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Creating Authentic Learning Experiences: A Case Study on Implementing Hands-on Activities and Project-based Learning Approach in Mechanical Design Courses

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ABSTRACT

CONTEXT

Project-based learning (PBL) has been widely recognised as an effective instructional approach in developing students' problem-solving, critical thinking, and communication skills. These skills are essential attributes for professional engineers. However, the implementation of PBL in engineering education often faces challenges in providing authentic learning experiences that simulate real-world engineering practices.

PURPOSE OR GOAL

UNSW offers a range of excellent facilities to engineering students, including teaching labs, makerspaces, and workshops operated by qualified technicians. However, it is surprising to see that most students lack practical skills. A lot of emphasis is put towards the theory and the design phase in a project, but, due to a lack of time and resources, the building and testing phases are often overlooked. The purpose of this case study is to investigate the impact of implementing hands-on activities within the PBL framework on students' learning experiences. Specifically, this study aims to answer the research question: How can hands-on activities enhance the authenticity of PBL, and what are the effects on students' learning experience?

APPROACH

This study was conducted in a 3rd and 4th year undergraduate mechanical design courses with cohorts of around 250 students in the Faculty of Engineering at UNSW. Both courses adopted the PBL approach with a 10-week-long project where students are required to work in teams to design, build and test a prototype following specific technical requirements and constraints. Qualitative and quantitative data was collected through student surveys at the end of the term.

OUTCOMES

PBL with hands-on activities has been successfully implemented since 2021 by providing students with opportunities to apply theoretical engineering concepts in a real-world context. The building and testing phases of the prototype promoted students' collaboration, communication, and problem-solving skills. Students reported higher levels of motivation and engagement in the project and are feeling more prepared to work in the industry as engineers.

CONCLUSIONS

This study highlights the importance of creating authentic learning experiences in engineering education to prepare students to solve real-world engineering problems. The findings suggest that engineering students appreciate hands-on activities. Thus, even though this approach can be challenging to implement, especially for very large cohorts, this does enhance the authenticity of engineering education and promote students' learning outcomes.

KEYWORDS

Authentic Learning, Hands-on experience, Practical Education, Project-based Learning

Introduction

Enhancing the learning experience for students is a continuous endeavour in engineering education. The integration of hands-on activities with project-based learning (PBL) has been widely recognised as being a highly effective approach to create authentic learning experiences. In traditional courses, students can have issues bridging the gap between theory and practice, leading to a lack of understanding of the course's relevance. Creating authentic learning and assessment is about asking students to do something they want to or need to do in the real world. Motivation and relevance are keys. By incorporating authentic learning and assessment tasks that align with real-world challenges, students are motivated and engaged in the learning process. These recommendations align with the guidelines set forth by the Tertiary Education Quality and Standards Agency (TEQSA) for delivering high-quality engineering education and exposure to professional practice.

This study evaluates the impact of authentic learning on students' satisfaction and overall learning outcomes in two Mechanical Design courses at UNSW, offered in the 3rd and 4th years. Both courses were designed using the principles of constructive alignment, ensuring a strong connection between learning outcomes, teaching activities, and assessment methods. The assessment structure has been carefully developed to replicate the milestones encountered in the industry during a product design project encompassing design, prototyping, and testing phases. However, implementing this approach in large and diverse classes presents its own challenges. Through this study, we will identify and address these challenges, providing recommendations for effective implementation. The data collected through student surveys will provide both qualitative and quantitative evidence of the impact of this approach.

It is expected that by developing this active student-centred approach, students will be more engaged in their learning and motivated due to the practical and industrial relevance of the project, leading to a deep learning approach. PBL with hands-on activities can effectively prepare engineering students for real-world challenges, fostering their problem-solving abilities and critical thinking skills and promoting teamwork.

Background

PBL (Project-Based Learning) has become widely implemented in various disciplines, particularly in engineering, as an educational approach that utilises real-world problems to stimulate learning. PBL aligns with constructivist approaches to learning, emphasising the construction of knowledge based on prior experiences (Carlile and Jordan, 2005). Unlike traditional problem-solving approaches, PBL places the problem before the learning process, prompting students to engage in self-directed study and discussions to apply their acquired knowledge and understanding. This active learning method shifts the focus from teacher-centred instruction to student-centred exploration (Felder and Brent, 2005).

