UNITED BY DESIGN: MODULAR AND FLEXIBLE LEARNING FOR UNDERGRADUATE ENGINEERING PROFESSIONAL PRACTICE

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ABSTRACT

Professional practice coursework is a cornerstone of engineering education, particularly where access to industry placements is limited. The Faculty of Engineering has consolidated its final-year discipline-specific professional practice units into a unified framework supported by a suite of online, self-paced modules. These modules, which cover topics such as ethics, sustainability, and project management, are aligned with the CDIO (Conceive–Design–Implement–Operate) framework to provide consistent, scalable learning across engineering disciplines. The modules include a mix of readings, case-based tasks, videos, and auto-graded quizzes to engage students and support active learning. This case study explores the design and initial evaluation of these modules from an educational designer's perspective, specifically examining how CDIO principles were applied to structure the learning experience. Early engagement analytics revealed discrepancies between the intended and actual use of the modules. Analysis of student behaviour indicated early access to content with minimal re-engagement, a limited uptake of optional materials, and quiz attempts that were often disconnected from the broader learning experience. These findings suggest that while the design aimed to encourage active participation, sustained engagement with the material was less evident than anticipated. This paper discusses the implications of these findings for online module design, particularly in the context of professional practice education. The study highlights the need for further investigation into how learning analytics can inform design iterations, ensuring that CDIO principles are fully realised in digital learning environments. By focusing on behavioural data and design alignment, this study contributes to a broader understanding of the challenges and opportunities in creating engaging and effective online learning experiences for large, diverse student cohorts.

KEYWORDS

Professional practice, Engineering education, Online learning modules, Learner analytics, Standards: 1-5, 7.

INTRODUCTION

Practical professional experience is an integral part of accredited professional engineering degree programs in Australia, offering students hands-on, immersive learning in their field. Despite the persistent high demand for professional engineers in Australia (Bell & Briggs, 2022; Kaspura, 2019; Australian Parliament Senate Education, 2012), students have struggled to secure industry placements and internships (Sher & Sherratt, 2010). Therefore, coursework exposure to engineering professional practice is still an integral part of engineering programs. To address this challenge and enhance the student experience, Monash University's Faculty of Engineering has streamlined its Professional Practice offerings within undergraduate programs, making it more consistent, flexible, and accessible for students to gain exposure to industry professional practice topics. A key feature of this new approach is a common set of self-paced online modules that all engineering students complete, designed to help them connect with their future profession.

Unified Professional Practice Offerings

Engineering students can now choose from a range of new Professional Practice units (see Table 1) pursue industry experience pathways that suit their preferred mode of engagement. This expanded framework enables students to align their industry experience more effectively with their interests and career aspirations. There is a tailored option for students whether they prefer working in student teams, engaging in work-integrated learning, or participating in the Co-op program. The units listed in Table 1 replace the previously segregated and department-managed Professional Practice units, providing students with consistent experiences regardless of their engineering specialisation. Table 2 provides further information about the purpose of the units, in the form of the shared learning objectives.

Table 1: Professional Practice offerings at Monash University Engineering

Professional Practice (PP) stream	Description
Curriculum embedded (abbreviated as PP(CE))	A classroom-taught unit where theory meets real-world challenges, acting as the crucial bridge between engineering studies and industry.
Student teams (abbreviated as PP(TEAMS))	Student learning is hands-on with authentic, real-world projects and challenges, working in diverse, multi-disciplinary teams. This is offered exclusively to current members of Engineering and Information Technology (IT) student teams. These members can be undertaking any degree at Monash.
Work integrated learning (abbreviated as PP(WIL))	Students are immersed in real-world scenarios through an unpaid internship, applying their knowledge to actual industry challenges in a professional setting.
Co-operative education (abbreviated as PP(COOP))	Students are immersed in real-world scenarios through a paid internship, applying their knowledge to actual industry challenges in a professional setting.

While the nature of the industry experience associated with each of the Professional Practice units is different, all students from all specialisations will be engaging with a newly developed set of online self-paced modules, including one discipline/specialisation specific module. The suite of self-study online modules are a key focus in this paper, and support the completion of the Unit Learning Objectives for the Professional Practice units (shown in Table 2).

