WIP: Exploring Curriculum Design for Introductory Electrical Engineering Subjects: A Review of the Australian Context

Matheus S. Xavier
Department of Electrical and Electronic Engineering
The University of Melbourne
Parkville, VIC, Australia
matt.xavier@unimelb.edu.au

Shannon A. Rios
Teaching and Learning Lab
The University of Melbourne
Parkville, VIC, Australia
shannon.rios@unimelb.edu.au

***Abstract*—This work-in-progress research paper describes a comparative analysis of introductory electrical engineering subjects within Australian universities. A mixed-methods approach was used which included a desktop review of subject handbook entries, extraction of key metrics from this data, and a content analysis of the learning outcomes and subject descriptions. The analysis revealed that most universities in Australia follow similar teaching and learning activities and assessment distributions and do not describe instructional strategies in their handbook. Where instructional strategies are described, they are mostly restricted to practical or lab work, or mention the use of real-world and authentic approaches. Analysis of the intended learning outcomes revealed a tendency for higher-order thinking skills to be mentioned, which is unique in an introductory subject. The study identifies key challenges and opportunities for educators to consider when designing their EE subjects.**

***Index Terms*—electric circuits, subject design, engineering curriculum, instructional methods, assessment strategies.**

I. Introduction

Introductory electrical engineering (EE) subjects cover topics such as basic circuit elements, resistive circuits, circuit analysis, first-order transients, operational amplifiers, and sinusoidal analysis. Traditionally, these subjects are taught using a combination of lectures and laboratories [1]. The lectures are often perceived as the most effective approach to cover the vast content typical of these subjects within the provided contact hours, particularly considering the large cohorts also typical of these subjects. However, traditional lecturing fails to promote a high level of learning or retention of knowledge and is not likely to develop the professional skills suggested by engineering accreditation bodies [2]–[4]. For the laboratory sessions, students are usually provided with pre-determined tasks related to the lecture content, which frequently involve the observation of phenomena described theoretically in lectures through a procedural lens. Hence, laboratory classes are often described as the point at which the theoretical learning meets practical application [1].

Conversely, one of the major movements in engineering education in the last decades has been the shift from passive, lecture-style teaching to more active, student-focused teaching and learning activities (TLAs) [2]. These learning environments are designed to actively engage students through, for example, cooperative learning and problem-based learning (PBL) [5]. For a similar subject, [6] argue that the participants' learning gains from PBL were twice their gains from a traditional lecture. Self-regulated learning strategies, where students are encouraged to construct their own knowledge and skills, have also been proposed [7], [8].

Team-based learning (TBL) was investigated in [4], [9] to develop professional skills, such as self-directed independent learning, problem solving, written and oral communication, and interpersonal team skills. In TBL, students are required to independently study new material prior to class, and to spend considerable class time working on assignments in groups, providing them with opportunities to discuss problems and alternative solutions and teach each other, which has produced deeper conceptual learning than traditional lectures [4].

In [1], the authors discuss active learning strategies proposed in over 10 studies focusing on electric circuit subjects. Pre-recorded videos, media-rich resources, or enhanced guided notes were shown to improve students' understanding of electric circuit concepts, particularly those with an abstract nature. In all studies where students reported improved learning, students were asked to solve a problem or explain a concept in an open-ended manner, rather than choosing an answer, which promotes deeper learning in comparison to traditional note taking. However, the authors also note that interactive activities were mostly limited to lab-based activities, and while innovative approaches have been reported in engineering classrooms, there is limited work aimed at capturing students perception about these approaches.

In [10], 13 studies on teaching circuits are used to evaluate evidence-based instructional practices, including: feedback, supplemented learning, PBL, TBL, real experimentation and virtual experimentation. The authors highlighted the overall lack of work done on investigating evidence-based instructional practices. However, the work that has been done generally showed success in facilitating student learning.

Currently, little work has been performed to compare the subject design of introductory electrical engineering subjects within the Australian context. The previous literature describes various novel teaching and learning methods, particularly around active learning, problem-based learning, project-based learning, flipped or hybrid classrooms, collaborative learning, and virtual experimentation [1], [10]–[12]. Nevertheless, it is unclear which of these approaches (if any) have found widespread application in EE programs in Australia.

In general, these subjects introduce some of the most important concepts and skills within an EE program and are the prerequisites of many subsequent subjects. Therefore, understanding the main pedagogical approaches used in their curriculum design is imperative to promote best practices and improve student learning.

