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Incorporating Emerging Technical Concepts into Introductory Engineering Courses via Tutorial-Laboratories

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ABSTRACT

In the rapidly evolving landscape of engineering education, there is a growing need to effectively integrate emerging technical concepts into curricula. Fostering a deeper understanding of these contemporary ideas prepares students to meet the challenges of the ever-changing technological field and ensures their skills and knowledge align with current industry demands. This study uses tutorial-laboratories (tutorial-labs) to incorporate emerging technical concepts into introductory engineering courses. The proposed tutorial-labs combine tutorial sessions with practical laboratory work, engaging students in hands-on experiences that mirror real-world applications. Tutorial-labs allow students to draw connections between theoretical concepts and their tangible applications, reinforcing their comprehension and retention of the theory at different stages of the program. Our findings suggest that tutorial-labs can significantly enhance students' grasp of emerging technical concepts in introductory engineering courses. While our study primarily focuses on electrical engineering, the approach and strategies can also be applied to a wider range of science and engineering disciplines, thereby potentially influencing the broader pedagogical landscape in other disciplines.

KEYWORDS

Curriculum development, electrical engineering education, introductory engineering courses, tutorial-laboratories, renewable energy

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Introduction

Industry contributors and tertiary education practitioners have acknowledged the significance of integrating emerging principles and technological advances into the pedagogical framework for engineering education (Craps et al., 2022; Leoste et al., 2021). Their integration into the established curricula often lags, owing to various factors, such as the constraints of rigid curriculum structures (Felder & Brent, 2003), the time required to update course content (Borrego & Newswander, 2010),

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or unfamiliarity with the latest industry developments (Howard et al., 2011). Nonetheless, these contemporary advancements are crucial for students to understand, given the demand for such knowledge in today's innovative industry landscape. Early exposure to emerging concepts in specific disciplines can foster student engagement and persistence in engineering fields (Xu et al., 2014).

The term "emerging concepts," as used in this study, refers specifically to those innovative technical ideas and procedures that have already gained prominence in the corresponding industry and are increasingly recognised as essential for the knowledge base of the future workforce. Yet, despite their growing relevance and application in the real world, these concepts have not found a robust presence within the existing coursework. This disconnection between industry needs and academic instruction is the gap this study intends to address, arguing for a more timely and responsive adaptation of our engineering curricula to align with the rapidly evolving technological environment.

In the global energy sector, the scale of renewable energy integration is expected to triple by 2050, according to the International Renewable Energy Agency. This exponential growth requires a surge in skilled workforce proficient in renewable energy technologies. In conventional electrical engineering programs at universities, students' engagement with renewable energy concepts is often restricted to advanced courses in the energy systems discipline once students have built a substantial knowledge base during the initial two years of their program. This traditional approach inadvertently limits the early capture of students' interest in the area, thereby reducing the possibility of providing an increased workforce to meet the surging demand. Instead, it would be desirable to embed renewable energy concepts across various courses at different levels within the program in a staggered manner. However, identifying and incorporating relevant technical concepts into the coursework for first- and second-year engineering students is challenging because their limited knowledge base clashes with the complexity of emerging concepts and technological advancements.

This paper aims to identify an efficient strategy for incorporating emerging technical concepts (e.g., renewable energy) into introductory engineering courses via the application of contextualised tutorial-laboratories (tutorial-labs). Tutorial-labs are integrated sessions that combine theoretical tutorials with practical laboratory exercises in a way that theoretical knowledge and practical application are seamlessly connected within the learning activities.

This study lies in its pioneering strategy of proposing and evaluating the use of tutorial-labs as a mechanism for integrating emerging technical concepts within the foundational engineering program.

The primary research questions this paper addresses are as follows:

- *How can real-world applications employing emerging technical concepts be adapted into a tutorial-laboratory (tutorial-lab) format?*
- *How effective are tutorial-labs in integrating emerging technical concepts into the curriculum in the early stages of the program?*

Literature Review

Traditional engineering curricula have a set sequence that may not always facilitate the integration of emerging technical concepts and real-world applications. Students are equipped with the necessary foundational knowledge and technical skills at the early stages of the program, with a prompt shift towards specialised knowledge in the field of interest (Felder & Brent, 2003). This traditional approach of heavily integrating advanced and emerging concepts within the course content at later stages demands a significant cognitive load to comprehend the newly presented concepts (Sweller, 1988). Specifically, students need to align the new content with what they have learned in introductory courses long before. As a result, a potential cognitive gap may exist between theoretical knowledge introduced in foundational courses and the real-world applications of specific areas in advanced courses.

The integration of emerging technical concepts and real-world applications into engineering curricula has been achieved via various pedagogical strategies, including project-based learning (PBL) and practice-based learning (Mitchell et al., 2021; Sukackė et al., 2022). These strategies immerse students in real-world scenarios, easing their transition into professional settings. Nevertheless, the limited knowledge base of early-year engineering students can often conflict with the complexity inherent in real-world applications. This was evident in studies conducted by Brinkworth et al. (2009) and Wrenn & Wrenn (2009), where students with foundational understanding struggled to apply the theoretical knowledge to a practical scenario.

