Implementation of Project-Oriented Design-Based Learning in a Second-Year Mechanical/Mechatronics Subject

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SESSION Integration of theory and practice in the learning and teaching process.

CONTEXT The School of Engineering at Deakin University has undergone a significant transition towards making design and projects the basis for the undergraduate curriculum rather than the more traditional approach based on lectures, texts, and examinations. A new curriculum, called Project-Oriented Design-Based Learning (PODBL), is now in its second year of implementation. The curriculum allows for approximately one half of the total content in the course to be based on design projects.

PURPOSE This study seeks to study and evaluate the effectiveness of a second-year mechanical unit in the new PODBL curriculum.

APPROACH SEM200, Machine Design, was developed as a new two-credit-point unit in the Bachelor of Engineering, mechanical and mechatronics streams. It runs in the first semester of the second year, and is takes up one half of the total content in the semester (two credit points). The remaining half of semester is shared between a unit on engineering mathematics and another on fluid mechanics (one credit point each). The main project for this unit is centred on the design of a mechanical-based machine that must perform a defined set of tasks with a defined set of criteria. The project aims to reflect a real-world engineering project environment. Students work in teams. The assessment consists of a team project plan, a team presentation of the final product, an interim report, and a final portfolio. The unit is offered both to on-campus students at Geelong and online.

RESULTS The unit been offered twice – in 2016 and again in 2017. The project for both years was to build a robot following the rules and specifications of the Engineers-Australia Warman Design-and-Build Competition. Forty-eight students completed the unit in 2016, and 100 students completed the unit in 2017. The average mark for 2016 was 66/100, and for 2017, the average mark was 67/100. Student reviews of the unit were mostly positive and the teaching team have learned a number of important lessons that will influence further offerings of this and other PODBL units.

CONCLUSIONS SEM200 is the third two-credit-point project-design unit in which mechanical and mechatronics students enrol. The academic performance of the students indicates that the content and assessment is appropriate for second-year students. The student feedback suggests that although the unit involves a great deal of work, students enjoyed both the challenge posed by the unit and the satisfaction of completing a complicated design project in the space of a single semester.

KEYWORDS Project-oriented design-based learning; PODBL; projects; design.

Introduction

A recent trend in engineering education in the past 15 years or so is the shift from an emphasis on the science of engineering to an emphasis on problem solving, projects, and design. This is one of the five major shifts in engineering education recently identified by Jeff Froyd of the IEEE (Froyd, Wankat, & Smith, 2012). Design is now commonly seen in engineering education as a very important component and that which distinguishes engineering from other fields such as applied physics.

The School of Engineering at Deakin University has very recently redesigned its Bachelor of Engineering courses to make design projects a major component of the curriculum. Deakin offers undergraduate courses in civil, electrical/electronics, mechatronics, and mechanical engineering. About 30% of the School's undergraduate students attends the University almost wholly online (Long, Joordens, & Littlefair, 2014). The revised courses use design projects as the focal points of learning. The new curriculum is called Project-Oriented Design-Based Learning, or PODBL (Chandrasekaran, 2013a; Chandrasekaran, 2013b). It developed from significant research into aspects of project-based learning, problem-based learning (Chandrasekaran, 2014; Chandrasekaran, Stojcevski *et al.*, 2012), and the School's long experience in teaching design projects (Chandrasekaran, Long, & Joordens, 2015; Joordens & Jones, 1998).

The PODBL model is a learning and teaching approach that is based on engineering design activities while driven by a project. It has been proposed to use PODBL in Deakin Engineering to encourage independent learning and a deeper approach to learning. It is also an approach that supports the development of information literacy and design thinking in the field of tertiary education - two of the key learning outcomes in engineering these days. There are many versions of project based learning as well as design based learning. Deakin's engineering approach is a unique combination of the two (Joordens, Chandrasekaran *et al.*, 2012). PODBL indicates that students learn through real engineering design activities while driven by a project that has a defined deliverable, and is presented to the students with an industry partner or an academic staff.

The new PODBL curriculum was designed to cater for online students (Maung-Than-Oo, Chandran, & Stojcevski 2014) as well as the more traditional on-campus students (Chandran, Chandrasekaran, & Stojcevski, 2013; Chandrasekaran, Littlefair *et al.*, 2014). Early trials of the PODBL approach in an electrical-engineering unit have been presented elsewhere (Chandran, Chandrasekaran, & Stojcevski, 2014, 2015). The new, full PODBL curriculum was first offered in 2016, and is currently rolled out to the first, second, and third years of the course. Fourth year will be offered from 2018.