Collaborative teamwork is an essential component of PBL, allowing students not only to acquire knowledge but also to develop valuable transversal skills such as teamwork, self-learning, creative thinking, autonomy, and communication (Woods and Learning, 2000). By working together, students gain a deeper understanding of the subject matter while honing skills that are highly sought after in the industry, as well as fostering meaningful connections. In this context, teachers play the role of facilitators, encouraging independent learning and guiding students in how to think rather than what to think. When students engage in a process-led activity, facilitators must clearly define learning objectives and strategies (Biggs, 1999). By immersing students in authentic learning experiences, PBL equips them with not only technical expertise but also the practical skills necessary for success in their future careers.

Authenticity as a mechanism to drive deeper learning outcomes is well established. Authentic learning (AL) had its genesis in 'situated cognition". This posits that knowledge is structured by context and progressively developed by use (Brown et al., 1989). Numerous studies have explored how to provide authenticity within the classroom (Savery and Duffy, 1995; Barab et al., 2000; Roach et al., 2018), with the conclusion being that suitable realism must be provided throughout task design to ensure adequate learner “buy in” (Herrington et al., 2003).

It is argued that transferable skills, such as problem-solving skills, communication skills and team working skills required by engineering graduates are not effectively assessed by traditional assessment practices (Burtner, 2000). On the contrary, authentic assessments evaluate engineering students’ mastery of professional skills. However, it may be complex to design such assessment tasks (Palmer, 2004). Besides the assessment, feedback is also critical to encourage students to become more self-regulated (Nicol and Marfalane-Dick 2006). By reflecting on their performances and identifying their strengths and weaknesses, students achieve better output and are more engaged with the feedback they receive (Selwyn and Renaud-Assemat, 2020).

Studies (Freeman et al., 2014) support that active learning, including hands-on activities, leads to higher achievement in learning efficiency compared to traditional lecturing. Mirkouei et al. (2016) developed a framework to improve scaffolded active learning in Manufacturing Engineering Education. This framework is composed of 4 pillars: define learning outcomes, create instructional resources, create active learning resources, and create summative assessments. The results of this study show that students perceived the hands-on learning framework as being more useful than traditional written assignments.

Methodology

Authenticity requires students to be able to extrapolate inherent meaning from their learning activities. The methodologies for both MECH3110 and MECH4100 were created to mirror the lived experiences of graduate engineers within the design industry. The focus of our current paper will be on building and delivering authenticity through the hands-on project-based learning assessment. It is worth noting that UNSW operates on a 10-week term; this raises profound challenges in the implementation of hands-on design, build and test assessments. The assessment design priorities underpinning our respective projects were:

a) Project milestones that reflect typical industry project progression.
b) Hands-on prototyping to apply theory into practice.
c) An appropriately weighted summative and transparent testing event that demanded full participation.
d) Gated reviews with penalties to ensure timely completion and satisfactory minimum quality.
e) Collaboration with industry manufacturing partners to achieve:
    i. Enhanced production capabilities (sheet metal laser cutting).
    ii. Engagement with real-world industry players.
    iii. Awareness of real-world lead times and inability to accommodate extensions.

An overview of the project’s hands-on prototyping assessment progression is outlined below.

Start of Term

Students formed groups at the start of term: MECH3110 allowed self-formation, whereas MECH4100 utilised a questionnaire to populate groups. Each course’s design brief was available from Day 1. The MECH3110 project was to design, manufacture and test a replacement gearbox out of steel to complete a task. The MECH4100 project was to design, manufacture and test an alpha-type Stirling engine powered by a tealight candle to complete a task (see images of test rigs in Figure 1.

A breakdown of the assessments in the design projects is shown in Table 1. It is important to note that the project design tasks are of sufficient complexity that groups are not able to “guess” a solution (which is common in first and second-year courses). All design work must be informed and underpinned by the engineering science that is taught in the lectures. Further, groups have no access to test rigs until the end of the term, which reinforces the need to utilise engineering science to produce a design, and it is not possible to use a heuristic approach.

