Design and Implementation of a first-year engineering design subject

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INTRODUCTION

Being able to produce engineering graduates with a thoroughly developed set of desired competencies is a challenging task and consequently the focus of much research in engineering education [1] [2] [3]. Engineers Australia, as the official accrediting body for tertiary Engineering degrees in Australia, have determined a list of graduate competencies that are supposed to be developed in engineering students over the course of their university studies [4]. However, the focus of typical engineering subject curricula largely remains entrenched in the thinking of the past - the development of technical skills, with so-called 'generic skills' often included as an afterthought or assumed to be picked up along the way without sufficient instruction, assessment or feedback.

In the first year of engineering study, it is particularly important to make students aware of how much these generic skills are valued by industry in graduate engineers, to inspire them as engineering students and to prepare the base of their learning for the years ahead. The ideal vehicle for this is via real-world design examples and the use of project based learning [5] [6] [7].

This paper will focus on the development, design, implementation and evaluation of a new large first-year engineering systems design subject as a means to develop particular "generic skills" types of graduate attributes, to broaden a student's knowledge of engineering and to encourage further study in engineering. The first-year subject curriculum was designed according to a specifically chosen set of Engineers Australia graduate competencies functioning as the intended learning outcomes. Teaching and learning activities were designed around these intended learning outcomes; the focus being a semester-long team design project with multiple dependent modules, each employing different disciplines of engineering. It is argued that such a purpose-built first year systems design subject exposes students to the importance of a range of graduate competencies, particularly generic skills, builds understanding of how such skills are developed and assessed, gives a taste of

engineering from multiple disciplines, and forms a sense of community amongst the student cohort.

Data was collected measuring academic performance, attendance and submission rates, peer ratings, feedback given and student perceptions of the subject, which was then analysed in order to assess if the intended learning outcomes were being met. From this it can be surmised that students improved specific graduate competencies such as communication and teamwork skills, and became inspired to continue on with their study of engineering through engagement with the assessment tasks such as regular reflection, feedback and self-assessment.

1   BACKGROUND

While the premise of creating an active learning environment [8] was foremost at the development of the teaching and learning activities for both general first year engineering subjects upon their inception in 2008, departmental pressures existed that shaped the curricula. Follow-on discipline-specific subjects in the second year of study assumed technical knowledge that would need to be provided in the first year subjects, and each department wanted their own 'wish list' of technical skills taught and assessed for entry into second year. Thus it would be a difficult task of balancing the requirements of the desired technical knowledge to be taught, keeping the content simple enough for all students to be able to learn it (assuming a fairly basic level of high school mathematics) and ensuring that the content was sufficiently engaging for students of both high and low academic performance levels. In addition, important generic skills such as communication skills, teamwork, and problem solving would have to be addressed.

In reality, Engineering Systems Design 1, the first semester subject, turned out to sit somewhat in the middle of these requirements. The subject consisted of three modules of roughly equal length – Engineers, Engineering and Society, System Modelling and Design and Algorithms and Problem Solving. The Engineers, Engineering and Society module consisted of subject matter such as the role of engineers, the different disciplines of engineering, safety, sustainability, problem solving, organisation and representation and design and decision making. The second module, System Modelling and Design, ostensibly focused on using MATLAB and some basic introductory fluid mechanics to complete a group design assignment. The final module, Algorithms and Problem Solving, utilised Lego Mindstorms robots for a design challenge that involved devising, testing and refining an algorithm to get the robot to perform a specific task. In each of these modules, students worked in small groups of three and worked on isolated structured assessment tasks or in-class assessments. Teaching and learning activities involved 3 one-hour lectures plus 1 three-hour workshop per week. A final exam was a hurdle requirement for passing the subject, which students would typically concentrate most of their efforts on.

