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Reimagining Approaches in Electrical Engineering Education: Reflections on Curriculum Redesign for an Electrical Networks Subject

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ABSTRACT

CONTEXT

Most introductory electrical engineering subjects are delivered through lectures, tutorials, and workshops. Given the large content typical of these subjects, they tend to lack the development of professional skills and default to conventional teaching and assessment practices. Nevertheless, the engineering education literature suggests incorporating active, student-focused teaching strategies to enhance learning. The subject “Electrical Networks Analysis and Design” (ENAD), a core subject within most electrical engineering degrees, blends theory, simulation, and hands-on experiments, necessitating effective teaching practices to motivate and engage students.

PURPOSE OR GOAL

This study presents our strategies aiming to improve the teaching and learning experiences in ENAD by addressing the challenges identified over four semesters. The main research questions are: (1) “*How can we improve our teaching within the context of an electrical networks subject?”*; (2) *“How can we enhance student learning in an electrical networks subject?*”. These questions guide the curriculum design interventions and the analysis of their impact on student engagement and performance.

APPROACH OR METHODOLOGY/METHODS

A Scholarship of Teaching and Learning (SoTL) approach was adopted, combining data from engineering education literature, self-reflection, student and staff feedback, and teaching observations to provide background and motivation for various interventions. Data on student engagement, satisfaction, and performance were collected through surveys, assessment results, and in-class observations to evaluate the effectiveness of these interventions.

ACTUAL OR ANTICIPATED OUTCOMES

The interventions led to increased student engagement, improved satisfaction scores, and enhanced performance in assessments. The introduction of formative assessments, project-based learning, team-based learning through collaborative workshops, and peer feedback mechanisms contributed significantly to these positive outcomes.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The study shows that a holistic and student-centred approach to curriculum design can significantly enhance student engagement and learning outcomes. The findings suggest that incorporating active learning strategies and formative feedback mechanisms are crucial for improving teaching practices in electrical engineering subjects. Future work will explore further innovations in authentic assessment and instructional strategies to sustain and enhance these improvements.

KEYWORDS
Electrical engineering education, curriculum design, active learning, student engagement.

Introduction

Most introductory electrical engineering subjects covering electrical or electronic circuits or networks are offered using a combination of lectures, tutorials, and workshops (laboratories). The lectures are generally associated as an appropriate mechanism to deliver the large content typical of these subjects, which generally cover over 400 pages in popular references such as Alexander and Sadiku (2020), Boylestad (2016), and Nilsson and Riedel (2021). In the workshops, students are usually provided with a list of pre-determined tasks to work through, which involve bringing the theory from the lectures into simulation or experimental studies. Then, the tutorials provide opportunities for students to work through suggested problems under the supervision of teaching staff members (although some workshops may also operate as tutorials).

The engineering education literature on similar subjects has suggested several active, student-focused approaches to teaching and learning in engineering, including problem-based learning (PBL), project-based learning (PjBL) and team-based learning (TBL) (Pitterson & Streveler, 2015; Espera & Pitterson, 2019; O'Connell & On, 2012; Yadav et al., 2011). Strategies and practices for self-regulated learning, media-rich resources, improved feedback mechanisms, flipped or hybrid classrooms, supplemented learning and virtual experimentation have also been proposed (Reagan et al., 2020; Turner & Webster, 2017; Lawanto & Santoso, 2013).

"Electrical Networks Analysis and Design" (ENAD), or similar versions such as "Electrical Circuits (2)", "Circuits and Signals", and "Circuits and Electronics", is a standard subject within electrical engineering degrees, where the content is adapted as needed given technology advancements and standard practices within the global engineering community, although the main theoretical frameworks are generally well-established. The theoretical material presented in this subject must also be accompanied by exposure to software tools for the simulation of electrical and electronic systems (e.g., LTspice and MATLAB) and the opportunity to develop electrical engineering laboratory skills using, for example, prototyping breadboards, various electrical components (e.g., resistors, capacitors, inductors, and operational amplifiers), digital multimeters, function generators, power supplies, and oscilloscopes. The combination of these three aspects (theory, simulation, and experiments) must provide a solid background for various subsequent subjects. Hence, a reasonable number of hours are spent in lecture environments where content is delivered to students, but also in laboratories where students test, prototype and troubleshoot many electrical and electronic circuits and devices. Most importantly, students can learn by acquiring, inquiring, practising, discussing, collaborating, or producing. Therefore, it is important to incorporate teaching practices that can motivate students through various exchanges, not only in class and not only through student-staff interactions.

