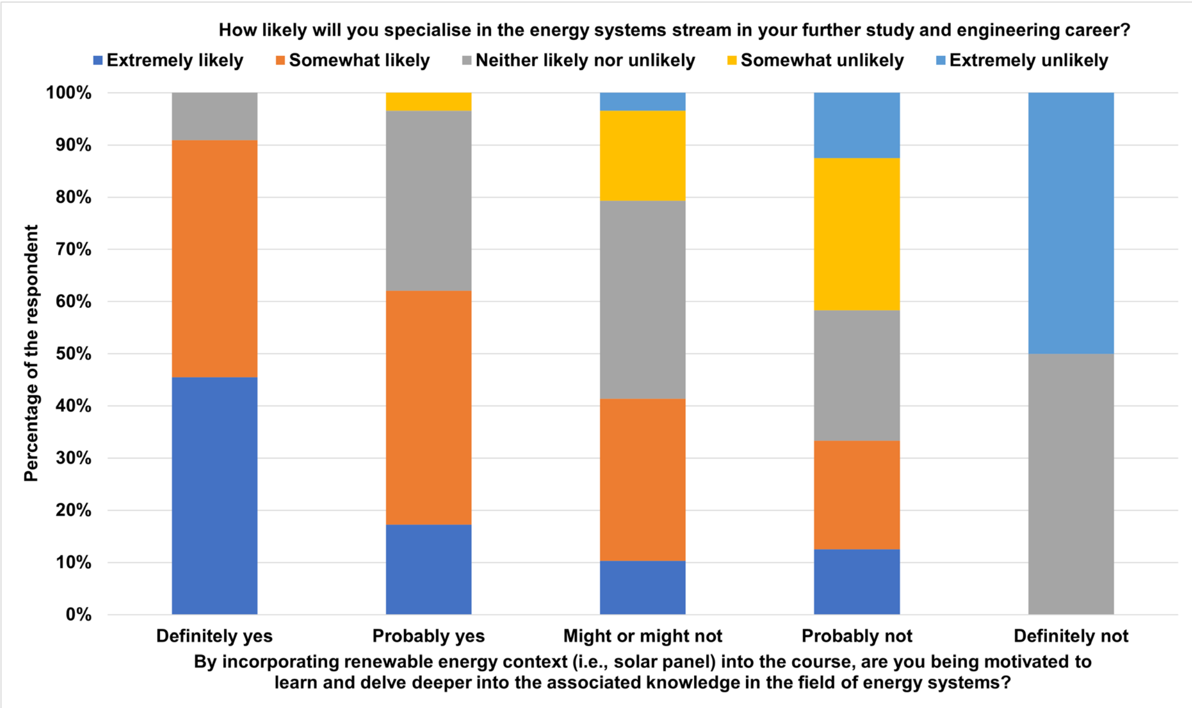


Figure 1: Crosstab analysis of Q3 and Q4.

Appreciation of real-world applications

Figure 2 shows that nearly 70% of the students and 85.7% of the teaching staff surveyed believe that students' awareness of real-world applications can be improved by incorporating renewable energy into the context of the course. Raising awareness of real-world applications not only deepens the students' understanding of the topics learned, but also develops their problem-solving skills in a complex context. It can be observed that the response of teaching staff is more positive than that of students. One possible reason is that academics are more experienced and may be more aware of the fact that applying theoretical analysis to real-world applications is of great importance when dealing with more complex engineering systems.

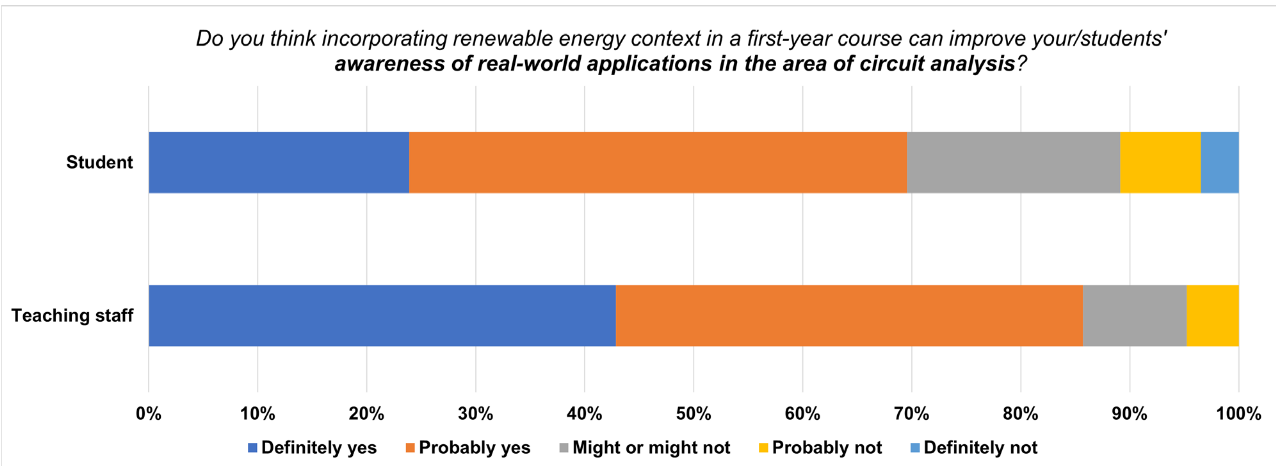


Figure 2: Perception of students and teaching staff in Q5.