These Professional Practice units focus on essential skills, including problem-solving, ethical decision-making, teamwork, and communication, aligning with CDIO standards framework and accreditation standards from bodies such as Engineers Australia (Engineers Australia, 2019) and the Engineering Accreditation Council Malaysia (Registration of Engineers Act 1967 [Revised 2015], s. 10, 2015). Integrating the United Nations Sustainable Development Goals (United Nations, 2016, 2017), these units emphasise sustainable, socially responsible engineering practices. By the end, students are expected to understand their professional responsibilities and be ready to lead and innovate for positive societal and environmental impact.

Table 2: Most recent published learning outcomes for PP(CE), PP(TEAMS), PP(WIL), and PP(COOP). Accessed 26 Nov 2024 (Monash University 2024a, 2024b, 2024c, 2024d). These have been mapped to the corresponding online self-paced modules.

Learning Outcomes **(related CDIO Standards # in brackets)**	Related module
1. Critically evaluate the roles and obligations of engineers in society and assess the health, safety, legal and cultural impacts of engineering work.**(#1)**	[SOC, LAW, RISK]
2. Integrate human, social, environmental and economic sustainability, proposing innovative solutions for sustainable development in engineering projects.**(#1)**	[SOC, SUST, FIN]
3. Reflect upon ethical issues with depth, developing a framework for ethical decision-making that reflects the profession's values and Engineers Australia and the Board of Engineers Malaysia's Code of Ethics in engineering practice.**(#2)**	[ETH, LAW]
4.Demonstrate advanced collaborative skills, leading and participating in teams effectively to deliver high-quality outcomes while fostering a culture of inclusivity and mutual respect.**(#1, #4)**	
5.Communicate complex engineering concepts and solutions effectively, employing a range of modalities to engage diverse audiences and facilitate informed decision-making in technical and lay contexts.**(#4)**	
6. Plan projects strategically, using established project and financial management methods to deliver project plans that meet quality, budget and time requirements.**(#3, #5, #7)**	[PJMT, FIN]
7. Demonstrate a commitment to lifelong learning, proactively seeking out emerging knowledge and skills to remain at the forefront of engineering innovation and professional development.**(#8)**	[all modules]
8. Demonstrate professional skills specific to the discipline, employing modern tools and evidence-based approaches to address and resolve pressing engineering challenges.**(#3, #7)**	[AERO, BMED, CHEM, CIV, ESCE, ENV, MSE, MECH]

Members of the educational design team were partnered with subject matter experts in developing a set of online professional practice modules embedded into four Professional Practice units. These modules cover seven core topics: Engineers & Society (SOC), Project Management (PJMT), Finance & Economics (FIN), Risk Management (RISK), Sustainability (SUST), Ethics (ETH), and Engineers & the Law (LAW). Students also complete a discipline-specific module for their engineering specialisation: Aerospace (AERO), Biomedical (BMED), Chemical (CHEM), Civil (CIV), Electrical & Computer Systems (ECSE), Environmental (ENV), Materials (MSE), and Mechanical & Mechatronics (MECH). Each module includes online quizzes that can be attempted twice, with baseline feedback such as correct/incorrect indicators and a numerical grade to inform students prior to their second attempt. More detailed feedback is released at the close of the quizzes in Week 10, enabling flexibility in meeting deadlines. Each module assessment has a total weighting of 3%.

CDIO & LEARNING DESIGN: EDUCATIONAL DESIGNER'S PERSPECTIVE

These online self-paced modules were set up in Moodle and included readings, real-world case studies and scenarios, video lectures, and interactive tools (e.g., H5P and GeoGebra). The design, guided by the CDIO principles outlined in Table 3, intended to create a robust curriculum that prepares students for the challenges of modern engineering.

Table 3: Design principles aligned with CDIO Standards for enhancing learner engagement in online self-paced modules