Overall, survey results indicated that students enjoyed the active-learning workshop classes and found that they increased their understanding of the subject material more than they did by attending lectures – see [9] where similar results were reported for the second semester subject Engineering Systems Design 2. However, there were numbers of complaints from students about the technical content not having much relevance to their desired engineering pathway and the subject was seen as being largely irrelevant to real-world problems.

Because of the focus on the development of technical skills, and the way the subject had been split into distinct modules based on technical content, the development of generic skills had been ultimately neglected. There were some mechanisms for peer

assessment, where students rated themselves and their peers' performance on assignments, but this was largely done in order to mitigate the 'freeloader' principle as opposed to actually developing teamwork skills through feedback. There was no room in the subject schedule for the teaching of communication skills and the content did not easily lend itself to developing such assessment. Additionally, academics teaching later year subjects were reporting that students were having issues with group work, communication skills and problem solving. Some had remarked that students had not completed a large-scale technical report before they entered their final year of the five-year Master of Engineering program.

On the other hand, students surveyed on completing their degree often commented that the capstone project, completed in the final year of the Masters of Engineering program, was what they learned the most from and found greatest satisfaction with. They found that being able to put their technical knowledge to practical use, the open-endedness of the project and the reliance of working in a team were highlighted as key to their feeling of satisfaction with the project. Often, students would have some physical product to keep that they had been required to develop or design as part of their project and this instilled a sense of 'ownership' and 'investment' in the project. Unfortunately students would have to wait until their fifth year of the study, assuming they decided to pursue the Master's degree, in order to have this positive experience.

2   DEVELOPMENT

In light of the above discussion and staff and student feedback, Engineering Systems Design 1 underwent a complete redesign for 2013/2014. The concept was straightforward – provide a miniature capstone experience for students, with a set of technical objectives determined by second year subjects, generic skills required by later years and a semester-long project to tie it all together and provide the vehicle for the delivery of the skills. To begin with, a set of the Engineers Australia graduate competencies were chosen to function as the intended learning outcomes of the subject, encapsulating both the technical and generic skills that were deemed as important for students to develop in their first semester studying engineering at university. The technical learning objectives for students completing Engineering Systems Design 1 are to be able to :
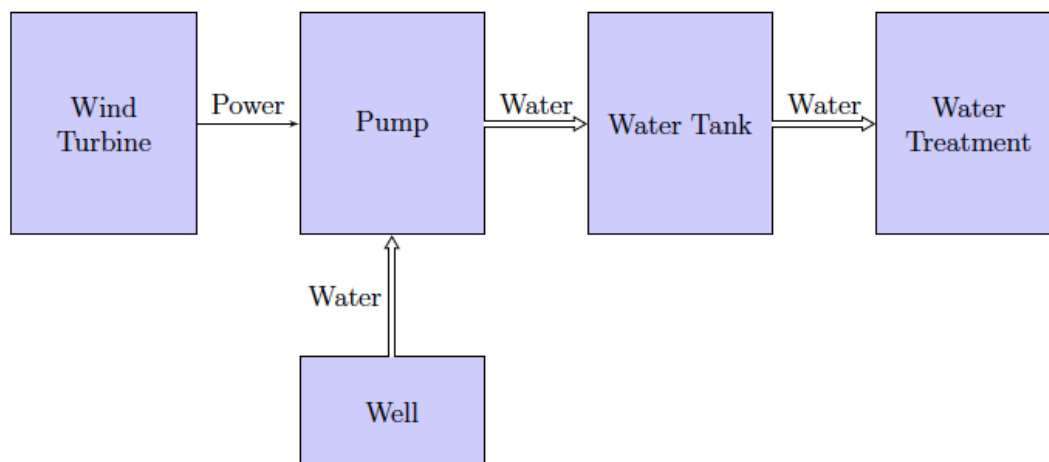
1. Explain the importance of engineers and the place of engineering in society.
2. Apply basic knowledge of fluid mechanics, chemical engineering and aerospace systems to solve design problems across multiple engineering disciplines
3. Identify the nature of a technical problem and make appropriate simplifying assumptions, in order to achieve a solution
4. Develop and construct mathematical, physical and conceptual models of situations, systems and devices, and utilise such models for purposes of analysis and design
5. Analyse possible alternative engineering approaches and evaluate their advantages and disadvantages in terms of functionality, cost, sustainability and all other factors
6. Demonstrate competency in current tools for analysis, simulation, visualisation, synthesis and design, particularly computer-based tools and packages