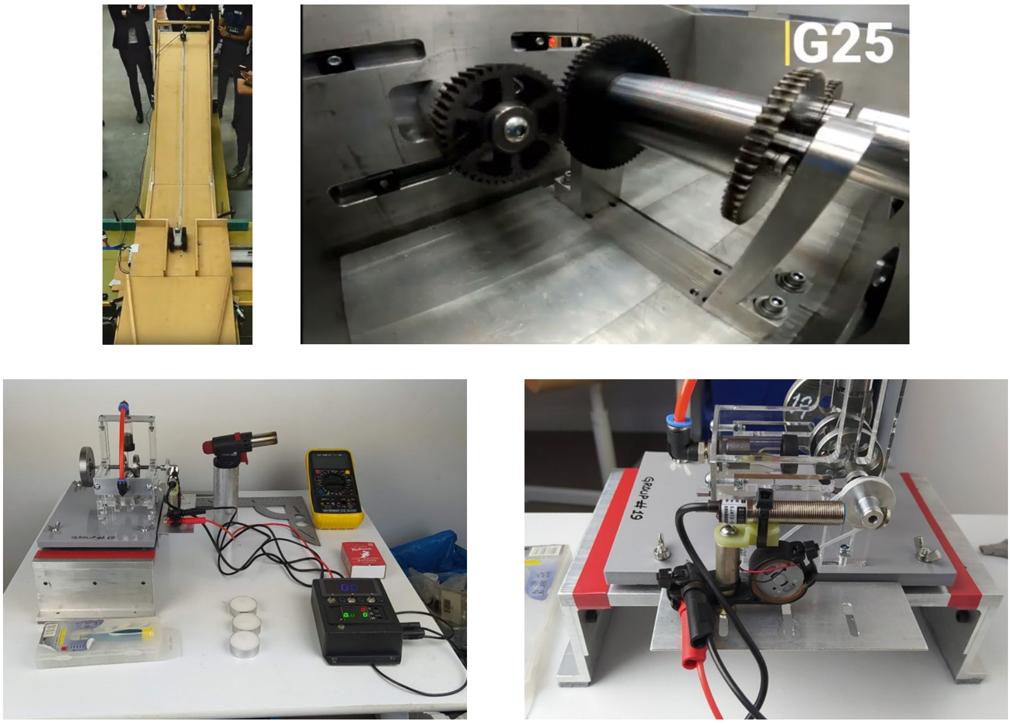


Figure 1: Test rigs of MECH3110 gearbox project (top), and MECH4100 Stirling engine project (bottom).

Table 1: Breakdown of project tasks

MECH3110		MECH4100		
Assessment Name	Weighting	Assessment Name	Weighting	Due Date
Technical Consultations	0%	Preliminary Design Review	10%	Week 3
Manufacturing Documentation	10%			Week 4
Design Report	15%	Critical Design Review + Manufacturing Documentation	40%	Week 5
Assembly Sessions	0%	Assembly Sessions	0%	Week 8
		Final Report + Oral Presentation	15% + 15%	Week 10
Prototype Testing	15%	Prototype Testing	10%	Exam Period

Technical Consultations and Design Review Sessions

Technical consultations and design review sessions offer student teams an opportunity to have their design checked by academics and qualified workshop technicians to ensure functionality and manufacturability. This also serves as a progress check to ensure teams can submit the subsequent project deliverables on time.

Manufacturing Documentation

The manufacturing documentation submitted by students includes Australian standard engineering drawings and industry-compliant laser-cutting DXF files. To ensure the quality is the standard necessary for the industry partner to proceed, a gated review is undertaken by the lead academics as well as the School's technical workshop staff. Teams that fail this review will have their files returned with an invitation to resubmit before a strict resubmission deadline with a small penalty. Approved drawings are collated and passed to industry partners for manufacturing.

Assembly Sessions

Parts are available for collection from industry partners typically within 2-3 weeks. Note, this represents a very compressed lead time for typical industry engagement. Groups were able to book into a supervised assembly session to begin the assembly of their prototype and address any issues that arose from inappropriate design decisions. For substantial errors that necessitated major intervention, an emergency manufacturing penalty was applied to their group's mark. Access to the test rig was allowed for interfacing purposes only, but no duty cycles were allowed to be performed.