This paper is a reflective essay that focuses on the staff and student experiences within Electrical Networks Analysis and Design, following a Scholarship of Teaching and Learning (SoTL) approach. The main research questions for this paper are presented below:

- *How can we improve our teaching within the context of an electrical networks subject?*
- *How can we enhance student learning in an electrical networks subject?*

To answer these research questions, this paper firstly describes the subject context. Then, we introduce the challenges that have motivated this work and present the corresponding curriculum design interventions, followed by the lessons learned from these interventions. Finally, we discuss the current limitations and further opportunities for improvement in this subject.

Subject Overview

This subject provides an overview of fundamental tools for the analysis of linear time-invariant electric circuits using both time and frequency domain techniques. Alongside "Foundations of

Electrical Networks” (FoEN), they form the foundation of many subsequent subjects in electrical and electronic engineering. The techniques presented in ENAD are then later further evaluated and expanded upon in various subjects in the Electrical Systems Major in the Bachelor of Science and the Master of Electrical Engineering degrees at The University of Melbourne.

The sub-sections below outline the subject information, intended learning outcomes and professional skills, assessment distribution (Table 1 for semester 1 in 2024), and teaching and learning activities. The professional skills draw inspiration from the Stage 1 competencies that must be demonstrated at the point of entry to practice (Engineers Australia, 2019).

Subject Information Summary

- Subject name: Electrical Networks Analysis and Design (ENAD)
- Level: third-year undergraduate or first-year master.
- Pre-requisites: “Foundations of Electrical Networks” (FoEN) or “Circuits and Systems”.
- Delivery mode: in-person, one semester (12 weeks, followed by examination period).
- Typical class size: 75-95 students in semester 1 and 30-50 students in semester 2.

Intended Learning Outcomes (ILOs)

- ILO1: Model and analyse the linear time-invariant behaviour of electrical and electronic systems, using both the time and frequency domain techniques.
- ILO2: Model, design, prototype and troubleshoot passive and active electrical and electronic networks that achieve desired engineering requirements, with a focus on filters.
- ILO3: Simulate linear and nonlinear electrical networks using software tools.

General/Professional Skills

- Ability to apply knowledge of basic science and engineering fundamentals to complex engineering problem solving.
- Ability to undertake problem identification and formulation, followed by the development of creative and innovative solutions.
- Ability to utilise a systems approach to design and operational performance.
- Effective oral and written communication with the engineering team and the community.
- Capacity for independent critical thought, rational inquiry, and self-directed learning.
- Orderly management of self and effective team membership.

Assessment Distribution

Table 1: Assessment distribution in Electrical Networks Analysis and Design (ENAD) in 2024-1.

Assessment	Length	Weighting	Timing	ILOs
Engineering reports	35 pages per student	20%	Weeks 1-10	ILOs 1-3
Mid-semester test	60-minutes	10%	Weeks 7-8	ILO 1
Team-based design project	Preliminary group report (8 pages), final group report (15 pages), and oral group presentation (15 minutes)	20% consisting of preliminary report (5%), final report scaled by peer review (10%), and oral presentation (5%)	Weeks 6-12	ILOs 1-3
Final Exam	3 hours	50%	Examination period	ILOs 1-2
Online weekly quizzes	60-minute quizzes	0%	Weeks 1-12	ILOs 1-2

Teaching and Learning Activities (Weekly)

- Lectures: 3 one-hour lectures.
- Workshops (laboratories): 1 three-hour workshop with groups of up to 24 students.
- Collaborative workshops: 1 two-hour open-invitation collaborative workshop/consultation.
- Consultations: 1 one-hour consultation with subject coordinator. Additional consultations prior to the mid-semester test and final exam, or as required.

Motivation

From coordinating ENAD over four semesters starting in 2022, ten initial challenges have been identified through (1) the engineering education literature; (2) lecture, workshop, and consultation observations; (3) self-reflection; and (4) feedback from students, workshop demonstrators and fellow staff members within the department. These challenges are summarised in Table 2.

Table 2: Challenges identified while teaching Electrical Networks Analysis and Design (ENAD).