The PODBL curriculum specifies that one half of a student's studies will be in the context of a design project. In the previous curriculum, each semester comprised four units of study, or eight each year, for a total of 32 units. Each unit was one credit point (cp), 0.125 EFTSL, apart from the final-year capstone project units, which were two cp each (0.25 EFTSL). In the PODBL curriculum, each semester has one two-credit-point design/project unit, and two one-credit-point support units covering core engineering concepts. For example, table 1 shows the course structure for the Bachelor of Mechanical Engineering. In a typical two-cp PODBL unit, the unit content is emphasised in the first half of the 11-week semester, and most of the lecture material is delivered then. In the second half of semester, the class-time shifts towards design-studio and project work. Students are normally put into teams. Most units follow the University's Cloud-Learning model (see for example, Long, 2015), where most lecture material is delivered by means of videos posted to the unit website, and class time is focussed on studios, seminars, and active learning.

Our previous AAEE presentation described the development of the first-year unit Engineering Fundamentals, one of the one-credit-point support units (J. M. Long, Chandrasekaran, & Orwa, 2016). In this paper, we present the first results from a fully-integrated, two-cp PODBL design unit: SEM200, Machine Design. We report on the design and delivery of this unit to mechanical and mechatronics students in 2016 and 2017, both on-campus and online. We present the unit's intended learning outcomes, the structure and delivery of the unit, the students' academic performance, their satisfaction with the unit, and the lessons we learned in this exercise.

Table 1: PODBL Course structure for BE Mechanical.

First year			
Sem-1	SEJ101 Design Fundamentals (2 cp PODBL)	SEB101 Engineering Fundamentals	SIT199 Applied Algebra and Statistics
Sem-2	SEJ103 Materials Engineering Project (2 cp PODBL)	SIT194 Introduction to Mathematical Modelling	SIT172 Programming for Engineers
Second year			
Sem-1	SEM200 Machine Design (2 cp PODBL)	SEP291 Engineering Modelling	SEM218 Fluid Mechanics
Sem-2	SEM201 Structural Design (2 cp PODBL)	SEM216 Stress and Failure Analysis	SEM202 Thermodynamics
Third year			
Sem-1	SEM300 Thermo-Fluid System Design (2 cp PODBL)	SED304 Product Development	SEM313 Manufacturing
Sem-2	SEM301 Industrial Control (2 cp PODBL)	SEM302 Advanced Stress Analysis	SEM327 Dynamics of Machines
Fourth year			
Sem-1	SEJ441 Capstone Project 1 (2 cp)	SEM400 Computational Fluid Dynamics	Engineering elective
Sem-2	SEJ446 Capstone Project (2 cp)	SEM406 Advanced Modelling and Simulation	Engineering elective

SEM200 Machine Design

SEM200 is a project-and-design-based unit that allows students to develop technical and professional practice skills relevant to machine design. The unit runs in the first semester of the students' second year. Students build on fundamental knowledge previously acquired in engineering design, engineering fundamentals, project management and professional communication. The main project for this unit is centred on the design of a mechanical-based machine that performs a defined set of tasks with a defined set of criteria/rules. SEM200 has six learning outcomes. Students who complete and pass the unit can:

1. Develop, implement and complete a project management strategy in a project team for the design and build of a machine to specific requirements.
2. Recall discipline specific knowledge relating to mechanical and mechatronic machines and machine elements.
3. Apply discipline specific knowledge relating to the design of machines in order to develop innovative engineering solutions.

4. Identify and communicate occupational health-and-safety (OHS) considerations of stakeholders and professional engineers.
5. Communicate effectively and in a professional manner to convey both technical and non-technical content.
6. Communicate design process, mechanical and mechatronic concepts, and evaluation of product, professional ethical considerations, and reflection of project team performance through a professional portfolio.

The student assessment is a mix of individual and team items:

- Team project plan 10%,
- Individual online tests (2 x 5% each) 10%,
- Team project gateway presentation 10%,
- Individual project gateway report 15%,
- Team product demonstration/showcase 20%,
- Individual final project portfolio 35%.