Design principles		**Implementation (CDIO Standards # in brackets)**
Learner-centeredness	Scaffold content to learner's needs and goals, facilitating a foundation for deep engagement	Offer core content and optional enrichment learning activities within modules to address the diverse needs of learners (Sanchez-Gordon & Luján-Mora, 2020). Foundational knowledge on the key professional practice skills provided to support students in their placements or course work (Crosthwaite, 2021). **[#2: Learning Outcomes; #3: Integrated Curriculum]**
Engagement through interactivity	Include interactive elements, such as applets, quizzes, and forums, to foster engagement	Embed quizzes and formative applets for immediate reinforcement of learning and opportunities for active learning (Hernández-de-Menéndez et al, 2019) and prompted reflections. Shared forums for all Professional Practice units for interaction with peers and teaching staff (Rivera et al, 2024). **[#8: Active Learning]**
Inclusive learning environment and learner autonomy	Cultivate a learning environment that supports diverse learners	Provide module materials in various formats and ensure accessibility (Rao, 2021). Students can access content and assessment online and on-demand. Multiple attempts at the quizzes enabled students to learn from mistakes. **[#5: Design-Implement Experiences; #7: Integrated Learning Experiences]**
Outcome oriented assessment	Develop assessments that align with the learning objectives	Provide clear descriptions of assessments that demonstrate the alignment of the task to the learning objectives. (Biggs, 2003) [#11: Learning Assessment]
Authentic learning	Contextualise theory with practical examples, scaffolding the application of concepts to integrated, real-world scenarios	Incorporate real-world case studies to connect theoretical concepts with practical application. (Roach et al, 2018) **[#4: Introduction to Engineering; #8: Active Learning]**
Feedback mechanisms for continual improvement	Seek input from user/target audience for improvements	Launch a dedicated anonymous feedback system available at the end of every module. Other feedback tools, e.g. early semester feedback, student evaluation of teaching and units (SETU) provide further opportunities for anonymous feedback (Nair et al 2012) **[#12 - Program Evaluation]**

The design incorporates features that empower students by prioritising autonomy, learner-centered approaches, and interactive elements, ensuring a tailored experience that meets diverse needs. It had been set up to foster real-world connections through authentic learning, encouraging critical thinking and problem-solving. Assessments were developed to be strategically focused on measurable outcomes and directly tied to engineering goals, while on-demand feedback drives ongoing progress and growth.

CDIO Connection

CDIO principles extend beyond the domain of engineering design, and can impactfully influence educational design. Each phase (Conceive, Design, Implement, Operate) contributes to the development of effective and engaging learning modules.

Engagement Goals Versus Reality

When initially designing the online self-paced, auto-graded modules, the intention was to foster meaningful, sustained engagement through strategies that emphasised active learning, interactivity, and relevance to real-world industry practices. The following strategies were incorporated:

1. **Active Learning**: To keep students actively engaged, interactive elements such as quizzes, applets, and shared forums were integrated into the modules. The goal was to allow students to apply what they learned in real-time, reinforcing learning while offering opportunities for peer interaction and social constructivism.
2. **Auto-graded Tasks**: To provide immediate feedback and foster a sense of progress, all attempted tasks were auto-graded. This was particularly important in a self-paced online learning environment where students can sometimes feel disconnected from their learning community.
3. **Industry Relevance**: Case studies, practical examples, and real-world scenarios were included to make the learning experience relevant and connected to the field of study. This would help students see the applicability of their learning beyond theoretical knowledge and strengthen their connection to their chosen engineering specialisation.

An analysis of learner engagement data for the suite of online modules revealed that students' engagement behaviour differed from initial expectations.

LEARNER ANALYTICS AND UNSUPERVISED MACHINE LEARNING (CLUSTERING)

This study leverages Learner Management System activity data logs to explore how learners interact with each module element, the timing and intensity of their engagement, and their progression through each of the modules. Feedback surveys did not have sufficient responses to draw conclusions. Hence for now, we will focus on a quantitative analysis of the learner engagement.

The joint grid visualisation presents a structured way to explore relationships between two numerical variables while also providing insights into their individual distributions. In this case, the main grid consists of a set of bivariate scatter plots, showing the relationship between two metrics:

- **Horizontal axis**: The number of visits to each page in the module.
- **Vertical axis**: The number of visits per day throughout the semester.

Marginal plots that display the univariate distributions of these variables are also shown:

- The **bottom marginal plot** shows the distribution of page visits per module.
- The **right marginal plot** shows the distribution of module suite visits per day, which is also **colour-coded by Professional Practice unit**, allowing for visual differentiation between units.

The common module pages are ordered sequentially from left to right and labelled as: Engineers & Society (SOC), Project Management (PJMT), Finance & Economics (FIN), Risk Management (RISK), Sustainability (SUST), Ethics (ETH), and Engineers & the Law (LAW).