A. Contributions and Research Questions

The purpose of this study, which is a work-in-progress (WIP) research paper, is to perform a comparative analysis of introductory electric circuit subjects within electrical engineering programs in Australian universities so that educators and faculties can better identify where their curriculum sits compared to others, and also to highlight gaps in how these subjects are taught with respect to current best practice teaching methods. It is intended that educators reading this paper will reflect on their own teaching practices and identify areas where they may improve the use of instructional and assessment strategies. Subject titles in this study are typically "electric circuits" (also, "electrical/electronic circuits" or "electrical systems") or "introduction to electrical engineering" (also, "foundations of electrical engineering" or "fundamentals of electrical engineering"). In addition, this work proposes several potential innovative teaching, learning and assessment practices based on the literature, and present this information in a format useful for educators looking to implement or enhance similar electrical engineering subjects. This would be the first step in better understanding why the teaching of electrical circuits (and possibly many similar engineering subjects) has not changed to reflect more modern teaching strategies.

This paper seeks to answer the following research questions: (1) "What do introductory electrical engineering subjects look like in Australian universities?", and more specifically (2) "What is the current state of teaching and learning activities and assessment strategies used in these subjects?".

II. Methodology

This study employed a mixed-methods approach to examine introductory electrical engineering (EE) subjects within electrical engineering programs in Australian universities. A desktop review was initially conducted across all 33 universities offering EE programs in Australia to collect the publicly accessible subject handbook data from university websites. Then, this data was processed to extract subject content, learning outcomes, delivery modes, recommended resources, teaching and learning activities (TLAs), workloads, and assessment strategies. The following theoretical frameworks are used to inform the analysis and discussion: adult learning theory [13] and constructive alignment [14].

Once the data was extracted, quantitative analysis was performed on the reported TLAs and assessment distributions to identify trends and common practices, and directly compare these subjects across different institutions. Next, the subject descriptions were analysed using a descriptive content analysis approach [15]. The purpose of the content analysis was to identify whether any instructional strategies were mentioned in the subject description. A quantitative analysis method was chosen as the text being analysed is technical in nature and written in a straightforward manner. To develop the code list, a deductive approach was undertaken to build up a code list as we read through the handbook entries. After the deductive stage, we consolidated the codes into broader categories representative of common instructional strategies. The results of this analysis can be found in Table I.

Finally, the learning outcomes were analysed to estimate the cognitive complexity of the learning outcomes using the constructive alignment theoretical framework [14] and Bloom's taxonomy [16]. This was done by counting the occurrence of the most common verbs within all 169 learning objectives.

Instructional Activity	Example Codes	Frequency
PBL	'Project and design based'	1
Types of Classes	'studios', 'seminar sessions', and 'lectures'	3
Practical Work	'practical experiences' and 'laboratory experiments'	8
Real-World	'application-oriented topics' and 'real-world problem'	3
Communities	'learning communities'	1
Collaborative Activities	'small teams work together' and 'group work'	2
Software	'exposure to software tools'	1
Active Learning	'active learning modules'	1
Online Learning	'online presentations' and 'use of online materials'	2

TABLE I: Instructional strategy categories.

A. Nomenclature

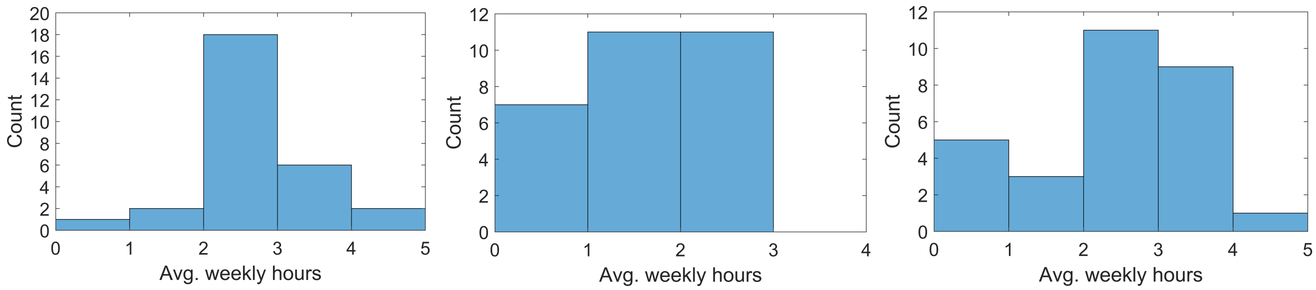
This section briefly clarifies some of the terminology used in this study, particularly within the Australian engineering education context.