Design Report

Unlike traditional assessment practices, the design reports in these courses focus on the justification of their practical design decisions, rather than mathematical accuracy. Students were asked to justify why their design is a conservative fail-safe solution, rather than the one correct solution. To solve these open-ended problems, students must make reasonable assumptions and use critical thinking and analysis.

Prototype Testing Event

Student prototypes were tested during the exam period. Test criteria were discretised across a range of sub-tasks and performance criteria to avoid an "all or nothing" outcome.

Teamwork Evaluation Mechanism

At the conclusion of each deliverable, a teamwork evaluation task was conducted. Students were required to rate the performance of each member across a range of criteria and provide justifying comments. All evaluations were moderated with an opportunity for group members to request a formal review in the event the teamwork evaluation was not perceived to be reflective of their contributions. This quantitative and qualitative peer review allowed for the establishment of a "mark modifier" which was applied to a student's group mark as shown by Eq. (1).

$$\text{Student Individual Mark} = (\text{Group Mark} * \text{Adjustment Fraction}) \times (1 + \text{Mark Modifier}) \quad (1)$$

The "adjustment fraction" was weighted at 50% for both courses.

Results and Discussion

At the end of each teaching term, students were surveyed on their experience in each course with a combination of rating questions and open comment questions. Prior to the implementation of hands-on activities and PBL in these mechanical design courses, students were assessed using hypothetical design tasks with paper-based design reports as the only design deliverable. Students criticised these tasks in the survey stating that "The level of analysis required is high, but expectations are not always clear for students.", and "marking should be based on the practicality of design rather than report writing skills." This indicated a misalignment between the learning outcomes of these mechanical design courses and the assessment structure prior to the implementation of the hands-on activities and PBL in these courses.

In addition, students were requested to assess their overall satisfaction with the course using a six-point scale that included the options of "strongly disagree," "disagree," "moderately disagree," "moderately agree," "agree," and "strongly agree." The overall course satisfaction rate is defined as the percentage of students who responded with "moderately agree," "agree," or "strongly agree" to the statement "Overall, I was satisfied with the quality of the course." As depicted in Figure 2, the implementation of hands-on activities and PBL in 2021 resulted in a significant improvement in the overall course satisfaction rate for both courses, consistently surpassing 90%. The satisfaction rate in MECH4100 in 2021 was lower than expected due to a complete redesign of this course. Additionally, the COVID-19 lockdown during Term 2 2021 prevented students from manufacturing and assembling their prototypes. These tasks were performed by technical staff, and the prototype testing event was recorded without student in-person attendance. Note that MECH3110 was delivered in Term 1, 2021, before the COVID-19 lockdown in Sydney. From 2022, students in both courses had the opportunity to assemble their prototypes in person, and this had a very positive impact on the overall course satisfaction rate.

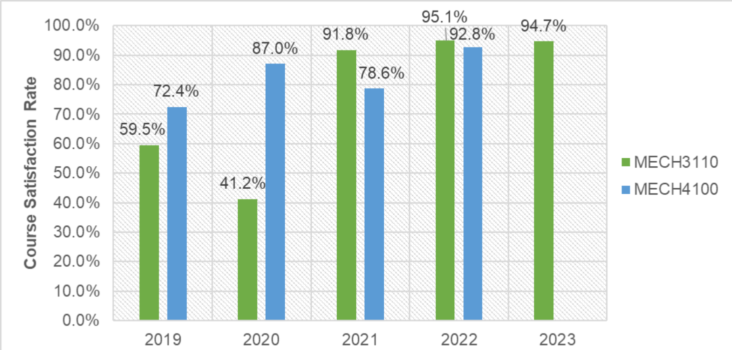
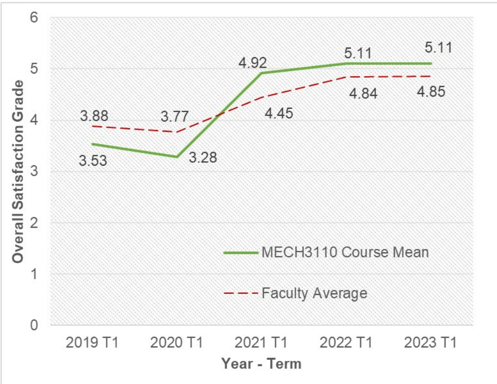


Figure 2: Overall course satisfaction rate in MECH3110 and MECH4100 from 2019 to 2023. Hands-on activities and project-based learning were implemented in 2021.