Yang discussed how emerging industry needs can be addressed using PBL in a course about integrated circuits (Yang, 2021). Yang's approach allowed students to progressively design and test an industry-standard circuit during laboratory sessions, which significantly increased students' ability to apply theoretical knowledge to practical design tasks. Within the energy systems domain, Joos illustrated the effective integration of industrial concepts, such as energy conversion, by incorporating industry partners and manufacturers into laboratory exercises (Joos, 2008). This practice-based learning approach encouraged students to apply lecture concepts in a workplace environment, enhancing their hardware setup and measurement skills. Though these studies confirmed the improvement in students' hands-on skills, they potentially overlooked the theoretical aspect of the experiments and were also reported to be difficult to implement in the context of first-year courses.

Aligned with the concept of tutorial-labs discussed in this paper, research has been conducted on strategies to seamlessly merge theory and practice, accentuating the importance of combining "education" and "training" (Swart, 2010). Cielniak et al. blended theoretical and practical elements of mobile robotics and vision into two computer science undergraduate courses (Cielniak, Bellotto, & Duckett, 2012). Despite this integration, the linkage between practical examples and the experiments was insufficient, posing difficulties for students when attempting to assimilate the same concepts from both theoretical and experimental angles.

In addition to these strategies, Diaz et al. (2020) and Harris (2015), underscore the importance of investigating effective strategies to incorporate emerging concepts into engineering disciplines from the early stages of education and throughout the entire program. However, such strategies should offer a comprehensive blend of theoretical and experimental aspects, promoting a holistic improvement in students' awareness and understanding of their chosen field. Moreover, the validation of the strategy's effectiveness is crucial to ascertain its reliability and acceptance.

While the primary emphasis of this work targets introductory courses, it is essential to underscore the broader potential of extending this contribution across the entire program. Recognising that student characteristics, the depth of knowledge and skills imparted, and the targeted learning outcomes differ at various stages of the program, adopting tailored pedagogical strategies is pivotal. The challenges and limitations would closely mirror those detailed earlier for introductory courses. Additionally, the validation method that we use in this study can be adapted to confirm the effectiveness of the strategy at each program level, which is imperative to ensure its adaptability and transferability.

Tutorial-laboratories

As arising from the literature review, there is a need of investigating effective strategies to incorporate emerging technical concepts and real-world applications into engineering disciplines from the early stages of education. This could help bridge the gap between theory and practice, equipping students with the necessary skills for their future careers in engineering. However, it also presents a considerable challenge stemming from students' limited knowledge base at an early stage, which often contrasts with the complexity inherent in real-world applications.

For effectively fostering students' application abilities, it is crucial to seamlessly integrate both the theoretical and practical aspects of a course within learning activities. This integration enables students to correlate theoretical concepts with practical applications in a real-world context. Traditional course formats typically follow a lecture with a tutorial session, providing practice questions to consolidate theoretical knowledge. Furthermore, laboratory sessions enable students to perform measurements and interpret experimental results, enhancing their practical skills. However, the context of tutorial and laboratory activities is usually disjointed, causing students difficulty connecting theory and practice (Cielniak, Bellotto, & Duckett, 2012). Effective integration of these course components can be achieved through the strategic combination of tutorials and laboratories into a single session, referred to as tutorial-laboratory (or tutorial-lab), which utilises the same real-world application for theoretical questions and practical experiments. Providing a real-world context, including emerging technical concepts, in tutorial-labs helps motivate students, as they can directly see the relevance and applicability of what they are learning. Additionally, it helps students understand the importance and future direction of the field from the outset, fostering a forward-thinking mindset and encouraging the exploration of cutting-edge areas of study.

Tutorial-labs are combined tutorial and laboratory sessions which share the same real-world application context to seamlessly integrate both the theoretical and practical aspects of a course within each session. In the tutorial or analytical part, students are tasked with applying the theories presented in the lectures to analyse a real-world application. Subsequently, in the laboratory or experimental part, students set up and test the real-world application in question, comparing experimentally measured results with calculated ones and emulating a real-world engineering process. The tutorial questions reinforce students' understanding of lecture concepts and foster problem-solving skills within an authentic context, while the laboratory experiments provide hands-on exposure, offering insights into future engineering roles.

Rather than spanning multiple sessions, as usually occurs in PBL, each session features a specific real-word application addressing a specific topic of the course (e.g., solar-powered pet house circuit to illustrate the fundamental topic "Basic Elements, Basic Laws and V-I Characteristics" in a first-year course, as will be seen in detail in the next section). The challenge in this case is to design applications that are realistic, but at the same time simple enough to be completed within a single session by students with a limited knowledge base (as happens with first- and second-year students). Specific examples of how this has been done in the context of electrical engineering at the University of New South Wales are provided in the next section, using renewable energy as the emerging technical concept to be incorporated into a first- and second-year course. Regarding the design of tutorial-labs, it is also worth noticing that most approaches used to embed real-world applications in the curriculum, such as experiential learning, PBL or practice-based learning (Mitchell et al., 2021; Sukackė et al., 2022), are quite focused on design, while questions in tutorial-labs are quite guided to reduce the cognitive load associated with introducing complex concepts at the early stages of the program.