Number	Observation	Year
C1	Heavy dependence on final exam and a significant proportion (>70%) of the overall subject mark in the final weeks of the semester.	2021
C2	Few opportunities for the development of general and professional skills.	2021
C3	Limited opportunities for (structured) group interaction outside workshops and limited lecturer-student interaction outside timetabled contact hours.	2022
C4	Low engagement with weekly recommended problems in the subject problem booklet, and limited student data and feedback.	2022
C5	Many requests from students for additional problem-solving classes.	2022
C6	Need for additional feedback mechanisms both for students individually and the class overall.	2022
C7	Issues with student team membership, including workload distribution (among group members and throughout the semester), accountability, and professionalism for the group project.	2022
C8	Lack of appropriate engineering design processes or systems approach for the group project and continued issues with team membership and workload distribution.	2023
C9	Improved but still moderate levels of engagement with weekly recommended problems in the new online platform.	2023
C10	Diverse levels of mathematical and electric circuits proficiency for students enrolled in the subject, and the need for a review of background material from previous subjects.	2022-2023

Curriculum Redesign

Considering the challenges listed in Table 2, several interventions have been implemented over the last three years, as summarised in Figure 1 for the respective challenges.

Weekly online quizzes and bespoke tutorials (formative assessment and feedback): to address C4 and C6, we have included optional (formative) online weekly quizzes within the “Mastering Engineering” Pearson platform (Nilsson & Riedel, 2021) since 2023. These problems allow students to practice and solidify the subject content and provide instantaneous self-feedback via multiple attempts and hints. Furthermore, the general data from class performance across different topics is used to inform and prepare bespoke tutorial classes, which then provide overall class feedback (addressing C5 and C6). Hence, the feedback here goes both ways: (1) students can appreciate the common misconceptions in the subject (self-regulation); and (2) it informs the subject coordinator of potential areas where students need further assistance, providing a mechanism to address these difficulties throughout the semester and prior to graded assessments.

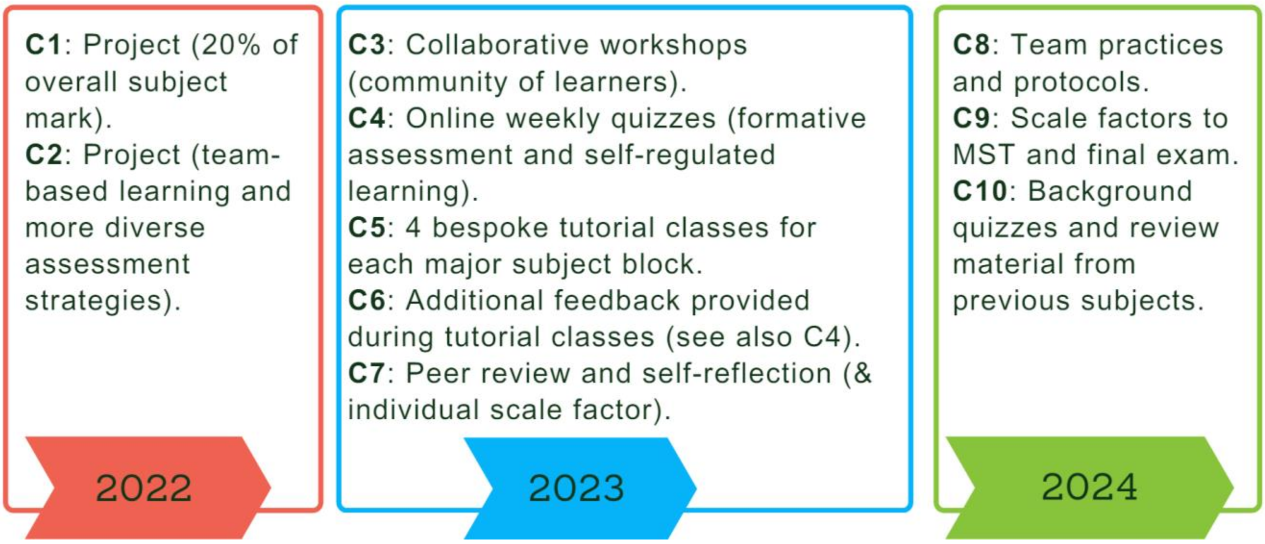

Figure 1: Timeline with summary of proposed changes to ENAD in each year.