The overall course satisfaction grade is determined by averaging all ratings to the question "Overall, I was satisfied with the quality of the course.", with "strongly disagree" assigned a value of 1 and "strongly agree" assigned a value of 6. As shown in Figure 3, it is clear that both courses are following an upward trajectory following the introduction of the implementation of hands-on activities and PBL in 2021, surpassing the faculty average.



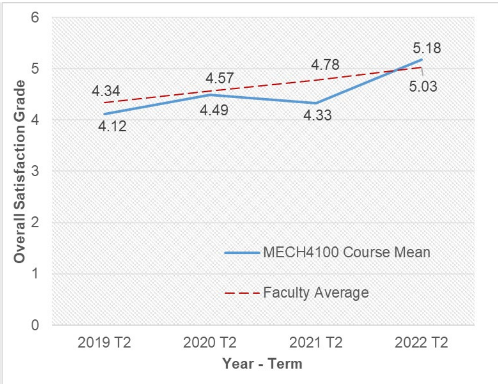


Figure 3: Overall course satisfaction rate in MECH3110 and MECH4110 from 2019 to 2023, plotted with the faculty average. Hands-on activities and project-based learning were implemented in 2021.

A review of the written feedback shows it is evident that the increase in overall course satisfaction is directly attributed to authentic assessments, with 77.3% of positive comments received in MECH4100 and 52.3% of positive comments received in MECH3110 attributed to the authentic assessments in the courses in the recent two years. When asked about the best aspects of these two mechanical design courses, students welcomed the implementation of hands-on activities in a project-based course. 97.3% of students in MECH3110 and 97.6% of students in MECH4100 agreed with the statements "The assessment tasks were relevant to the course content" and "Assignments gave me the opportunity to demonstrate my knowledge". Below is an extract of written student feedback in response to the question, "What were the best things about this course?"

> *"I loved the assignments, they really made us think critically and not look for one good answer but to be able to justify our design choices."*

> *"This course gave a very hands-on approach to learning which I really liked. the content was very applicable to real world applications."*

"The practical aspect, being able to apply theory to practice and actually build and assemble the Stirling Engine was very valuable to my learning. It was also super fun!!"

"The best part about the course is the practical aspects. Being able to fully utilize the knowledge learned over the years and produce an actual working prototype has been amazing."

"I really like that we get a chance to utilise our design skills accumulated over 4 years of engineering in a hands on project that tests all our knowledge. The assessment tasks were all relevant to real world engineering and I actually felt like I was using what I learnt from industry in a course which indicates the course is actually useful for real world engineering practices."

Each of the learning activities for the PBL task provided students with many opportunities to experience authentic learning. Below are some of the key experiences associated with the assessments that students underwent throughout each project.

Manufacturing Documentation

Manufacturing documentation such as engineering drawings are typically assessed summatively in the first year, formatively, if at all, thereafter. As a result, the quality in later years is poor to non-existent. Engineering drawings are critical to the realisation of engineering design in the industry, and poor drawings cost time and money. The marking of the manufacturing documentation in these courses forces a heavy focus on authenticity by highlighting these issues and tying successful component manufacture, and thus prototype production, to the quality of their drawings. Drawings are assessed from two standpoints: the academic(s) review the designs from an engineering standards perspective (AS1100), whereas workshop technical staff review them from a manufacturing viability point of view. It is important to note that an AS1100-compliant drawing may not necessarily be manufacturable. It is the workshop staff perspective that provides unique authenticity. Students are provided feedback in terms of difficulty in converting their design to reality, as well as unintended consequences such as manufacturing time and cost.