The duration of the sessions can be decided based on the specific requirements of the course, but three-hour sessions, where the first hour is used to complete the analytical part and the last two hours are used to complete the experimental part, are recommended (as will be seen in the next section). Rather than asking students to complete a report and mark it asynchronously, marking for both the analytical and experimental parts is done in-class. This makes it possible for students and teaching staff to engage in conversations that go beyond the tutorial-lab content and allows to get detailed, instant feedback on the work done.

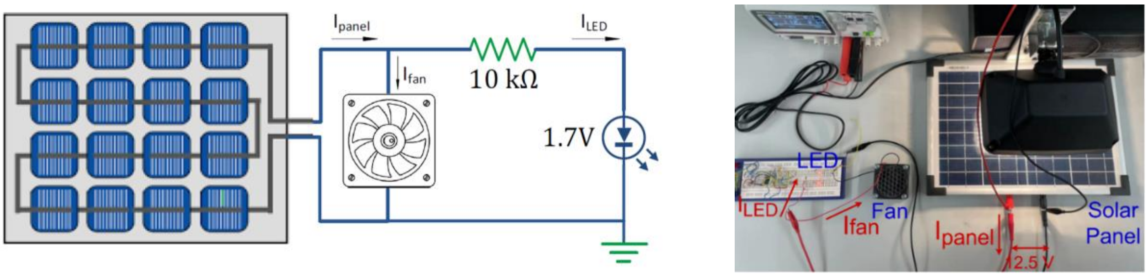
Finally, it is worth noting that although the strategy discussed is in the context of electrical engineering, it has broader applicability across diverse engineering disciplines, thereby extending the benefits of contextualised, application-driven learning beyond the confines of engineering. Engineering educators can adapt and align theoretical questions with hands-on experiments using the same real-world application as context for both, which is the main idea of tutorial-laboratories. The application used needs to be appropriately simplified in accordance with the student's background knowledge. The reconciliation between the "theory" and "hands-on training" aligns the "knowledge and skill base" with the "engineering application ability", which are the critical competencies of professional engineers in the curriculum accreditation standard (Lowe et al., 2022). This approach has the potential to stimulate students' motivation to learn and delve deeper into associated knowledge and accelerate their growth in specialised disciplines.

Transitioning real-world applications with renewables to tutorial-labs

'Electrical Circuit Fundamentals' and '*Circuits and Signals'* are, respectively, first- and second-year foundational courses in the Electrical Engineering Bachelor program at the University of New South Wales, introducing electrical elements and circuits alongside the technical skills required for their analysis and implementation. "Renewable energy" related concepts are contextually integrated in these courses to align with the evolving energy sector.

A solar panel was chosen for this purpose in the first-year course, given that the circuit modelling can be simplified without changing the electrical characteristics. This facilitates the effective incorporation of the emerging concept of "solar energy". Solar panel circuits can be complex to model and understand, particularly at the beginning of the engineering studies. Choosing a simplified model from basic elements and coupling it with a more complex context is a balanced learning challenge. This trade-off allows students to apply basic principles to understand and solve more complex, real-world problems while maintaining a manageable overall difficulty level. Thus, it caters to the foundational needs of entry-level learners while fostering comprehension and application of relevant principles in the industry.

In this case, a solar-powered pet house circuit, including a fan and a light, is used as the authentic application to illustrate the fundamental topic "Basic Elements, Basic Laws and V-I Characteristics", introduced at the beginning of the term. The tutorial-lab worksheet first describes the application and simplified model of the photovoltaic (PV) panel. It also presents additional reading material in the form of references that provide intricate details about the solar panel, making students aware of its actual complexity. In the tutorial part of the tutorial-lab, students revisit the theories and analytical methods covered in the lecture, applying them to the analysis of the solar-powered pet house circuit. Students are then asked to set up the circuit in the laboratory part, measuring the same parameters calculated in the tutorial part and reflecting on the differences between the analytical and experimental values. Figure 1 illustrates the alignment of theory and practice for the specific example of the solar-powered pet house circuit.