The unit's project centres on a modified version of the Warman Student Design-and Build-Competition that is run annually by Engineers Australia (Churches & Smith, 2016). In 2016, the competition required students to build a machine that would deliver a payload after crossing a gap between two table-tops along an upward-sloping pole. The machine had to find the pole, attach itself and traverse the pole, drop off the pole and drive to a destination. In 2017, the competition requires students to design and build a robot that collects golf balls, squash balls, and racquetball balls, separates the golf balls from the others, and places the golf balls into one container and the remaining balls into another container (Engineers Australia, 2017). The students were divided up into teams of six students each. Each team worked on its robot, completing it in time for a unit competition in the final week of semester. Figure 1 shows examples of the projects built by the students in the two years the unit has been offered.

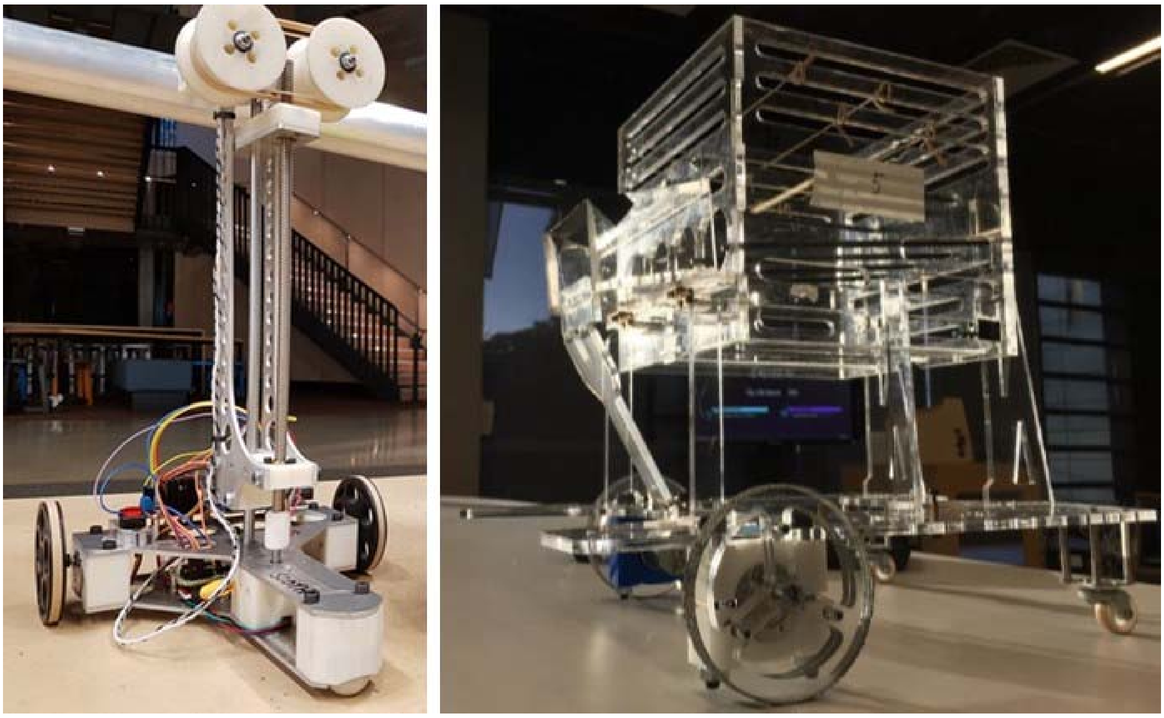

Figure 1: Examples of student-built machines for the SEM200 projects for 2016 (left) and 2017 (right).

During the 11-week semester, weekly on-campus class time is divided up into two lecture classes (one hour each), seminar/tutorials (two hours each), and practical studios (two hours each). Each student attends both lectures, one seminar, and two studios each week. Lectures and tutorials were used to convey the primary unit content to the students. They used the studios to work on the project in their teams. In addition, the studios allowed the teaching team to scaffold the learning towards the requirements and deliverables for the project. Engineering topics covered in the unit include computer-aided design (CAD), Arduino programming, project management, safety, mechanical and mechatronic components, and ethics (table 2). Lectures, seminars, and many studios were video-recorded and posted to the unit website for the benefit of all students, on-campus and online. Weekly online seminars and two-hour studios were held by means of the *BlackBoard Collaborate* web-conferencing software (Long, Cavenett, Gordon, & Joordens, 2014). On-campus and online students were brought together in week 7 as part of the School's residential week for all students.