Industry Partner Engagement

The decision to work with industry partners to leverage manufacturing capability provides several sources of authenticity. Firstly, outside of the largest engineering companies, it is rare to manufacture components for in-house designs due to cost. Thus, this provides insight into how companies navigate such transactions every day. Secondly, it forces a serious element to "why" the drawing quality must be acceptable as students understand they cannot "negotiate" with an industry partner (as opposed to course staff) as to why their drawing is not fit for purpose. Thirdly, as students must provide drawings well before the parts return for assembly, they must commit with confidence to their designs. This is in direct contrast to projects that allow students the use of readily accessible materials.

Unforgiving Materials

Requiring engineering students to work with metal is another layer of authenticity. Students are often shocked upon arrival at university to find that in engineering design, they are working with plywood, plastic or worse, cardboard, whereas in secondary school, they had been working with sheet metal. Most engineering industries require extensive application of metal in design. Metal manufacturing processes are more demanding, thus necessitating an industry partner/technical workshop for production at scale. The other important source of authenticity involves the commitment to design before progressing. Whilst projects that use wood/plastic can be easily modified/replaced if mistakes are made, this is not the case with metal. Many students had an incredible learning experience where they realised that they had not placed the drill holes correctly in their designs, and as a result, two interfacing components did not line up. Another common issue was specifying hole sizes too big, and suddenly the specified fasteners fell right through.

Confidence in Engineering Science

A key complaint levelled at engineering design courses is the lack of engineering science accountability. Students are often expected to utilise various equations to underpin their designs, but without an appropriate prototyping assessment, students are left to guess whether the equations even mattered. This type of disconnect between engineering science and the final product is corrosive to authenticity. Our projects required students to perform the necessary calculations to achieve/predict a desired outcome. The complexity of the projects was designed in such a manner that it was not possible to employ a trial-and-error approach. Students reported that being required to commit to a design well before parts arrived for manufacture based on their engineering science was very unsettling. However, students also reported feelings of extreme satisfaction and pride when witnessing their prototype being assembled and completing the testing event. Such pressures are truly authentic as these mimic the testing phases of a Verification and Validation phase in engineering programs. In MECH3110, 97.3% of the students agreed with the fact that “the course encouraged me to be self-directed in my learning”, 98.8% in MECH4100. A student in MECH4100 mentioned that they “appreciate the fact that the way the course is designed, you aren’t guided completely along the way, allowing you to call upon and use skills and capabilities learnt from previous courses.”

Conclusion

The findings of this case study provide valuable insights into the benefits and challenges associated with a PBL approach, particularly in creating authentic learning experiences for engineering students. By incorporating real-world design challenges and promoting collaborative teamwork, this approach has demonstrated its potential to bridge the gap between theory and practice in students’ perceptions, fostering problem-solving abilities and critical thinking. Students are encouraged to construct their knowledge based on prior experiences.

Keys to delivering an authentic experience within PBL:

- Careful design of authentic assessment tasks: Assessment tasks must be aligned with the learning outcomes and the teaching activities, but most importantly, they must be authentic. Are the tasks relevant in a real-world context, do they align with industry standards and practices?
- Real-world problem identification: The authenticity of the problem plays a crucial role in maintaining student motivation through the process.
- Fostering collaborative teamwork: It is well known that most students are reluctant to group-work. Encouraging teamwork not only reflects real engineering practices but also develops essential transversal skills such as managing conflicts and communication skills. Group dynamics should be carefully managed to ensure effective collaboration and equal participation through a peer review process.
- Engaging in hands-on activities: Integrating a prototype testing activity in the process clearly enhances the authenticity of the learning experience. This is the accomplishment of the project and the evidence that the initial design was correct or needed some modifications.
- Time management: Implementing hands-on activities requires more time and organisation compared to traditional lectures. Careful course planning, clear timelines between the stakeholders and efficient use of resources are critical to the success of this approach.
- Student motivation and engagement: Maintaining student motivation such that they become independent learners requires constant encouragement. Regular feedback is necessary to improve students’ confidence in tackling open-ended projects.

Overall, the process underpinning the design of PBL activities shows remarkable success in fostering a sense of authenticity for students. The implementation of authentically focused hands-on activities has improved students’ satisfaction and learning experience. Students are more active and engaged to adopt a deep learning approach through the authentic context of the course.

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