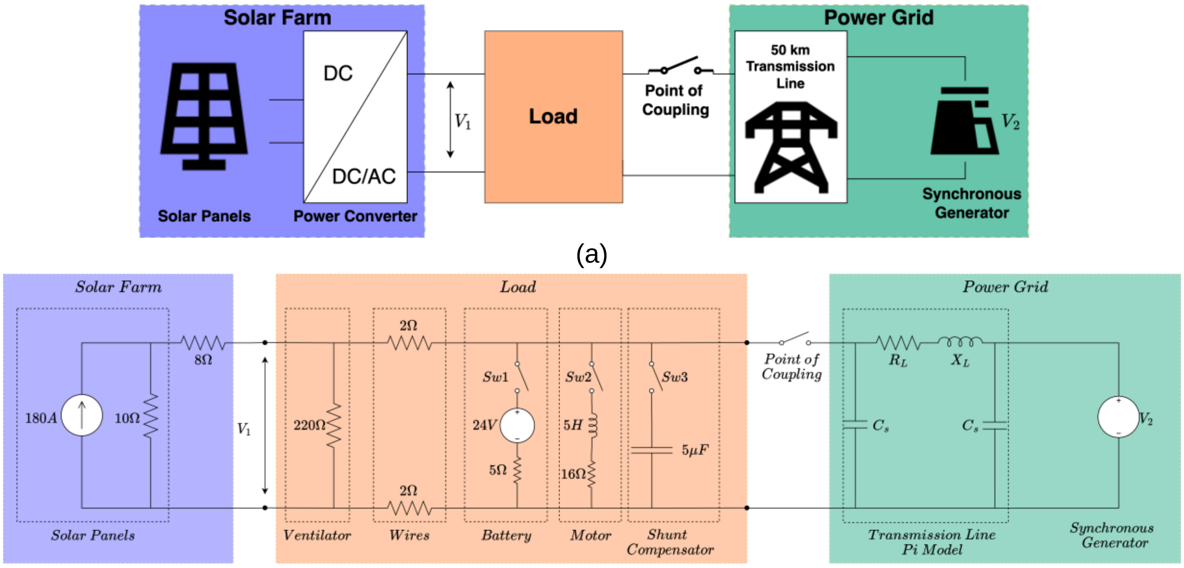


(a) (b)

Figure 1: Alignment of theory and practice in a tutorial-lab using a solar-powered pet house in a first-year course: (a) circuit configuration (theoretical aspect in tutorial part) and (b) circuit setup (practical aspect in laboratory part).

Tutorial-laboratories for the first-year course last for 3 hours, where the first hour is used to complete the analytical part and the last two hours are used to complete the experimental part. Each session features a specific real-word application addressing a specific topic of the course, as seen in the example above. The ratio of staff to students in these laboratories is 1 to 12.

In the subsequent second-year course, *Circuits and Signals*, students are asked to perform circuit analysis in the DC and AC domains for a renewable-based microgrid interconnected with a power system. Although students have not been exposed to concepts such as microgrids, power converters, point of coupling, or transmission lines in their previous courses, these concepts are introduced at a level that provides students with contextual understanding and practical applications, without delving into excessive theoretical complexity that might overcomplicate the questions. The pedagogical strategy adopted also involves presenting these unfamiliar concepts as ‘sets’ of elements used during the students’ first-year course on circuit analysis (see example in Figure 2). This way, students can still apply the analytical tools they have previously learned despite a lack of detailed theoretical comprehension of renewable energy-based power systems. For instance, the modelling of transmission lines is a concept typically introduced in third- or fourth-year courses in most power engineering curricula. Despite the sophisticated comprehension and advanced knowledge base required to grasp the complexities of the modelling theory, the circuit model only comprises basic circuit elements (i.e., resistors, capacitors, and inductors), all of which are introduced in the first-year course. Therefore, limited theoretical impediment prevents students who have completed these fundamentals from analysing a circuit involving transmission lines. Inevitably, questions might arise, such as “Why are transmission lines modelled using these circuit elements in this particular configuration?” However, the implications of these queries will be addressed in subsequent stages of the program. This strategy mitigates the cognitive load when students encounter these concepts in later courses. In essence, students will find understanding transmission line modelling less challenging, given that these concepts are introduced in advance, as opposed to relating the content directly back to first-year knowledge without any preceding context.



(b)

Figure 2: Introduction of emerging concepts related to renewable energy-based power systems in a second year-course: (a) schematic diagram of a local microgrid connected with a power system and (b) equivalent circuit using basic circuit elements. Switches (Sw1, Sw2, Sw3 and point of coupling) are used to control the level of difficulty by targeting only parts of the full circuit based on different scenarios.

Tutorial-laboratories for the second-year course last for 6 hours, which are split into two 3-hour sessions running in consecutive weeks. The first 3-hour session focuses on the analytical part, while the second one focuses on the experimental part and on marking. In particular, 2 hours are spent on the experiment and 1 hour is spent on marking and providing feedback of both the analytical and experimental parts. The ratio of staff to students in these laboratories is 1 to 10.

Data collection

To address the research questions, statistical analysis has been used to investigate students' perspectives on how their conceptual understanding was improved in both the theoretical and practical aspects after tutorial-labs in two introductory courses. The data was collected using an anonymous survey. The use of questionnaires and the handling of gathered data was approved by the ethics committee of the University of New South Wales.

Study design

The study population comprises students enrolled in two introductory engineering courses, which are prerequisites for the advanced courses in the energy systems discipline. A total of 439 students participated in the survey. A summary of the population and sample size is listed in Table 1. In this study, the calculation of an appropriate sample size is grounded in using a 95% confidence interval, coupled with a margin of error constrained to less than 10% (Adhikari, 2021). These parameters are chosen to ensure the statistical significance of the survey results.