Similarly, the discipline-specific modules are labelled Aerospace (AERO), Biomedical (BMED), Chemical (CHEM), Civil (CIV), Electrical & Computer Systems (ECSE), Environmental (ENV), Materials (MSE), and Mechanical & Mechatronics (MECH).

This visualisation facilitates the tracking of engagement trends, such as whether higher page visits within a module correspond to increased overall activity across the module suite or whether certain Professional Practice units exhibit distinct patterns of engagement over time.

Furthermore, leveraging unsupervised machine learning methods allows for the identification of broad patterns in learner behaviour. These methods can cluster students into distinct engagement groups based on their activity profiles, revealing trends such as consistent versus sporadic engagement or preferences for particular types of content.

A broad comparison of learner trajectories through the self-paced online Professional Practice modules and learning activities can be made using clustering. The analysis used the timestamps for each interaction recorded to reflect the sequential order of learner progression through different online learning module items. The timestamps for each interaction sequence were adjusted so that the first interaction with the module was treated as the starting point, with subsequent interactions measured relative to this time. These sequences were categorised by type of module items (lesson, H5P, quiz) and organised in a table, with each row representing a learner's progression through a single module, and columns containing timestamp sequences (in nanoseconds) related to different module item types.

Since interactions by module item type were considered together in the analysis, and noting that differences in levels of recorded engagement could unfairly favour particular item types, a normalisation treatment was applied to the columns. The normalisation process calibrates all values to fall within a consistent range (typically between 0 and 1).

Each student's timestamp sequences for engaging with module items can vary greatly in length, and potentially can be quite long. For the purposes of visualisation, a dimension reduction operation called principal component analysis (Kherif & Latypova, 2020) was used to optimise the handling of the timestamp sequences. Principal component analysis (PCA) produces a consolidated representation of the timestamp sequences which enables the flexibility to project each student's record of engagement with module learning items into the two-dimensional space (via the helper principal components). By using the principal components, we can plot each student's interaction with a module as a single data point, and observe relationships to other students.

Key Findings (From Joint Grid Visualisation)

Common modules:

- Data indicates that the opening pages of each topic in most modules receive high traffic, especially early in the semester, aligning with the detected peaks. Engagement activity (show by the shading of the cells in the grid) seems to consistently decline rapidly after the opening set of pages.
- The modules vary in length, and this appears to be a factor in overall student module engagement depth. The common modules that are mapped to later in the semester timeline (Ethics and Engineers & the Law), are also longer and more content intensive.