These optional quizzes build upon the principles of formative assessment and self-regulated learning since they facilitate the development of self-assessment in learning, deliver high quality information to students about their learning, allow for opportunities to close the gap between current and desired performance, and provide information to teachers that can be used to help shape teaching (Nicol and Macfarlane-Dick, 2006).

Project-based learning: to address C1-C3, we introduced an open-ended project in 2022 where students are provided with a complex engineering problem that can be solved using multiple methods building on the techniques discussed in the subject. The project aims to emulate a real-world situation where students are asked to “think as engineers” and work together to come up with an innovative solution. This design project is used as a vehicle to motivate and integrate peer and self-directed learning, enhance students’ motivation, and develop engineering intuition by shifting their thinking paradigm from engineering theory to interaction with hardware (Dym et al., 2005).

While the typical guided workshops provide students with opportunities for applying and evaluating their knowledge, they have limited aspects of innovation. In contrast, the open-ended workshops associated with the project allow for not only these aspects but also creating novel and original products, the most complex skill within the Bloom’s taxonomy, and usually considered one of the most important outcomes of education (Krathwohl, 2002). The introduction of the open-ended project exemplifies a model of experiential learning (Kolb, 2014). Further, previous research has indicated that participants’ learning gains from problem-based learning were twice their gains from traditional lectures (Yadav et al., 2011). The project assessments and associated activities also include opportunities to develop both research-oriented and workplace-relevant skills around complex problem solving, critical thinking, communication, and collaboration, as listed in the general/professional skills in our subject.

The assessment for the project in 2022-2023 included a final report and oral presentation, both conducted in the last teaching week (Week 12). However, we have noticed a significant proportion of students not contributing to the project prior to week 10 (or even Week 11), in addition to consistent team issues with workload distribution and accountability. Hence, to address C7 and C8 and ensure students are engaging in a cyclical, experiential learning process rather than just leaving all work to the last minute, we introduced the submission of a preliminary report for the design project in Week 9 for the 2024 iteration. This also provides students with further feedback during the semester, which can be actioned prior to the final group report. In 2024, to address C8, we also introduced an activity around team practices and protocols (including an associated file with detailed instructions) to help students formalise the practices and processes for team collaboration. Our inherent objectives are to support students with the workload distribution, time and conflict management, and the development of a team culture where members ‘divide, conquer, and combine’ repeatedly throughout the semester.

As discussed in Nicol & Macfarlane-Dick (2006), including the preliminary report as formative assessment helps students identify target areas that need work and helps the teaching staff recognise where students are struggling. In addition, this (arguably formative) assessment contributes to the final report (summative assessment), which lowers the workload on the students and provides them with necessary feedback to improve their final performance.

Peer review: following a few issues with workload distribution, accountability, and overall professionalism (challenge C7), we introduced peer feedback and self-reflection in 2023 as fundamental components of the project. The marks provided by students in 7 categories are then used to generate individual scale factors which are applied to their group project marks. As highlighted by Nicol et al. (2014), the benefits of peer feedback include: (1) exposing students to a range of views other than those of academic staff; (2) information may be more detailed and easier to understand than comments from academic staff; and (3) allowing students to uncover critical insights about the quality of their own work, hence helping develop vital skills in the areas of evaluative judgement and self-regulated learning.

Collaborative workshops: to address C3 (and partially C4-C6), we introduced optional collaborative workshops in 2023 where the subject coordinator assists groups of students working through suggested exercises (e.g., from the online quizzes, problem booklet or past tests) in a shared whiteboard environment. These semi-structured workshops are a great opportunity to ask questions, meet people, and develop subject proficiency. The collaborative workshops have been specifically designed to build learning communities and encourage students to interact both within and outside their teams (Arkoudis et al., 2013).

Challenges and Opportunities

At The University of Melbourne, the main student learning survey is the end of subject survey (ESS), which reports results for 6 items on a scale of 1 (strongly disagree) to 5 (strongly agree). The ESS results from 2021 to 2023 are summarised in Table 3 (response rates are around 30-40% for each semester). Overall, these results show that students have valued the proposed curriculum interventions, particularly as reflected by increased scores related to feedback, resources, and opportunities for collaboration among students.

Table 3: Subject survey (ESS) scores for ENAD.

