Engineering Fundamentals in a new Undergraduate Curriculum

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CONTEXT
In recent years there has been a push in Engineering education to change the basic model from students learning discrete subjects, followed by design projects in third and fourth year, to learning and practicing the design process from the first year. At the same time, there has also been a push towards "active learning" (Prince, 2004) as opposed to the more traditional lecture/tutorial/practical approach. This year, Deakin University has launched a new design-centred curriculum in undergraduate engineering. Named "Project-Oriented Design-Based Learning" (PODBL), the new course structure is running in first and second years. In semester one of first year in the new course, students enrol in one double-unit of design, one unit of maths, and one unit of fundamental science.

PURPOSE
This work seeks to determine whether a new fundamental-science unit called "Engineering Fundamentals" fulfils the educational needs of first-year students in the PODBL curriculum. It also seeks to determine student perceptions of the new unit.

APPROACH
The unit was first offered in semester-one, 2016 to two separate on-campus cohorts and an off-campus cohort. Innovations in this unit include using the CADET model for teaching combined practical-tutorial seminars, a shift in lectures from delivering conceptual content to teaching problem solving and applications (flipping the classroom), and extensive use of online videos and study guides for delivering primary content (Cloud Learning). Student learning was assessed by means of problem-based online quizzes, practical reports, and a final exam. Student perceptions were queried by a standard unit-evaluation system and by a more focussed set of surveys given to students in three separate cohorts.

RESULTS
The academic results in this unit were compared with those in the previous unit. No substantial differences were observed in the marks of this unit in 2016 compared with the 2015 marks of the corresponding previous physics unit. On-campus students showed more general satisfaction with the unit than did off-campus students. However, not all on-campus students were happy with the flipped-classroom model.

CONCLUSIONS
As the course changes from a traditional approach to a design and project-based approach, it is best if all units in the course adapt in some way to the new teaching style. Not all units need be completely project or design based. In the case of "Engineering Fundamentals," we believe that due to the wide variety of topics covered, making the entire unit design-based is inappropriate. However, some design and project components can be built into the unit via the practicals. Semester one 2016 was a successful first offering of the unit. We recommend that in future years a design/project component be considered for the unit's practicals.

KEYWORDS
design-based learning, project-based learning, PODBL, physics.

Introduction

The School of Engineering at Deakin University offers Bachelor-of-Engineering courses in mechanical, electrical and electronic, mechatronics, and civil engineering. The courses have been offered both on-campus and off-campus (external studies) for many years (Long, Joordens, and Littlefair, 2014). The School is proceeding down three new avenues in the development of its undergraduate pedagogy.

First is the opening of the "Centre for Advanced Design and Engineering Training" (CADET), a new education centre specifically catering to engineering-design education from primary school all the way to postgraduate university (Littlefair and Stojcevski, 2012; Loussikian, 2015). In addition to a new state-of-the-art building and teaching facilities, the Centre has formed multiple partnerships with local primary and secondary schools to give younger students an experience in engineering and design (Steinwedel, 2016). The building also has specialised teaching spaces to bring the connection between engineering design and practice closer to each other and encourage active learning (Collins, Hilditch, and Joordens, 2015).

Secondly is the trend toward flipping the classroom. Named "Cloud Learning," the University is in the process of shifting most of its on-campus courses towards a more active approach, where primary lecture content is delivered via video streamed from unit websites, and class time is reserved for active learning activities such as practicals and seminars (Catford, 2012). Indeed, across the University, "lectures" are now called "classes" and tutorials have been renamed to "seminars" or "studios." Video material is either produced in-house or imported from multiple external sources, including YouTube.