The following are supporting excerpts from the students' perceptions:

"Learning real-world applications is fun and engaging. The link between the tutes and labs definitely helps with learning and understanding the concepts!"

"The elements like LED lights and solar panels make the lab very interactive, and I learned possible scenarios to apply what I learned in the lectures."

Future learning and engineering endeavours

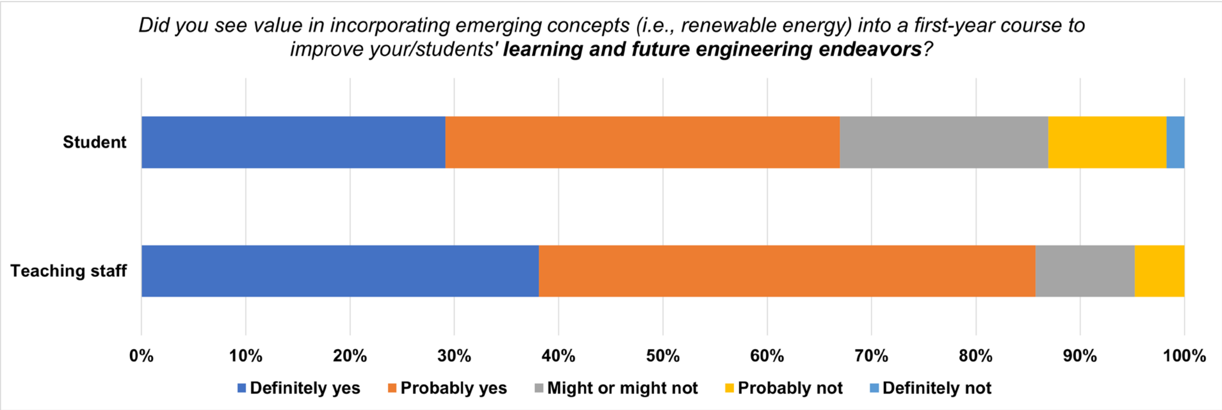


Figure 3: Perception of students and teaching staff in Q6.

Figure 3 illustrates the perception of students and teaching staff in the improvement of students' learning and future engineering endeavours. As can be seen, 67% of the students and 85.7% of the teaching staff indicate that there is value in incorporating emerging concepts (i.e., renewable energy) into a first-year course, which improves students' learning and future engineering endeavours.

The implementation of contextualised tute-labs with emerging concepts and technologies at the start of the program yields a teaching strategy beyond traditional course assignments. In electrical engineering programs, students learn circuit analysis in their first year, and growth in awareness of real-world applications in circuit analysis may occur across all four years of undergraduate study. According to Bruner (2009), embedding key concepts earlier in the curriculum allows students to master basic principles that are reserved for more specialised courses. The students gain a more profound understanding if the concepts are revised repeatedly with deepening layers of complexity throughout the program. This ensures that students' conceptual and contextualised perceptions are improved simultaneously and progressively, which smooths the transition from theory to practice. In terms of future endeavours, the real-world applications in the tute-lab develop the students' analytical and problem-solving skills in a practice-oriented context, which are transferable skills in demand not only in electrical engineering, but in any other engineering discipline. The reconciliation between the "theory" and "hands-on training" also aligns the "knowledge and skill base" with the "engineering application ability", which are the key competencies of professional engineers, as defined by Engineers Australia.

Conclusion

This paper discusses how real-world applications using emerging technical concepts can be effectively integrated in a first-year engineering course using tutorial-laboratories (tute-labs). Engineering educators can adapt and align tutorial questions with hands-on laboratory experiments using the same real-world application as context for both, which is the main idea of tute-labs. The relatedness between the two components can build up the knowledge base and facilitate the students' engineering application ability, which is a key competency of professional engineers. The application used needs to be simplified properly in accordance with the background knowledge of the students. Using tute-labs as a strategy for integrating emerging technical concepts in the early years of a program can be applied not only in electrical engineering, but also in other engineering disciplines.

Tute-labs have been demonstrated to be an effective strategy to improve the students' familiarity with emerging concepts and benefit their learning at a later stage of the program. Additionally, the initiative motivates students to learn and delve deeper into the associated knowledge and accelerates the growth in the ability to apply analytical and hands-on skills to a specialised discipline (e.g., energy systems). In this regard, the strategy could better prepare the students for the professional world and supply the workforce demand in the energy sector.

For a more comprehensive analysis of the students' and teaching staff's perceptions, future work in qualitative data collection and analysis should be considered to generate more reliable and meaningful results via a mixed-method approach.

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