- Subject: discrete unit of study, also known as module, unit or course (in North America).
- Course: a structured program of study (e.g., bachelors or masters), also known as program (in North America) or degree.
- Laboratory: a TLA where engineering tasks, such as fabrication, assembly, repair, and experimentation, are carried out. In this study, all practical activities including laboratories, workshops (when conducted in lab environments), practicals and studios are lumped into the laboratory category.
- Tutorial: a TLA designed to provide additional guidance, explanation or practice on a particular topic covered in a subject. In this study, all typical problem solving activities including tutorials and workshops (when conducted in typical classroom environments) are lumped into the tutorial category.
- Quizzes: typically shorter assessments to evaluate students' understanding of specific topics and provide ongoing feedback.
- Progression tests: more comprehensive assessments, usually conducted in one or two stages during the semester. These tests (e.g., midterms) are longer in duration than quizzes and normally assess a broader range of topics.

III. Results

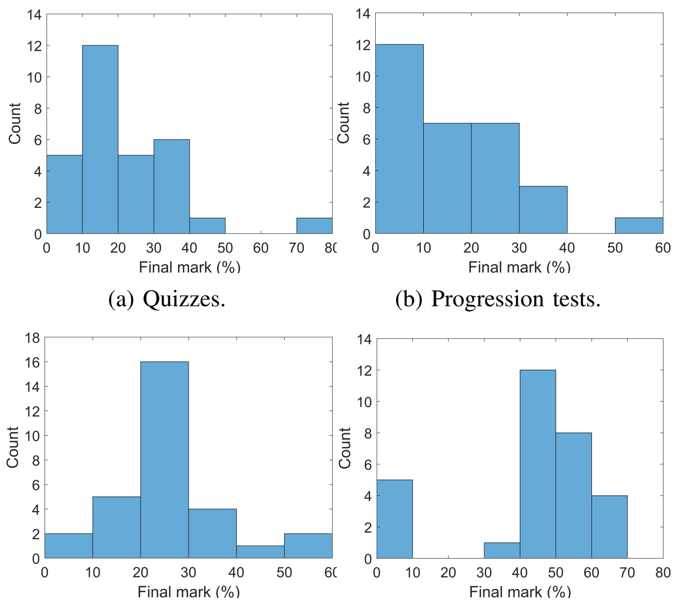
From the 33 Australian universities included in this study, 4 universities did not describe the teaching and learning activities in their respective online handbooks. From the remaining 29 universities, the initial quantitative analysis revealed that most universities in Australia use similar TLAs, as shown in Fig. 1. The following weekly averages are typical of these subjects: 2 to 3 hours of lectures, 2 to 4 hours of laboratory activities, and 1 to 3 hours of tutorials. Subjects require, on average, 63 contact hours (synchronous face-to-face) per semester with a total workload of 155 hours.

Furthermore, 3 universities did not describe assessment distributions. From the remaining 30 universities, four types of activities were typically reported, as shown in Fig. 2,



(a) Lectures. (b) Tutorials. (c) Laboratories.

Fig. 1: Average weekly contact hours distribution of teaching and learning activities (TLAs) for the three common types of activities in introductory electrical engineering subjects.



(a) Quizzes. (b) Progression tests. (c) Lab reports. (d) Final exams.

Fig. 2: Assessment distribution for the four common types of activities as a percentage of the final subject mark.

which shows the following typical spread of percentage values of the final subject mark: (1) weekly assessments such as weekly quizzes or assessed tutorials (10-40%), (2) progression tests such as mid-semester tests (0-30%), (3) laboratory reports (20-30%), and (4) final exams (40-60%).

In addition to the results shown in Fig. 2, the quantitative data showed that (1) only 6 out of 33 universities explicitly reported a project component; (2) only 3 universities included oral or video presentations as part of their assessment strategies; (3) only one university reported a student portfolio assessment, which accounts for 60% of the final subject mark; (4) on average, individual marks account for 80% of final subject mark; (5) for the delivery modes, 26 universities follow a semester model, 6 universities follow a trimester model, and one university uses a block model, where each subject is covered one at a time in four-week blocks; (6) for the subject year, 23 universities offer these subjects in the first year of the degree, and 10 universities offer them in the second year; (7) one university reported residential schools as part of the TLAs; and (8) for the recommended resources, the most used books were Hambley [17] ($n = 8$), Nilsson and Riedel [18] ($n = 4$), Boylestad [19] ($n = 3$), and Alexander and Sadiku [20] ($n = 2$).