Project-Oriented Design-Based Learning

Finally, and of interest to this paper, the overall engineering curricula are adopting an approach that is led first by design and projects. Design and projects have always been an important part of all the courses in the School. An example is the mechatronics course, where significant design projects as learning experiences were introduced in the late 1990's (Chandrasekaran, Long, and Joordens, 2015; Joordens and Jones, 1998). Other design-led approaches to teaching, such as CDIO , have been investigated (Ferguson, 2008). A further development in the School is the adoption of a new project-based, design-led curriculum across all undergraduate courses. Called "Project-Oriented Design-Based Learning" (PODBL), it integrates design projects as the basis of learning across all four years of the undergraduate engineering course (Chandrasekaran, 2013a; Chandrasekaran, 2013b). PODBL is essentially a combination and further development of project-based learning and design-based learning. Student are given extensive design projects as the learning context from semester one of first year, and every semester thereafter. Considerable research went into studying how design and project based learning could enhance student experiences and learning. This research includes at least one postgraduate thesis (Chandrasekaran, 2014a), and extensive consideration on how the new curriculum would be delivered to off-campus students (Chandrasekaran, 2014b; Chandrasekaran, 2014c). One feature of this new course structure is that one-half of the course is taken up by double-credit design units. Each of these units assigns to the students a design project to be completed during the semester. For about half the semester, the teaching staff give classes on the necessary content and skills necessary to complete the project. In the remainder of the semester, the students work in teams to complete their projects. The remaining units in the course are single-credit-point (cp) units covering core engineering knowledge, such as physics, maths, computing, and topics central to the course. In some ways the course structure resembles those proposed in the CDIO model (Crawley, 2014). Table 1 shows a sample course structure with its associated units. Semester one this year marked the first intake of students into the BE with the PODBL course structure.

Table 1: PODBL Course structure for BE Electrical and Electronics.

First year			
Sem-1	SEJ101 Design Fundamentals (2 cp PODBL)	SEB101 Engineering Fundamentals	SIT199 Applied Algebra and Statistics
Sem-2	SEJ102 Electrical Systems Engineering Project (2 cp PODBL)	SIT194 Introduction to Mathematical Modelling	SIT172 Programming for Engineers
Second year			
Sem-1	SEE210 Power Engineering Design (2 cp PODBL)	SEP291 Engineering Modelling	SEE206 Measurement and Instrumentation
Sem-2	SEE213 Distributed Generation System Design (2 cp PODBL)	SEE216 Analog and Digital Systems	SEE215 Microcontroller Principles
Third year			
Sem-1	SEE332 Electrical and Electronics Project 3A (2 cp PODBL)	SEE307 Systems and Signals	SEE308 Electrical Machines and Drives
Sem-2	SEE333 Electrical and Electronics Project 3B (2 cp PODBL)	SEE312 Industrial Data Communication	SEE344 Control Systems
Fourth year			
Sem-1	SEJ441 Engineering Project A (2 cp PODBL)	SEE407 SCADA and PLC	Engineering elective
Sem-2	SEJ446 Engineering Project B (2 cp PODBL)	SEE406 Electrical Systems and Safety	Engineering elective

In semester one of first year of the PODBL engineering course, students take the unit SEB101, Engineering Fundamentals. The unit will also be offered off-campus only in summer semester. This unit covers the fundamental science that forms the foundation of engineering. In previous years this unit was named SEP101 Engineering Physics. The School decided that the name change was necessary because the unit covers physics (9/11 weeks) and engineering mechanics (2/11 weeks), and because it is aimed first at engineering students. Students from other disciplines are a minority.

Structure of SEB101

SEB101 was first offered in semester one 2016. There are five learning outcomes for the new unit. Students who complete and pass the unit are able to:

1. Explain basic principles in physical mechanics, electric fields, and engineering moments.
2. Apply these principles to natural phenomena.
3. Solve technical problems in basic mechanics, electricity, and engineering moments.
4. Perform and report on basic physical measurements.
5. Employ experimental methodology.

These learning outcomes are very similar to those of the predecessor unit Engineering Physics. The only difference is that the earlier unit (SEP101) did not cover electricity but did cover oscillations and waves. Both units taught an introduction to engineering moments and the importance of moments of inertia of cross-sections in beams. Because SEB101 is concerned with fundamental engineering knowledge, its content covers all four areas of engineering taught by the School (table 2). Assessments for the unit are a 60% exam, 20% problem-based assignments, and 20% practicals, identical to that of the earlier unit Engineering Physics. The text is based on a popular physics book (Halliday, Resnick, and Walker, 2014) and readings in mechanics (Hibbeler, 2010). The unit is offered to on-campus students both at Geelong and in suburban Melbourne, and as an off-campus unit.

Table 2: Topics in SEB101 and related engineering fields.