Table 2: Weekly class topics and activities.

Week	Lecture topics	Seminar topics	Studio topics
1	Introduction; Project and team management	Review of CAD basics	Introduction to Warman Competition and benchmarking; teamwork
2	Product development (PD) process overview; PD Problem formulation	Part and assembly modelling	Team and project management; Prototyping
3	Design for safety; PD concept development;	Advanced assemblies	Safety by Design; PD problem formulation, concept development, concept screening
4	Intro to machine elements: gears, cams, bearings, links, pulleys	Detailed design in CAD	Detailed design considerations 1; Team check-up and assignment work
5	Intro to mechatronics: transducers, actuators, sensors, basic control	Intro to Arduino, basic control systems, programming	Detailed design considerations 2; Intro to basic mechatronic components
6	Machine elements calculations 1	CAD communication and project work	Mechatronics practical activities
7	Scheduled classes, studios and seminars replaced by two full days for Intensive Week for both Campus and Cloud students	Intensive Week focuses on activities related to Project Gateway tasks	Intensive Week will also focus on professional practice activities (OHS, WSA, ethics in engineering design)
8	Machine elements calculations 2; Mechanical design and safety factors	Machine elements - CAD and hand calculations	Ethics in engineering design; Discussion and feedback from Intensive Week and Project Gateway tasks;
9	Drawings, dimensioning, tolerancing	Arduino programming review and	Finalise design and/or work on manufacturing prototype
10	Tolerancing; Mechanical failure	Part drawings	Finalise prototype build
11	Tolerances 2; SEM200 review/summary	Assembly drawings	Finalise prototype build; Campus competition - practice and final

Methodology

For this study, enrolment numbers, student final marks and attrition were examined for 2015 and 2016, for both on-campus and online students. Student satisfaction was also examined by means of the University-wide standard survey of completing students. In the student-satisfaction survey, 12 questions are posed to the students and the students indicate their agreement on a Likert scale (table 3). Students are also invited to make written comments on aspects of the unit with which they are happy and aspects most need of improvement.

Table 3: Survey questions on student satisfaction.

No.	Statement
1	The learning outcomes in this unit are clearly identified.
2	The learning experiences in this unit help me to achieve the learning outcomes.
3	The learning resources in this unit help me to achieve the learning outcomes.
4	The assessment tasks in this unit evaluate my achievement of the learning outcomes.
5	Feedback on my work in this unit helps me to achieve the learning outcomes.
6	The workload in this unit is appropriate to the achievement of the learning outcomes.
7	The quality of teaching in this unit helps me to achieve the learning outcomes.
8	I am motivated to achieve the learning outcomes in this unit.
9	I make best use of the learning experiences in this unit.
10	I think about how I can learn more effectively in this unit.
11	Overall, I am satisfied with this unit.

The survey is anonymous and the data collected is used for research purpose without any identification linked to it. The research study survey was approved and acquired a ethics clearance from the Human Ethics Research Committee at Deakin. The students are not compelled by any teaching academics to participate in this survey. It is not compulsory and it will not affect their marks or curriculum participation in anyways. The survey was given by a third person who is not part of the teaching team. The cohort of students are aware of participation based on their own consent.

Results

Table 4 shows the academic results for this unit. On average, on-campus students performed at a Credit level, whereas online students performed a bit better, a low Distinction. There were few differences in academic performance from 2016 to 2017. Student satisfaction results are given in figure 2. In 2016, from 17 answered surveys (on-campus only), and in 2017, from 24 answered on-campus surveys and 11 from online students, the results indicate that students were very satisfied with most aspects of the unit. The lowest scoring area was in relation to feedback on student submissions (statement No. 5). It can be noted that on-campus satisfaction on this statement increased significantly from 2016 to 2017. Most students were satisfied with the delivery of the unit.

It is evident that in 2017, the student satisfaction results were above the School average on most questions. When both on-campus and online student satisfaction scores are combined, the 2017 survey shows results that are above the School average in all but one area (feedback). Averaging all responses for all questions in 2017, the survey results show that the percentage agreement for SEM200 was four percentage points above the School average.