The study's demographic consists of three distinct cohorts: Y1A, Y1B, and Y2, as detailed in Table 1. Both Y1A and Y1B cohorts experienced the tutorial-labs for the first time in the first-year course in two subsequent years. The Y2 cohort consists of students who had completed the Year 1 course the year before. This latter group had prior exposure to the redesigned tutorial-labs, implying that they had already developed some level of proficiency in analysing such questions and conducting the associated experiments. The study's design, with a focus on these cohorts, allows for a comparative analysis of the impact of the tutorial-labs across different stages in the program.

Table 1: Participants of the surveys.

Surveyed cohorts	Population size	Sample size	Margin of error
First-year course (Y1A)	373	230	5%
First-year course (Y1B)	510	143	7%
Second-year course (Y2)	205	66	10%

Research instrument, validity and reliability

Data collection was carried out using structured surveys. The surveys comprised Likert scale questions designed to evaluate students' perspectives on the integration of emerging concepts into the courses. The surveys were disseminated to students upon the conclusion of the courses. A comprehensive overview of the surveys' scope and individual questions are provided in Table 2.

The validity of the survey questions was improved by using expert review and pilot testing, which are effective ways to provide acceptable validity in survey data collection (Brooks, Reed, & Savage, 2016; Davis, 1992).

Table 2: Survey questions.

No.	Topic	Available options
Q1	Familiarity with the integrated concepts before the course	Likert scale (1 – 5)
Q2	Familiarity with the integrated concepts after the course	Likert scale (1 – 5)
Q3	Level of difficulty of tutorial questions	Likert scale (1 – 5)
Q4	Level of difficulty of in-lab experiment	Likert scale (1 – 5)
Q5	Identification of knowledge gaps affecting theoretical/practical aspect	Likert scale (1 – 5)
Q6	Evaluation of incorporating emerging concepts for real-world application • Facilitates systematic application of circuit analysis • Enhances theoretical analysis of real-world applications • Enhances practical analysis of real-world applications • Aids in aligning theory with lab results	Likert scale (1 – 5)
Q7	Motivation to explore renewable energy/power systems further	Likert scale (1 – 5)
Q8	Impact of incorporating emerging concepts on awareness of real-world applications in circuit analysis	Likert scale (1 – 5)
Q9	Value of incorporating emerging concepts for learning and future engineering endeavours	Likert scale (1 – 5)

Data Analysis

Familiarity with the concepts

The assessment of student familiarity with concepts relevant to renewable energy was carried out using a paired t-test on responses to questions Q1 and Q2. Table 3 summarises the paired sample statistics.

Table 3: Comparison of pre- and post-course familiarity.

		Mean (M)	Std. Dev. (SD)	Std. Error Mean (SEM)	Paired t-test				
					Mean Difference (MD)	SD	SEM	t	Sig. (p-value)
Y1A	Before	2.13	1.11	0.07	0.78	1.03	0.07	11.49	0.000*
	After	2.91	0.91	0.06					
Y1B	Before	1.98	0.84	0.08	0.98	0.86	0.08	12.53	0.000*
	After	2.97	0.94	0.09					
Y2	Before	2.26	0.83	0.11	0.53	0.78	0.10	5.24	0.000*
	After	2.79	0.91	0.12					

From the data provided, it is clear that there has been a significant increase in students' familiarity with the introduced emerging concepts, such as "solar panels" and "microgrids", after completing the courses. This is indicated by the positive mean gain values across all iterations of the courses (Y1A, Y1B, Y2), showing the students' self-reported familiarity with these topics increasing on average by 0.78, 0.98, and 0.53 points, respectively, on the rating scale. The low standard deviations (1.03, 0.86, and 0.78) suggest high agreement among students. The p-values (all 0.000) and high t-values (11.49, 12.53, and 5.24) confirm that the improvements are statistically significant.

Knowledge gap and level of difficulty of tutorial-lab

The perceived knowledge gap and level of difficulty of the tutorial and laboratories are evaluated using Questions 3 to 5. Table 4 presents the statistical results of the students' responses to the questions.

Table 4: Results of Levene's test, t-test, and Cohen's d-effect size analysis of Q3 – Q5.