Topic area	Duration (weeks)	Mechanical	Civil	Electrical/ electronic	Mechatronics
Basic mechanics and Newton's laws	3	✓	✓	✓	✓
Energy	1	✓	✓	✓	✓
Rotation	1	✓	✓	✓	✓
Electric fields, voltage, and Ohm's law	3			✓	✓
Static equilibrium	½	✓	✓		
Force moments	½	✓	✓		
Centre of mass, centroids	1		✓		
2^{nd} moment of area	1		✓		

The conceptual content is delivered by the "Cloud-Learning" method developed for the predecessor unit Engineering Physics (Long, 2015). Embedded in an extensive online study guide are 75 short video presentations on the various topics and subtopics. Students are instructed to watch the videos and read the text material before class time. In place of traditional lectures, the instructors mainly conduct problem-solving sessions. In the on-campus tutorials (now called seminars), students spend about half the two-hour sessions practicing problem solving in small groups and half the time in the adjacent teaching laboratory observing demonstrations or performing short experiments. Off-campus students attend weekly online tutorials, where they spend time with the lecturer going over concepts and solving problems. These tutorials are run by means of the web-conferencing software *Blackboard-Collaborate* (Blackboard Inc., 2016), and are similar to online tutorials that were given in SEP101 via *Elluminate-Live!* (Long, 2014a).

Originally, the practicals were envisioned to have a significant design component to them, and would include experiments for all four engineering areas in the course. It was proposed that each student would select a two-session design experiment from a list of suggested experiments covering all engineering fields in the course. The remaining experiments would be standard guided experiments with a nominal three-hour duration. Limitations in budgets, availability of technical staff, and even the in structure of CADET resulted in six standard experiments being offered (table 3). These experiments had been offered in the School for a number of years (Long, 2012) in SEP101. Each experiment also has a corresponding video to explain the theoretical background and show how it is performed, especially in the case where students use data loggers (Long, 2014b).

Table 3: Lab experiments offered in SEB101.

Experiment	Title	Reference
1	Introduction to Microsoft Excel and measurement uncertainties	(Bloch, 2000; Wilson, 1998)
2	The simple pendulum and Hooke's law	(Loyd, 1997)
3	One-dimensional motion and the inclined plane	(PASCO-Scientific)
4	Projectile motion	Pasco
5	Friction	Pasco
6	Rotational inertia of a flywheel	(Worsnop and Flint, 1951)

On-campus students performed experiment one in their tutorials, and the remaining five in three-hour practical classes. Off-campus students performed either of experiments 1 and 2 at their home address. They completed the remaining four experiments at an on-campus residential school (Long, Cavenett, and Chandrasekaran, 2015), in a single eight-hour lab session. All students were instructed to submit a lab report before week five of semester. The submissions were marked against a rubric by the lecturers, who returned formative feedback via the unit website. The lecturers also published three sample lab reports at this time. At the end of semester, the remaining lab reports were marked against the same rubric and given a score out of 20.

Methodology

For this study, student marks for the exam, practicals, and final grade were compared off-campus versus on-campus, and 2016 marks with those of SEP101 2015. The authors believe that a comparison between 2015 and 2016 is important as this unit continues to serve as a fundamental physics unit in the Engineering course, and it is important to see whether there has been a change in students' academic performance between the old unit and the new. Student satisfaction was also measured by means of two separate surveys. The first (*A*) was the standard University survey of student satisfaction that is delivered to the students for all their units (Palmer, 2012). Out of a total of 11 statements, of interest here is whether the students agree with four statements on the structure and resources of the unit (table 4).

Table 4: Survey-*A* statements given to the students at semester's end.

No.	Statement set survey *A*
1	The learning *experiences* in this unit help me to achieve the learning outcomes.
2	The learning *resources* in this unit help me to achieve the learning outcomes.
3	The *workload* in this unit is appropriate to the achievement of the learning outcomes.
4	Overall, I am satisfied with this unit.

The second survey (*B*) was more specialised. Separate surveys were given to on-campus and off-campus students. Ten questions were posed to each, five on the lecture and tutorial content, and 10 on the practicals. Students were asked to indicate their agreement on a five-point scale: strongly disagree, disagree, neutral, agree and strongly agree. Table 5 lists the survey statements posed to the students.

Table 5: Survey-*B* statements given to the students at semester's end.