	2021-2	2022-1	2022-2	2023-1	2023-2
Number of students	11	19	18	23	13
Subject was engaging and stimulating	4.18	4.47	4.44	4.52	4.77
Clear expectations (assessment requirements)	4.27	4.21	4.44	4.26	4.69
Useful feedback	4.00	3.68	4.17	4.39	4.85
Helpful resources and materials	4.09	4.42	4.33	4.43	4.85
Opportunities for useful interaction with other students	4.18	4.47	4.44	4.52	4.69
Good learning experience	4.09	4.32	4.33	4.39	4.69

Despite progress in student engagement and satisfaction as a result of the strategies discussed in the previous section, a few challenges should be noted. As discussed below, these challenges include the distribution of summative and formative assessments, the shift to active learning strategies (particularly with the open-ended project and the associated team collaboration), engagement with lectures and formative assessments, and further opportunities for innovative instructional strategies and authentic assessment practices.

Significant percentage of subject mark toward the end of the semester: typically, in similar subjects, at least 70% of the student grade is associated with assessments around the end of the semester, and there are limited (formative) assessments earlier in the semester beyond workshop reports. One strategy could be allocating a higher weighting to the team design project and an even lower dependence on the final exam. One proposed weighting distribution could be: (1) final exam allocation reduced from 50% to 30%; (2) weekly online quizzes (formative assessment) included in final mark (10%), e.g., 8 best out of 10 quizzes; and (3) increased allocation to design project (from 20% to 30%), including the following formative assessments in Week 9: preliminary report (8%), peer-feedback (1%) and self-reflection (1%). On the other hand, a sole reliance on project-based learning may also generate knowledge gaps. As noted in O'Connell (2014), student teams often find ways of solving open-ended problems that do not require them to learn and use the content covered within the subject. Considering the fundamental role this subject plays in the future subjects of the electrical engineering degree, authentic assessment approaches at appropriate stages throughout the semester are required to ensure students develop mastery of the intended content. The development of authentic assessments for project-based learning is particularly relevant considering the recent advances in generative artificial intelligence, e.g., ChatGPT. We also note that modifications to assessment distributions generally require significant resources multiple university approvals, which are often slow, time-consuming, and possibly difficult to obtain.

Engagement with formative assessments and online discussion platform: prior to 2022, students would mostly complete practice problems provided in a booklet, although a few problems were also recommended within the Pearson platform. From 2023 onwards, we changed the message and set the completion of weekly online problems within this platform as the baseline expectation from all students. This expectation was made clear during the lectures (especially the bespoke tutorial classes) and through every weekly announcement, which resulted in a higher percentage of students completing these problems. However, in 2023, we noted that less than 40% of students would engage with these problems (challenge C9). Hence, to motivate completion of these practice problems every week (and to provide us with a rich source of information around students' misconceptions), scale factors to the mid-semester test and final exam were implemented in 2024 for the completion of all problems with an average score of at least 70%. Following this measure, we observed over 75% of students engaging with the weekly problems, which was an encouraging result and allowed us to provide more concrete feedback to the class during the bespoke tutorials. A more detailed breakdown of average marks and completion rates for selected weeks is shown in Table 4. Likely due to the increased engagement with weekly formative assessments and collaborative workshops, we also observed a significant increase in engagement with the online discussion platform used in our subject (Ed Discussion), as shown in Table 5. We note that, as an alternative to scale factors, we have also considered a scenario whereby the weekly quizzes are directly embedded into the overall subject mark. It is unclear, however, if this alternative strategy would further motivate students to complete the weekly problems, especially considering the students who do not complete these problems tend to minimally engage with all other activities in the subject.

Table 4: Average mark and completion rates for weekly problems in ENAD.

	2023-1	2024-1
Week 1	Average: 89.1%. Completion: 59.7%.	Average: 96.0%. Completion: 87.6%.
Week 6	Average: 79.0%. Completion: 41.2%.	Average: 94.6%. Completion: 85.6%.
Week 11	Average: 62.5%. Completion: 17.9%.	Average: 94.2%. Completion: 70.1%.

Table 5: Student engagement in Ed Discussion for ENAD.

	2023-1	2024-1
Total number of students	69	97
Total views	9.5k	22.2k
Total threads (initial posts)	83	171
Total answers and comments	170	333

Open-ended nature of group project: while some students enjoy doing their own research and coming up with their own solutions, we have noticed during workshops that many students struggle to get started on the project or make significant progress in the early stages of the project. This issue partially arises due to their unfamiliarity with the engineering design cycle, but also from a passive learner attitude or a reliance on explicit instructions, as provided in most previous subjects. Consequently, some students have suggested that further instructions should be provided for the project, even when the goals, objectives and expectations are clearly stated. This challenge highlights the need to clearly embed engineering design processes and systems engineering approaches prior to the introduction of open-ended projects. It also points out to limited opportunities for systematic and complex engineering problem solving in previous subjects.