Topic	Year	M	SD	Levene's test Sig.	T-test Sig.	MD	Cohen's d
Level of difficulty – tutorial	Y1	2.54	0.85	0.126	0.002*	0.36	0.43
	Y2	2.90	0.82				
Level of difficulty – lab	Y1	2.82	0.90	0.002	0.380	-0.27	-0.29
	Y2	2.55	1.11				
Identification of knowledge gaps	Y1	2.73	1.14	0.053	0.789	-0.04	-0.04
	Y2	2.69	1.02				

Y2 students reported a higher average difficulty (M=2.90, SD=0.82) of the tutorial part (i.e., analytical questions) compared to Y1 students (M=2.54, SD=0.85). With a p-value of 0.002, the difference was statistically significant. The positive mean difference of 0.36 indicates that Y2 students perceived the tutorial questions as more challenging than Y1 students. The moderate strength of this difference, quantified by Cohen's d value of 0.43, falls into the medium effect size category, according to the standards where 0.2 is weak, 0.5 is medium, and 0.8 is strong. On the other hand, the perceived level of difficulty of laboratory sessions was higher among Y1 students (M=2.82, SD=0.90) than among Y2 students (M=2.55, SD=1.11), with no statistically significant difference between the responses from the two cohorts ($p=0.38>0.05$). Finally, Y1 (M=2.73, SD=1.14) and Y2 (M=2.69, SD=1.02) students demonstrated similar mean scores in identifying knowledge gaps in theoretical and practical areas.

Appreciation of alignment of tutorial-lab with real-world applications

The students' appreciation of aligned tutorial-lab with real-world applications is examined in Q6. Table 5 shows that Y1 and Y2 students perceive the strategies to affect their learning positively, although there are some differences in their responses.

Table 5: Students' perceptions on key aspects of tutorial-laboratory integration.

Topic	Year	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Systematic application of circuit analysis	Y1	34.32%	53.35%	7.51%	4.83%	0.00%
	Y2	21.21%	65.15%	6.06%	6.06%	1.52%
Theoretical analysis of real-world applications	Y1	44.24%	42.63%	9.12%	4.02%	0.00%
	Y2	28.79%	56.06%	12.12%	3.03%	0.00%
Practical analysis of real-world applications	Y1	45.84%	41.82%	9.12%	3.22%	0.00%
	Y2	40.91%	37.88%	10.61%	10.61%	0.00%
Alignment of theory with lab results	Y1	43.43%	41.82%	11.53%	2.41%	0.80%
	Y2	34.85%	51.52%	6.06%	4.55%	3.03%

The response to "the systematic application of circuit analysis" exhibits a similar level of agreement among Y1 and Y2 respondents, with 87.67% of Y1 and 86.36% of Y2 respondents broadly agreeing (combining "Strongly agree" and "Somewhat agree"). When surveyed on the level of "theoretical analysis of real-world applications", a significant proportion of both groups affirmed its benefits: 86.87% of Y1 and 84.85% of Y2 students broadly agreed that the approach enhances their ability to analyse real-world applications theoretically. Additionally, the survey results for "practical analysis of real-world applications" showed a similar trend, with both cohorts agreeing that the approach enhances their practical analysis skills. Interestingly, Y1 students had a slightly higher agreement (87.66%) than Y2 students (78.79%). When it comes to "aligning theory with lab results", the majority of students from both cohorts agreed that the method aids in this process, with 85.25% of Y1 and 86.37% of Y2 respondents broadly agreeing.

Student engagement and appreciation of the real-world application

When evaluating the impact on student engagement and their recognition of real-world applications, discernible trends were observed across the Y1 and Y2 student cohorts. Analysis of responses to the relevant questions highlighted a more positive trend in the second year. Specifically, the mean values for questions Q7, Q8, and Q9, as detailed in Table 6, revealed more elevated values for the Y2 cohort in comparison to Y1 students.

Table 6: Results of Levene's test, t-test, and Cohen's d-effect size analysis of Q7 – Q9.

Topic	Year	M	SD	Levene's Test Sig.	T-test Sig.	MD	Cohen's d
Motivation from context	Y1	3.15	1.10	0.349	0.333	0.15	0.14
	Y2	3.30	0.98				
Real-world application awareness	Y1	3.93	0.95	0.329	0.226	0.29	0.31
	Y2	4.22	0.78				
Value of integration	Y1	3.97	0.98	0.528	0.114	0.21	0.22
	Y2	4.18	0.89				

The data from Q7 suggests that the tutorial-lab setting enhanced motivation and engagement more effectively for Y2 students, with mean scores indicating M=3.30 (SD=0.98) for Y2 as opposed to M=3.15 (SD=1.10) for Y1. Both year groups showcased considerable understanding of this connection, raising students' awareness of real-world applications. Notably, Y2 students exhibited a slightly amplified awareness (M=4.22, SD=0.78) relative to the Y1 students (M=3.93, SD=0.95). Additionally, Q9 delved into the students' appreciation of integrating emerging concepts into the courses. Y2 students, averaging M=4.18 (SD=0.89), marginally surpassed Y1 students, who averaged M=3.97 (SD=0.98). Statistically, non-significant differences were observed for the three aspects, including motivation from the renewable context, development of real-world application awareness and value of integrating emerging concepts, as seen in Table 6. Both groups were equally motivated ($p=0.349>0.05$, i.e., no statistical difference) to delve into the knowledge further and similarly believe that incorporating renewable energy context can improve their awareness of real-world applications in circuit analysis ($p=0.329>0.05$). Lastly, both cohorts saw value in incorporating emerging concepts (i.e., renewable energy) into the courses to improve learning and future engineering endeavours ($p=0.528>0.05$).