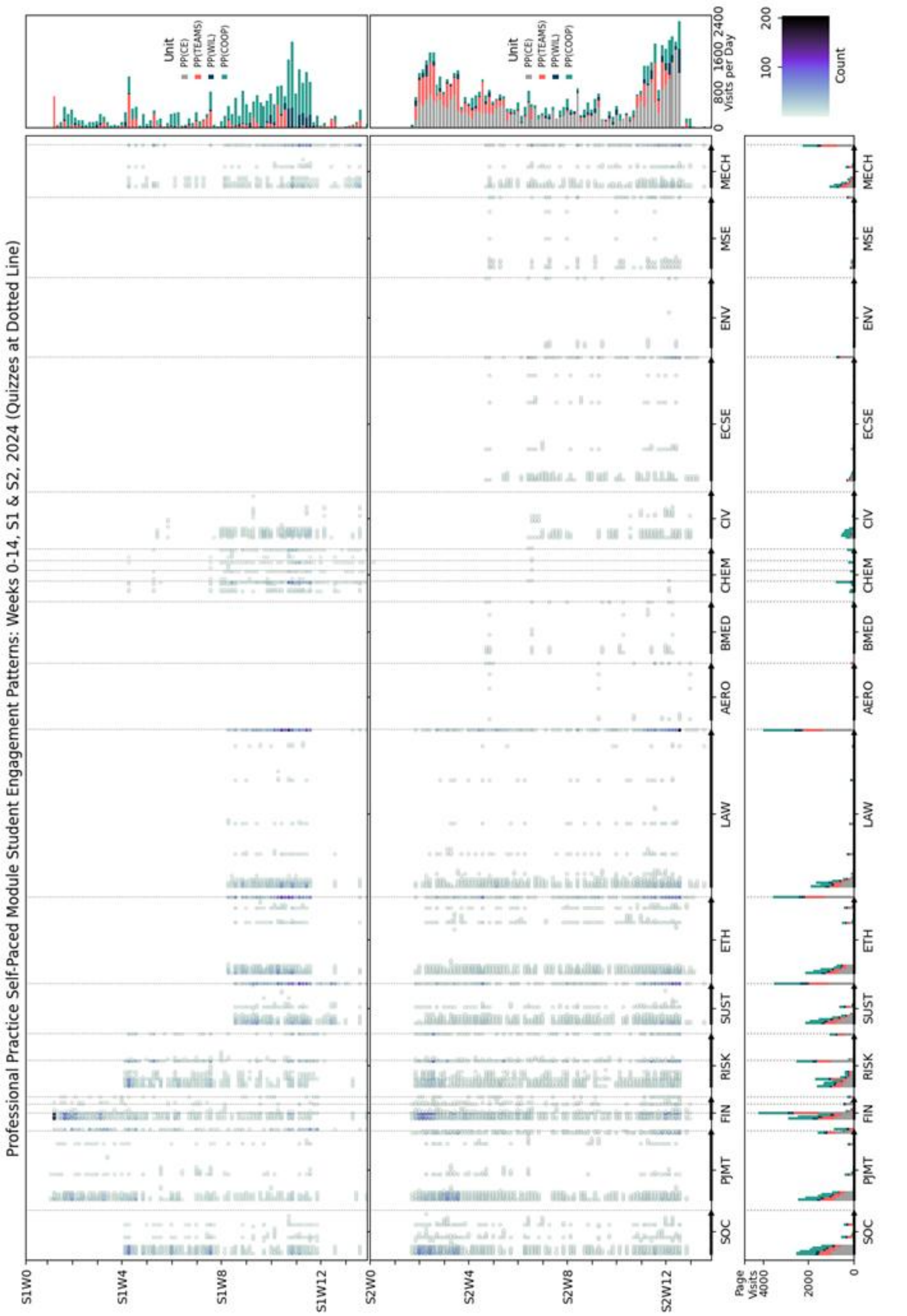

Figure 1: Joint grid visualization showing the trends between module page visits (x-axis) and visits per day (y-axis) with scatter plots. Marginal plots display univariate distributions: page visits per module (bottom) and daily visits (right), colour-coded by PP unit.

- This structure may contribute to a more noticeable decline in engagement as the semester progresses.
- Quizzes are attempted even if the content in the modules have not been viewed, especially at the end of the semester.
- Staggered release of the modules (as seen in S1) appears to have prompted more students to engage with the modules throughout the semester. This contrasts with S2, where all the common modules were available from the start of the semester.

Discipline-specific modules:
- Note: In S1, only Chemical, CIvil and Mechanical & Mechatronics modules were available.
  Generally these modules have been released later in the semester than the common set of modules, and they have lower engagement. Mechanical & Mechatronics has noticeably higher activity than the others.

Cohort differences
- All cohorts demonstrate heightened levels of engagement at the beginning and end of the semesters.
- Co-operative education professional practice, PP(COOP), demonstrates strong and consistent engagement with the suite of modules in S1.
- The curriculum-embedded professional practice, PP(CE), which only started in S2 appears to have a cohort that engaged with the modules most consistently throughout the semester.

Key Findings (From Clustering)

Shared diverse student engagement trajectories

An initial visual inspection of the engagement trajectories for the 2024 cohort of Professional Practice students, as shown in the figure, highlights similarities in broad patterns. The overall spread and shape of the data points suggest general consistency, regardless of whether students submitted the summative quizzes for each module. Engagement patterns are consistent among students who failed (F), achieved passing grades (P of high pass, HP) or did not submit quizzes (X). Most students who completed the online module quizzes passed the assessment. However, distinct differences in learner behaviour are evident between unit cohorts. Notably, while students from non-quiz-submitting cohorts show generally similar engagement patterns, the PP(COOP) cohort exhibits unique characteristics. The streak-like structure of the data indicates that engagement trajectories are diverse yet follow similar underlying patterns.

LESSONS LEARNED & CONTINUAL IMPROVEMENT

In conclusion, adopting a structured, iterative CDIO approach has proven essential for evolving instructional design in response to real student experiences and engagement patterns. By consistently reassessing student motivations during the **Conceive** phase, educators are given the opportunity to reflect on whether the learning modules remain relevant and meaningful. Gathering direct feedback from students and subject matter experts is expected to provide actionable insights that inform necessary design improvements, ensuring the learning experience aligns with the needs and expectations of the students.