No.	Statement set survey *B*	Campus
1	I watched the vast majority of the lecture videos that were included in the online study guides.	on & off
2	I found the lecture videos useful for my learning.	on & off
3	The quality of the lecture videos was adequate.	off
4	I learned more from the textbook than from the videos.	off
5	I would prefer that the lecture material be delivered in a traditional lecture setting.	on
6	I liked the tutorial format (classroom work plus lab activities in a single two-hour session).	on
7	The on-line tutorials helped me to obtain the unit learning outcomes.	off
8	The seminar format helped me to obtain the unit learning outcomes.	on
9	The prac videos assisted me to carry out the experiment in the lab.	on & off
10	Three hours is an appropriate time for one on-campus prac class.	on
11	Eight hours is appropriate for performing four off-campus practical experiments.	off
12	The prac videos were useful in preparing me for prac class.	on & off
13	Prac videos like these would be useful throughout the rest of my course.	on
14	I would prefer to do the pracs at home than attend an on-campus lab day	off
15	The five practical experiments adequately balanced the educational needs of students in mechanical, civil, and electrical/mechatronics.	on

Results

At the start of semester there were 152 on-campus and 143 off-campus students enrolled. At the end of semester 125 on-campus and 66 off-campus students were assessed. Table 6 shows the median academic results of this unit for semester-one 2016. The corresponding results for SEP101 2016 are also shown for comparison. The overall marks were almost steady for on-campus. The off-campus final marks increased by about seven percent. The increase in off-campus overall marks is likely due to the large increase in practical marks from 2015 to 2016 (30%), which is encouraging, given that most off-campus students find the practical component very challenging. The other assessment items do not show such dramatic changes. Exam marks from 2015 to 2016 show no change for on-campus and a slight decrease (–3%) for off-campus. A clearer picture of the academic trends from 2015 to 2016 will emerge after this year's summer-semester offering.

As for student satisfaction with the new unit, figure 1 shows a results summary of the two surveys that were given at the end of semester one. Survey *A* received 30 off-campus responses and 25 on-campus responses. Unfortunately survey *B* only received six off-campus and eight on-campus responses, nowhere near enough to produce statistically significant results. Nonetheless, survey *B* does give an indication of the attitudes of some students who had a strong enough opinion to answer it.

Table 6: Academic results for SEB101 2016 and SEP101 2015.

Cohort	No. students assessed	Median final mark %	Median exam mark %	Median prac mark %	Median assignment mark %
2015 on campus	118	66	60	71	82
2015 off campus*	71	64	60	64	77
2015 all	189	65	60	68	80
2016 on campus	125	67	60	75	77
2016 off campus**	66	69	58	85	78
2016 all	191	67	59	75	78

*semester one and summer
**semester one only

In survey *A*, the on-campus students who responded were more satisfied (83% agreement) with the learning experiences than were the off-campus students (67% agreement). Off-campus students were slightly more satisfied with the learning resources than the on-campus students. Both groups showed greater than 70% satisfaction. Nearly half the off-campus students (45%) thought that the workload was too high, compared with only 24% of on-campus students thinking that way. Overall satisfaction among the respondents was 84% for on-campus, 57% for off-campus.

Survey *B* had too few respondents to reliably consider quantitative results. However, these results do indicate for *some* students, on-campus preferred traditional lectures and tutorials over a flipped-classroom model. Off-campus students in this survey tended to rely on the recorded class and study-guide videos more than the on textbook for their learning, but some were unhappy with the perceived quality of the videos. Only half of the off-campus students in this group were satisfied with the online tutorials. One student commented that online tutorials, whilst welcome, now need to be active learning experiences rather than passive.

As for the practicals, on-campus students were much more satisfied with the prac videos than were the off-campus students. The off-campus students were quite clear in their recommendation that the numbers of days set aside for each student to perform his on-campus experiments be doubled from one to two days. Interestingly, the majority of off-campus students who responded prefer to attend an on-campus prac day than do their experiments at home. Unlike the on-campus students, off-campus students were satisfied with the selection of experiments for use in 2016.

Discussion and recommendations

As this paper considers the first offering of this unit, there is much more data to collect and analyse. For instance, in addition to collecting marks and survey data from future semesters, it would be very useful to examine student use of the study-guide and class videos. One video recording of an on-campus class picked at random was viewed only 27 times by 16 students. This is disappointing in the light of over 250 enrolments at the time the class was recorded. Another randomly selected study-guide video in the electricity module was viewed

44 times. Given the considerable effort going into producing these videos, it is worth examining how often they are viewed during semester and for how long.