Discussion

The statistical analysis in the previous section offers a comprehensive examination of students' perspectives on how their conceptual understanding of an emerging concept (renewable energy in this case) was improved in both the theoretical and practical aspects after attending tutorial-labs in two introductory courses.

First, students' familiarity with concepts relevant to renewable energy before and after completing the tutorial-labs was analysed in this paper. Results indicated an overall enhancement in student understanding after completing the tutorial-labs, as per Table 3 values. The expected improvement in students' foundational understanding (including abilities to recall, recognise, and develop familiarity with the concepts) is a significant accomplishment for introductory engineering courses. The groundwork laid by this acquired knowledge can potentially facilitate students' ability to apply and analyse related concepts in subsequent specialised courses (Hamlen & Chu, 2022). As such, the proposed scaffolded approach serves as a stepping stone, setting the stage for more complex learning and future advancement in the program (Churakos et al., 2024; Nikolic et al., 2024).

In terms of level of difficulty of tutorial-labs, as per the results shown in Table 4, second-year (Y2) students reported a higher average difficulty of the tutorial part (i.e., analytical questions) compared to first-year (Y1) students, implying that they found the tutorial part more challenging. This could be due to the more complex nature of the context being provided in the Y2 tutorial-lab, where more emerging concepts were integrated into the questions. This could then potentially be seen in the light of the cognitive load theory (CLT), according to which, learning is more effective when cognitive load is optimally managed during instruction, given that human cognitive processing has inherent limitations in terms of working memory (Sweller, 1988). According to CLT, for Y1 students, the tutorial questions were focused on a single concept, "solar panel," which aligns with the theory suggesting that learning is more effective when information is presented in manageable amounts. This singular focus likely reduced cognitive overload, enabling Y1 students to grasp the concept more easily. In contrast, Y2 students encountered a broader array of emerging concepts, such as microgrids, power converters, point of coupling or transmission lines (see Figure 2). This increased complexity aligns with the principles of "scaffolding" in educational theory, where students are progressively introduced to more complex material. However, the integration of an overwhelming number of new terminologies could have elevated the cognitive load significantly, making it more challenging for students to process and apply new information while having a limited working memory capacity. Instructional methods should consider this limitation to enhance learning (De Vera et al., 2021). Without additional guidance and explanation of the new concepts, the surge in complexity for Y2 students requires more cognitive effort to bridge their current understanding with the new concepts introduced, increasing their perceived difficulty.

On the other hand, the perceived level of difficulty of the laboratory part of tutorial-labs (i.e., lab experiments involving hands-on measurements) was higher among Y1 students than among Y2 students, although the difference was non-significant, as per the results shown in Table 4. The slightly lower perceived level of difficulty reported by Y2 students could suggest that they find laboratory work less challenging because of their practical experience and familiarity with the lab equipment and procedures during their first year. The non-significant difference between the students' responses can also be interpreted using CLT. Theoretical content often involves abstract concepts and symbolic representations, while hands-on skills, particularly those that only involve physical measurement and operation, often have a procedural aspect and are tied to specific contexts. This type of learning can be facilitated by embodied cognition (Skulmowski & Xu, 2022), which posits that cognitive processes are deeply rooted in the body's interactions. Consequently, hands-on tasks require reduced cognitive load because learners can rely on perceptual-motor cues in addition to cognitive resources (Wilson, 2002). Given that the technical and hands-on skills demanded by the experiments in the two courses share substantial overlap (for instance, the use of oscilloscopes and multi-meters), the complexity of these tasks remains relatively uniform. In this regard, the influence of learners' prior knowledge might be less pronounced, provided that the instructional design is appropriately crafted.

In terms of knowledge gap, Y1 and Y2 students demonstrated similar mean scores in identifying knowledge gaps in theoretical and practical areas, as per the results shown in Table 4. This similarity suggests that students from both cohorts face comparable challenges in discerning knowledge gaps that influence their comprehension of theoretical and practical aspects in contextualised questions and experiments. Despite the inclusion of references (e.g., relevant literature) in the instruction materials, students' comprehension of the complexity of real-world applications remains constrained by the lack of scaffolded learning experiences (Churakos et al., 2024; Nikolic et al., 2024). While the additional resources are helpful, they may still be too advanced for first- and second-year students who are in the process of building the knowledge foundation and exceeding their current cognitive load capacity. The primary role of the supporting resources is to provide an authentic context and cannot replace the structured, progressive learning experience in the later stages of the program (Rathi & Nirgude, 2022). Therefore, revisiting these concepts repeatedly in subsequent courses is essential to gradually diminish the knowledge gap (Woodward, 2019).