The survey also provides the student the opportunity to provide written comments on what aspects of the unit they found helpful and what areas need improvement. Due to space limitations, the full detail of these comments cannot be included in this paper. However, the authors have attempted to summarise the main results of these here. Regarding the helpful aspects of the unit, the most number of written comments were relating to the project itself, its hands-on and practical nature, the fact that it was a "real" problem that was being solved and the fact that the project allowed the students to complete a full design cycle from concept development, to detailed design, to building and testing. Qualitatively, the areas where the student comments noted needed most improvement were relating to: the timeliness and amount of feedback; the high workload associated with this unit (although it is a two cp unit); the requirement to sort through and digest a large amount of information and content; and the need to focus more on project management techniques.

Table 4: Summary of academic marks 2016-2017.

Cohort	No. students competed	No. students withdrawn	AVG final mark (%)	Standard deviation	Median final mark
2016 on campus	44	4	65	13	64
2016 online	4	3	71	6.8	72
2017 on campus	72	5	65	11	65
2017 online	28	4	72	11	72

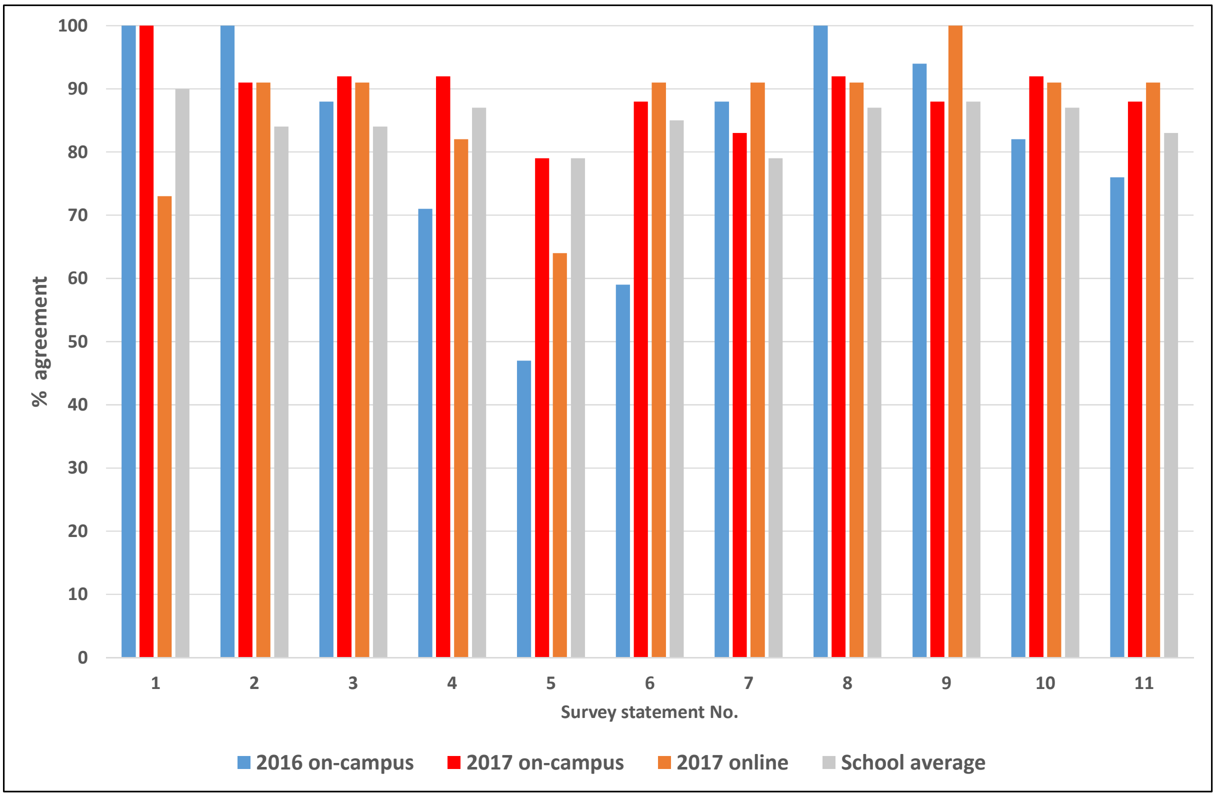

Figure 2: Results of the student-satisfaction survey.

Discussion

This is the first time Deakin has developed an engineering unit based on the Warman competition. There are only a few universities in Australia with engineering courses that use Warman as the basis of an engineering-project unit, such as ADFA (UNSW Canberra), Monash University, University of Newcastle, and RMIT. Apart from RMIT, these engineering units are Deakin's equivalent of one credit point. Like RMIT's MIET2420, Mechanical Design 1, SEM200 is two credit points.