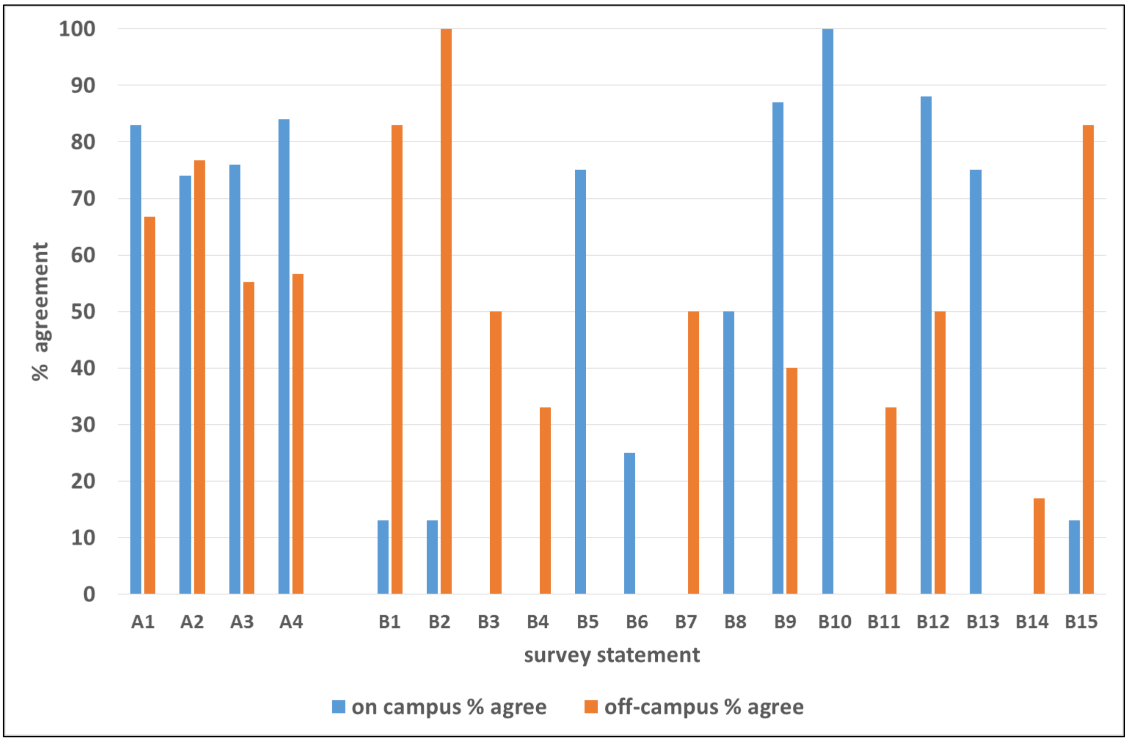

Figure 1: student-satisfaction results for semester one 2016.

Anecdotal evidence has suggested that as the years go by, student satisfaction with specific educational innovations tends to wane unless further development occurs. An example of this is the online tutorials. When the authors first employed web-conferencing to deliver tutorials and prac sessions online, the student response was overwhelmingly positive. Now the off-campus students expect online tutorials in all units. One student in this unit called for multiple online tutorials each week, in spite of their low attendance all semester. Students showed greater satisfaction overall with the prac videos in 2014 than in 2016. This evidence and our anecdotal experience shows that student expectations on the quality of educational materials increases year-by-year. It is a great challenge for the lecturers to keep up!

From our experience with running SEB101 for the first time following tentative recommendations for further work can be proposed:

1. Begin the process of updating the study-guide videos.
2. Introduce two new experiments into the practical programme, one electrical and one civil.
3. Consider introducing an open-ended experiment that the students design themselves.
4. Investigate the extent to which students watch the videos.
5. Investigate the students' academic performance by module.
6. Begin research on how to turn online tutorials into effective active-learning experiences.
7. Compare this teaching approach with that of other universities that implement design- and project-based learning.

These recommendations will be further refined after the unit is offered a few more times and more data is obtained.

Summary and conclusions

As part of a new undergraduate engineering curriculum called project-oriented design-based learning, an existing unit in first-year physics was redeveloped as SEB101, Engineering Fundamentals. The new unit covers the three areas of basic mechanics in physics, engineering moments and moments of inertia, and static electricity. The unit ran on-campus and off-campus for the first time in semester one 2016, starting with 290 students. There was no substantial difference in academic marks between 2016 and those from the corresponding physics unit in 2015. In general, on-campus student satisfaction was higher than that for the off-campus students. The development of this unit will continue into 2017, and further research will be performed to ascertain its teaching effectiveness.

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