In terms of students' appreciation of the alignment of tutorial-labs with real-world applications, as per the results shown in Table 5, the data clearly suggests that students perceive the teaching strategies positively in facilitating systematic and practical application of knowledge and enhancing real-world problem-solving abilities. However, there is a noticeable decrease in "Strongly Agree" responses from Y1 to Y2 in all categories (i.e., systematic application of circuit analysis, theoretical and practical analysis of real-world applications, and alignment of theory with lab results). This may be attributed to the differing extents of the linkage between theory and experimentation in the two courses. In the Year 1 course, the experimental components closely mirror the theoretical aspects, as shown in Figure 1. This alignment allows students to seamlessly validate their results across both segments, typically observing minimal discrepancies between theoretical and experimental results. However, in the Y2 course, the complexity of the circuit to be analysed increases significantly, making it impractical to replicate the exact experimental setup. Consequently, a simplified circuit is utilised for experiments, maintaining the same underlying concepts. However, the results from these experiments do not correspond directly with the theoretical part as in the Y1 course. This incomplete and less transparent linkage means that Y2 students may find it more challenging to validate and compare results as effectively as they did in the Y1 course.

In terms of student engagement and appreciation of the real-world application, as per the results shown in Table 6, the upward trend in the Y2 students in all three aspects addressed (i.e., motivation from context, real-world application awareness and value of integration), indicates a notable strengthening linkage between the stage of the program and the perception of real-world applicability in academic learning. The interplay can be attributed to the students’ accumulated knowledge from prior coursework and increased exposure to practical content potentially sourced from other courses. The enriched knowledge foundation broadens their understanding of contemporary and advanced engineering paradigms. Consequently, the students become more receptive to pedagogical approaches that integrate authentic engineering concepts, recognising the potential value of knowing these concepts in shaping their future career paths.

In summary, results show that the conceptual understanding of an emerging concept (renewable energy in this case) in two introductory courses was improved in both the theoretical and practical aspects after students attended tutorial-labs. In addition, students from both cohorts broadly agree that incorporating emerging concepts as real-world applications in tutorial-labs facilitates the systematic application of circuit analysis, enhances the theoretical and practical analysis of real-world applications, and aids in aligning theory with experimental results. Students from both cohorts have also reported to be motivated to delve into the knowledge further and believe that incorporating context related to an emerging concept such as renewable energy can improve their awareness of real-world applications in circuit analysis. Lastly, students from both cohorts saw value in incorporating emerging concepts (i.e., renewable energy) into the courses to improve learning and future engineering endeavours.

However, it needs to be acknowledged that the approach requires intensive resources when integrating new content, not only in terms of hardware setup but also the effort and time needed to restructure the course and the program to make the flow of the integration more logical and coherent. Although the effectiveness of the strategy mentioned in this study has been proved, whether the incorporation will be successful relies heavily on instructors’ backgrounds, indicating the necessity of extensive professional development to bring educators up to speed (Whitchurch, Locke, & Marini, 2021). Moreover, adding new technical content to the curriculum could lead to an overload of information for students, especially if it’s not seamlessly integrated with existing course materials. Balancing new and existing content without overwhelming students is still a significant challenge, considering specific courses’ learning outcomes and structure. If the strategies are adopted by other courses or programs, developing new assessment strategies that accurately reflect students’ learning in the adopted courses adds another layer of complexity.

Conclusion

This study explores the pedagogical strategy of using contextualised tutorial-laboratories as a way to introduce emerging concepts in the lower-division curriculum.

The overarching proposition of tutorial-labs involves the alignment of tutorial questions with hands-on laboratory experiments, utilising the same real-world application as a contextual link between both aspects, which enhances students' knowledge base and fosters their engineering application abilities. Instead of spanning multiple sessions, each tutorial-lab session focuses on a real-world application tied to a specific topic covered in a course. The challenge lies in designing realistic yet manageable real-world applications that students with limited knowledge can complete in a single session. Examples from Electrical Engineering have been used to illustrate and evaluate this approach.

The effectiveness of this strategy has been proven to enhance students' familiarity with emerging concepts while increasing engagement and appreciation of real-world applications. This approach not only stimulates students' motivation to learn and delve deeper into associated knowledge but also accelerates their growth in applying analytical and hands-on skills to specialised disciplines such as energy systems in electrical engineering.

Future research could employ longitudinal studies and explore alternative methods to gauge longer-term impact. For instance, cohort-level comparisons or program-wide curriculum mappings may capture changes in overall student preparedness without identifying individuals. Additionally, mixed methods approaches, such as focus groups or interviews with representative students, might provide qualitative insights into how these early encounters with emerging concepts affect their eventual specialisation and career interests.

It is worth noting that this strategy, although discussed in the context of electrical engineering, has broader applicability across diverse engineering disciplines. The implications for future curricular development are substantial, suggesting that such an approach could be instrumental in preparing the next generation of engineers to meet the complex demands of a rapidly evolving technological landscape by bridging the gap between theoretical knowledge and practical application at the early stage of the program. Moreover, the positive outcomes associated with this strategy may encourage educators in other fields to adopt similar methodologies, thereby extending the benefits of contextualised, application-driven learning beyond the confines of engineering.

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Declaration of Interest

There is no conflict of interest in the paper.

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