The generic skills objectives for students completing Engineering Systems Design 1 are to be able to :

1. Ability to interact with people in other engineering disciplines and professions to broaden their knowledge and achieve successful outcomes in an engineering design project
2. Ability to realistically assess the scope and dimensions of a project or task, and employ appropriate planning and time management skills to achieve a substantial outcome
3. Communication skills in order to make effective oral and written presentations to technical and non-technical audiences and with other team members
4. Ability to apply creative approaches to identify and develop alternative concepts and problem solving procedures
5. Perception of their own learning and development; understanding the need to critically review and reflect on capability and undertake appropriate learning programs

Once these objectives were settled on, the 'constructive alignment' [10] paradigm of curriculum development was applied. Teaching and learning activities were to be designed to support these intended learning outcomes with the continual focus being a semester-long team design project with multiple dependent modules, each employing different disciplines of engineering. The existing lecture / workshop structure that students felt worked well was retained, although the actual content was vastly different to the previous incarnation of the subject.

The design project was chosen to mimic a potential real-world engineering design project. The goal of the project was to design a low-maintenance water pumping and storage system for the drinking-water requirements of a remote community incorporating renewable energy and water filtration. The three 'subsystems' were the power generation system, the water pumping and storage system, and the water treatment system as shown in *Fig. 1*. Teams of six were formed for the project, which ensured that tasks could easily be subdivided. While still being discipline-based, students could focus more on their strengths within the team rather than be forced to work outside their comfort area. The benefit of having a larger team also meant that the self and peer assessment would be less prone to personality conflicts that had previously occurred in the subject within smaller teams of two or three students.

Fig 1. Systems in design project

In order to ensure that students had the necessary experience to tackle such an open-ended project, a collection of workshops had to be developed comprising both drill-style questions and scaled-down experiments utilising a model experimental rig. The engineering subsystems could be tackled as separate entities via exercise problems and experiments, but the design components of the project would be co-dependent and have to be integrated together. Each system module would require experiment, modelling, design and verification as part of an iterative process to ensure that the specifications were met.

The assessment was divided into tasks that would encourage the development of both technical and generic skills and also be amenable to working together as a team. Assessment tasks are given in *Table 1*, where the timing of each was specifically chosen with respect to the lectures and progress in the project over the 12 week semester.

Table 1. Assessment details

Team Assessment	Weighting	Due
Team Contract	5%	Week 3
Online Blog	0%, 5%, 5%	Weeks 4, 8, 12
Self and Peer Assessment	Moderate team marks	Weeks 4, 8, 12
Presentation	10%	Week 8
Report	25%	Exam period
Individual Assessment		
Reflective Journal	10%	Weekly
Quiz	5%	Week 7
Exam	35%	Exam period

In order to continually keep students immersed in their project, the reflective journal and online blog were staggered in between other major assessments. These were less formal assessments, designed more for reflection and discussion than on analysis or design. Students were encouraged to take photos of their work and provide web links to any reading they had been doing outside of class in order to add a level of 'ownership' to their work.

Presentations were performed in Week 8 after a series of lectures on communication skills. Teams would be marked on the content and design of their presentation, with feedback being given to individual speakers on clarity, voice and style. Self and peer assessment was performed three times during the semester – once for feedback only, and then twice to moderate the team presentation and team report marks. Each round of peer assessment was distributed back to teams for discussion in order to improve the way the team operated.