Team membership and leadership: despite our efforts to include a peer review cycle in Week 12 and the introduction of a team practices and protocols activity, multiple teams still experienced issues with workload distributions, particularly when highly motivated students are paired with students who are satisfied with baseline performance. For future semesters, we are introducing a requirement for completion and marking of group practices and protocols (since multiple groups did not decide on norms and processes for the team to collaborate and operate effectively). In addition, peer-feedback and self-reflection will be included with the preliminary report to provide additional feedback that is detailed, corrective and forward-looking, rather than just evaluative.

Balancing large contact hours: although typical for core subjects in electrical engineering that require significant new content to be rigorously discussed and both theoretical and practical skills to be developed, the contact hours for ENAD are arguably quite high (60-72 hours). As a result, this has created the constraint that the collaborative workshops are optional. Therefore, new weekly distributions may be of interest, particularly: (1) 2x1-hour lectures, 1x2-hour workshops (labs) and 1x2-hour collaborative workshops; or (2) 3x1-hour lectures, 1x2-hour workshops (labs) and 1x1-hour collaborative workshops. We believe the first option would provide a great opportunity for students to solidify their knowledge and engage with other students in the subject; however, the second option could potentially default the collaborative workshops to more traditional tutorials.

Flipped classes: an interesting debate is shifting toward a flipped learning style. Here, two main concerns arise: (1) in engineering subjects, this has typically resulted in very low attendance levels; (2) there has also been further concerns around reduced face-to-face (on-campus) hours, but increased total commitment hours, generating conflicts with other subject coordinators. Our current approach is to run most lectures in a traditional style, but the four tutorial lectures in a flipped style, which provides some variation in activities within the lectures to motivate student engagement. However, it is also noteworthy that lectures are usually attended by ~20-40% of students. An additional ~30-40% of students watch the lecture recordings, which means over 30% of students do not engage with the lectures in any format throughout the semester. Arguably, the only method to reach these students is through official announcements. As an alternative, in-class active learning strategies such as “think-pair-share”, “muddiest point”, “thinking hats”, minute papers and online surveys or games (e.g., “Poll Everywhere” or “Kahoot!”) may be incorporated to motivate students to attend class and engage with the lecture content.

Summary and Conclusions

This paper provides a reflective essay motivated by ten initial challenges identified through teaching a content-heavy core electrical engineering subject over four semesters. Using a SoTL-based approach, we discuss the proposed interventions implemented in this subject, identify the current challenges, and propose various other strategies for future consideration.

As described throughout the paper, although some remnants of a traditional “lectures-and-exams” subject are still present, the current subject design demonstrates a unit that is constantly evolving and a commitment to strong curriculum that further engages students and enables the development of the professional skills listed in the Section “Subject Overview”. Overall, the curriculum design for ENAD has been informed by a holistic and student-centred approach that considers the engineering education literature (e.g., constructive alignment and adult learning theory), student feedback, staff feedback (peer review cycles), multiple teaching observations within The University of Melbourne, self-reflection, and our experiences across different subjects and universities.

Since introducing the new practices discussed in this paper, we have seen a mostly consistent increase in our ESS scores, with our mean overall learning experience score improving from 4.09 (out of 5) in 2021 Semester 2 to 4.69 in 2023 Semester 2, which has placed our subject within the top 20% of results across the School of Electrical, Mechanical and Infrastructure Engineering for three consecutive semesters. We have also noticed improved student engagement, both in-class and online (e.g., via "Ed Discussion" and "Poll Everywhere"), and improved student performance, even when provided with more challenging assessments.

In summary, through iterative improvements and reflective practice, ENAD has evolved into a more engaging and effective learning environment. While the interventions showed positive outcomes, challenges such as workload distribution in team projects and engagement with lectures and formative assessments persisted. We hope this paper will motivate academics involved in similar subjects to consider the interventions, opportunities and challenges discussed here in their own teaching contexts. Future work will focus on exploring the integration of more authentic assessment methods and leveraging technology to further enhance student learning experiences.

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