In his study, Felder identifies 'Engineering Design' as a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints (Felder & Silverman, 1988). Design problems are classified as open-ended problems that generally have multiple solutions. A formal systematic problem-solving methodology is useful for these types of problems. Design is a continuous process of problem solving that many involve multiple iterations. The design process starts by identifying the problem. This allows students to search for possible opportunities to assist them in understanding the problem and therefore develop a design brief. Through research, students can then gather information on different methods, approaches and ideas to allow them to seek new solutions (Atman, Adams *et al.*, 2007; Bailey & Szabo, 2007). When a new solution is implemented, a model or prototype is developed. The prototype is then tested and evaluated against the specifications developed in the design brief for functionality.

In a PODBL environment, participants work in teams of four to six members with a facilitator. The same group meets regularly throughout the trimester to work on a series of design activities. The learning and teaching delivery is a combination of cloud and located learning activities. Cloud learning enables students to evidence their achievement. Units contain integrated short, accessible, highly visual, media-rich, interactive learning experiences rebuilt for the mobile screen, and integrating learning resources created by Deakin and other worldly universities and premium providers. Cloud learning require students to be generators of content, collaborators in solving real world problems, and evidence their achievements in professional and personal digital portfolios. With located learning experiences in place, students who come to campus will have the opportunity to engage with teaching staff and peers in opportunities for rich interpersonal interaction through large and small team activities.

As mentioned previously, the area which scored the lowest with respect to the student-satisfaction surveys was with regards to student feedback. However, this was also one of the areas of largest improvement from 2016 to 2017 – i.e. an increase of over 21% when considering both the online and on-campus students. The improved results in this area can be attributed to: (i) improved rubrics and assessment criteria for assessment tasks, which also aided in (ii) improved timeliness of feedback, and (iii) increased informal discussions between teaching staff and teams during studio activities on progress towards project.

Additionally, the area of largest improvement in the student survey results from 2016 to 2017 was relating to statement No. 6 – *The workload in this unit is appropriate to the achievement of the learning outcomes*. This was particularly interesting considering that the student workload was not reduced from 2016 to 2017. (In fact, it may have increased slightly with some small modifications to the assessment tasks.) However, more attention was given by the teaching team to ensure that the teaching and learning activities (including the course material, seminars, studios and assessment tasks) were explained with respect to how they aligned with the learning outcomes of the unit. It also worth noting that the academic marks between 2016 and 2017 do not show any notable differences (Table 4).

Finally, the survey results show some small differences between the on-campus and online students. However, considering the average of the percentage agreement for all statements in the survey in 2017, it is evident that the online students resulted in a small 1.8 percentage points less agreement compared to on-campus students. The largest differences were relating to statements No. 1 and No. 5. The academic results showed that the online students performed better than the on-campus students. This aligns well with the experience of academic staff at Deakin University, where the demographic of the online students are skewed towards mature-aged students with trade or similar qualifications and so tend to perform better with more applied/practical units.

In 2017 the third year of the PODBL curriculum is being offered for the first time. In addition to refining this unit for 2018 and beyond, we intend to consult the lecturers of the third-year PODBL units to gain further insight into the students' conceptual development, and to ensure that in terms of the conceptual knowledge required of graduate engineers, nothing is left out.

Summary and Conclusions

The implementation of Project Oriented Design Based Learning was successfully in the second-year unit of the undergraduate mechanical engineering and mechatronics degrees. Over 140 on-campus and off-campus students have completed the unit over 2016-2017 with student satisfaction that was in general above the school average. Feedback from students will be used to improve the delivery of the unit in future years.

Project Oriented Design Based Learning is generally regarded as a creative and innovative method for engineering education. When compared to traditional lecture-based or teacher-centered engineering curriculum, the PODBL model appears to inspire an enhanced learning environment for students. The conversion and implementation of this particular unit from the Mechanical Engineering program to PODBL is a gateway to enhance the relationship between the program and current University practices in the future.

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Acknowledgements

The authors wish to thank M. Norton, S. Cavenett, and R. Leen for their significant assistance with teaching SEM200. Many thanks are also given to the workshop staff who assisted students with their projects: P. Todd, R. Seiffert, R. Hall, and L. Tyrrell. The authors also thank the reviewers of this manuscript for their many helpful comments and suggestions.