Following the quantitative analysis on TLAs and assessment distributions, the content analysis highlighted the general lack of explicit instructional strategies in the subject handbook descriptions, with only 12 of the 33 subjects in this study mentioning any type of instructional strategy and a total of 22 mentions across these subjects. Of the instructional strategies mentioned, practical work was by far the most frequent, occurring in 8 of the 12 subjects. Following that, “Real-World” and “Types of Classes” had the second highest with mentions in 3 separate subjects. Of the 12 subjects that mentioned instructional strategies, half of these only mentioned one strategy and only three mentioned more than four strategies each. Table II shows the breakdown of instructional strategy per subject.

When looking at the intended learning outcomes (ILOs) across the subjects, the average number of ILOs was 5. Three subjects did not report ILOs in the handbook entries, and one subject had fifteen ILOs listed. An online text analyser was used to count the frequency of words across all 169 ILOs. Ignoring function words such as “and” and “the” and domain specific words such as “circuits” and “electrical”, the 5 most common verbs were: “analyse” ($n = 41$), “apply” ($n = 39$), “design” ($n = 21$), “explain” ($n = 16$), and “demonstrate” ($n = 16$). Other than “explain” these verbs all related to higher-order thinking [16]. Moreover, assuming that, on average, each ILO uses only a single verb, these four verbs are present in almost 70% ($n = 117$) of the ILOs.

Finally, 16 of the 33 subjects had pre-requisite requirements. The pre-requisites were most commonly mathematics ($n = 14$) and physics ($n = 3$), followed by a combination of foundational engineering subjects. Further analysis is required to correlate ILOs, pre-requisites and use of instructional strategies.

IV. Discussion

The quantitative analysis revealed that most universities in Australia follow similar teaching and learning activities and assessment distributions. These subjects typically rely on a traditional lecture format to deliver the vast technical content covered in these subjects, which usually encompass over 500 pages of material in the recommended references described in Section III.

The content analysis showed that very few subject handbooks highlighted instructional strategies in their descriptions, and those that do mostly highlighted ‘practical work’ or ‘real-world’ skills. It is important to note that this does

Subject Code	Instructional Strategies
ENG223	Online Learning
ENEE12014	Practical Work
SEJ102	PBL; Collaborative Activities; Types of Classes; Practical Work;
ENS1253	Types of Classes
EGB120	Types of Classes; Real-World; Practical Work
ELEC ENG 1100	Real-World; Online Learning; Collaborative Activities; Practical Work
ELEN20005	Software
EEE1201	Active Learning; Communities; Synchronous Learning; Asynchronous Learning
48510	Real-World; Practical Work
ENSC2003	Practical Work
ENGG104	Practical Work
ELEC 1003	Practical Work

TABLE II: Subjects mentioning instructional strategies in their handbook descriptions.

not mean that subjects do not use innovative or novel instructional strategies, but it may highlight a lack of value associated with these practices. Looking at the common verbs in the ILOs revealed a significant proportion of "apply" and above level verbs indicating a focus on higher-order thinking [16], which align with expectations that engineers need to design and analyse complex systems, but may be above what should be expected in a first year subject, and not inline with the TLAs and instructional strategies used.

Before addressing the challenges and opportunities for these introductory EE subjects, we recall that this WIP paper has only made use of publicly available information, as displayed in the subject handbooks. These descriptions, however, showed significantly different structures and levels of information across different institutions. As a result, not all details for these subjects were provided, and innovative TLAs and assessment strategies present in these subjects may not have been discussed, hence the handbook may not reflect the actual TLAs in these subjects. Another limitation of this study is the use of non-standardized language across different institutions. In this study, we attempted to sort this information as per the categories defined in Section II-A.

A. Challenges

1) *How to embed professional skills in introductory EE subjects*: from this preliminary investigation, we observed that most introductory electrical engineering subjects generally lack the development of professional skills such as effective oral communication, creative and pro-active demeanour, project management, and effective team membership or leadership. However, it is important to note that these subjects provide the required backbone for most subsequent subjects in the EE degree. As such, they generally require significant new content to be rigorously discussed, with appropriate opportunities to practice, so that students can grasp this important foundation for their degree.