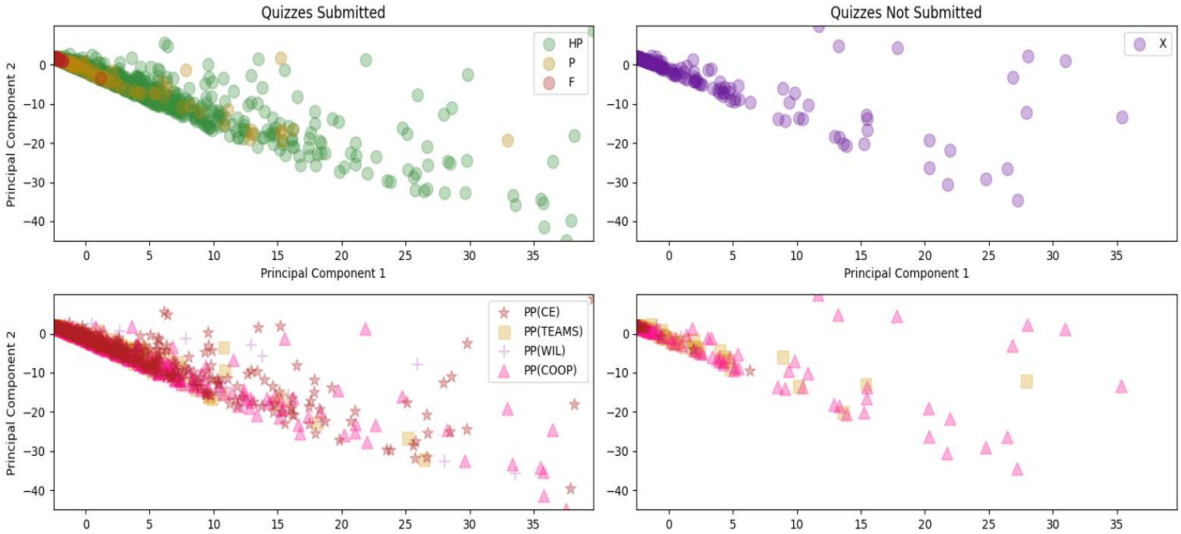

Figure 2: Principal Component Analysis (PCA) was applied to timestamp sequences of student engagement with module items. Each point represents a student's interaction with a module, revealing patterns about assessment submission (Quizzes submitted VS Quizzes not submitted columns) and relationships across the cohort vs whole of the Professional Practice cohort in subplot rows.

The **Design** phase has highlighted that even small refinements, such as experimenting with the progressive reveal of content, can positively influence student engagement behaviour. Additionally, structuring longer modules with intermittent quizzes, rather than relying on a single final assessment, helps maintain cognitive engagement and minimizes learner fatigue. This approach reinforces the importance of pacing and regular interaction in supporting sustained learning.

In the **Implement** phase, the inclusion of professional practice engagement features, such as peer discussions, has shown promise in promoting deeper learning and collaboration. These elements support students in connecting with the practical relevance of their learning and help cultivate a sense of community in self-paced environments. While these features have been beneficial, the impact could be further improved with more regular facilitator engagement and prompting, ensuring continuous interaction and encouragement for students to actively participate. This could further enhance both student engagement and understanding, particularly in independent learning settings.

Finally, the **Operate** phase ensures that the design process remains dynamic and responsive. By leveraging analytics to continuously evaluate the impact of changes on student engagement, instructional designers can refine and optimise the learning experience over time. This ongoing cycle of data-driven decision-making supports the continual enhancement of the course, ensuring that improvements are sustainable and aligned with student needs while working within existing constraints.

The iterative nature of this CDIO approach affirms the importance of being responsive to student feedback and engagement data, allowing for continual improvements that can enhance both learner outcomes and engagement in online self-paced, auto-graded modules. Ultimately, this reflective and adaptive process offers a robust framework for instructional design that drives long-term success and learner satisfaction.

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AI Usage Declaration

During the final editing phase, generative AI (ChatGPT) was employed to provide feedback on the tone, clarity, and overall flow of the writing. The author carefully reviewed the AI-generated suggestions, making adjustments to improve readability and coherence where appropriate. However, no text directly generated by the AI was substituted for the author's original content.

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