2) *How to improve TLAs to support diverse learners*: this study has shown a propensity for homogeneous and traditional TLAs and instructional strategies which imply a one-size-fits-all curriculum design approach. As reported in [1], even within studies of TLAs to promote engagement in electric circuit subjects, there was a lack of discussion on the use of multiple modes of representation to convey knowledge of the concepts being taught. In this context, Universal Design for Learning (UDL) can be promoted to design and deliver flexible approaches to teaching and learning that can address this increasing student diversity and improve the learning experience for all students [21].

3) *How to integrate active learning strategies into technical subjects*: the engineering education literature provides significant evidence supporting active learning strategies and further opportunities for group work. The adult learning theoretical framework [13] suggests building knowledge upon the principles of constructivism, self-directed learning, goal-oriented learning, workplace integration, and communities of practice, to name a few. However, as noted in [9], in various PBL settings student teams often find ways of solving open-ended problems that do not require them to learn and use the intended content knowledge, which generates knowledge gaps. Additionally, academics may be reluctant to update their subjects due to fear of upsetting the balance (i.e., "if it ain't broke don't fix it") or due to the workload required to implement these changes.

B. Opportunities

1) *Expand use of innovative assessment practices*: our analysis showed the propensity for subjects to utilize high-stakes exams, and the general lack of project-based or oral assessments. In the current format, many subjects have back-ended assessments, with over 60% of the overall mark concentrated at the final exam or last few teaching weeks. Educators could consider alternative ongoing assessments building upon the principles of formative assessment and self-regulated learning, providing further opportunities to close the gap between current and desired performance. Future assessment practices should be more authentic and secure, focusing on assessing the process and overall engineering design, rather than the final product. This is also relevant due to the rise of generative AI, which has emphasized the need for more invigilated assessments [22]. Some examples of alternative assessment practices include: viva or oral assessment of technical and practical skills [23], observational assessments [24], or portfolios and journals [25].

2) *Expand use of innovative instructional strategies*: instructional strategies appear to be mostly limited to lab-based activities, with lectures typically comprising the largest single face-to-face learning modality. Nevertheless, in the lecture environments, online in-class surveys can be used to monitor student's progress and discuss problem solving. The use of online tools for both synchronous and asynchronous TLAs may also promote engagement, particularly within diverse student cohorts, e.g., EAL/ESL (English as an Additional/Second Language) students or other underrepresented groups. These initiatives lend themselves to flipped or blended style learning. Although there are challenges related to implementing flipped learning (e.g., low attendance levels and balancing total student commitment hours), studies have reported positive responses from students for flipped lecture styles [26] and the development of videos or other media-rich resources, as opposed to text-based resources, as a means to increase time for problem solving applications during lectures [27], promote independent learning [28], and improve their understanding, especially for highly mathematical or abstract topics [29], [30].

As noted by [5], to maximize students' achievement for subjects such as electric circuits, which are conceptually complex and content-dense, instructors should not allow students to remain passive. This could be achieved, for example, by incorporating cooperative interaction into classes. As a result, subject coordinators could aim at embedding more authentic forms of instruction where knowledge is constructed and applied through the learning journey of the students [13]. In [9], team-based learning (TBL) was introduced into their basic electric circuit theory sequence consisting of two first year subjects, providing an effective way to teach technical concepts and develop professional skills simultaneously. Other approaches worth considering include inquiry-based learning [31] and differentiated learning [32].

For the lab-based environments, in [33], it is suggested that the combination of real experimentation (laboratory experimentation) and virtual experimentation (computer-based simulations) enhanced students' conceptual understanding of electric circuits more than the use of only real experimentation. Similarly, as indicated by [34], students who used properly designed computer simulations using virtual equipment in lieu of real equipment learned more content, performed better on conceptual questions related to simple circuits, and developed a greater facility at manipulating real components, which challenges the traditional view that students learn more via hands-on experience.

V. Conclusions and Future Work

This work-in-progress paper on the current state of introductory electrical engineering subjects sheds some light on how student engineers are being trained in Australian EE programs. By integrating quantitative analysis with qualitative insights, this paper provided a holistic view of these subjects using the subject handbook entries. Overall, the results demonstrated the prevalence of certain pedagogical approaches and limited professional skills development in these subjects.

This preliminary work also provides a guide for educators starting or re-designing similar subjects, identifying three key challenges and two main opportunities for EE educators to consider in their context. Future work will take a more in-depth look at how these subjects are delivered by interviewing and directly observing the teaching and learning practices present in the subjects. Additionally, we will expand our investigation to look at the impact of the student cohorts, institutions and teaching staff.

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