The final technical report was a team effort, where each team member would rate their own and every other team member's contribution to the report, and was due in the exam period. The reduction of the importance of the final exam (from 60% to 35%) was intended to shift the emphasis of the subject more to the learning and practice of developing skills in an ongoing fashion during semester, rather than specifically learning particular technical skills to demonstrate within the constraints of a final exam.

3   IMPLEMENTATION

The subject was rolled out for semester 1, 2014 with an enrolment of approximately 600 students. It was felt that with such a shift in focus to generic skills assessment, it would be important to manage the students' expectations early on. In particular, an industry survey [2] was presented in the second lecture highlighting that the top three skills desired by industry in a graduating engineer are problems solving, teamwork and communication skills, respectively. In Week 2, an overview or 'big picture' document was released allowing students to comprehend the scope of the project without having to concern themselves with the technical details, until they had covered the relevant theory later on. The details of the technical requirements for the three design modules were then released in a staggered manner to ensure that students did not suffer from information overload and to maintain relevance with the lecture topics.

The three-hour workshop classes ran in two halves – Part A contained basic drill-style questions in order to build up basic technical skills, while Part B focused on the design project and typically involved experimental work with the rig or modelling and design work in MATLAB. Towards the end of semester, teams were given some free time in workshops to complete any outstanding tasks they may have.

4   EVALUATION

The subject was evaluated using several forms of feedback – student surveys, student focus groups and tutor debriefings. Other statistical data that was collected measured academic performance, attendance and submission rates and peer assessment ratings. *Table 2* compares the results between 2013 and 2014 of an end of semester subject survey, in which students respond to several questions via a 5-point Likert scale, with 1 representing Strongly Disagree and 5 representing Strongly Agree. The results indicate the effect of the implemented changes on students' perception of learning.

Table 2. Student survey feedback

Question	Score (out of 5)	
	2013 (N=335)	2014 (N=330)
Overall, this subject has been intellectually stimulating	3.2	3.4
I learnt new ideas, approaches and/or skills	3.7	3.8
I have been part of a group committed to learning	3.7	3.9
I have improved my communication skills	3.3	4.0
I have improved my ability to work in a team	3.4	4.1
I received valuable feedback on my progress	3.1	3.4

From these survey results it is clear that students under the new project-based subject have had a significant improvement with their learning, especially in terms of generic skills, which is in line with the revised intended learning outcomes.

Student focus groups, comprised of volunteers from the subject reported a strong overall positive reaction to the role of the design project underlying the learning objectives of the subject and could see its value as a "true real-world example of

what might have to do once we are employed as an engineer". The fact that some of the design work could be done at home felt "less like homework than other subjects" and the publishing of breakthroughs and team status updates via the online blog "made the work much more exciting… to let people know not just when but how we did things". Some students commented on the "sense of belonging to a cohort" that was missing from other subjects.

While the focus groups were united in their overall praise of the design project, some students were particularly concerned about its open-endedness; in that there was not just a single solution that satisfied the specifications. In order to obtain a viable solution, students would have to begin by making assumptions and justifying them, something which some felt uncomfortable with. When pressed further on this, it appears as though this could be due to the lack of experience with such types of problems at the high school level and in their other first year subjects, which tended to have much more prescriptive problems and easier to follow procedures in order to obtain a solution.

Differences in academic results are difficult to ascertain due to the large change in the subject from 2013-2014 including differing subject material, assignments and percentage weightings. The one assessment that remained constant between iterations of the subject, the reflective journal, showed slightly higher submission rates in 2014 (average 92% versus 84% in 2013), which could be an indication of increased engagement with the subject.

5   DISCUSSION

While the results in terms of student feedback are encouraging, there are still further refinements to be made to the subject. Primarily, there were many technical issues with the experimental rigs that caused problems with students not being able to collect the necessary experimental data and thus being put under severe time constraints. Secondly, the lectures can be more tailored to suit the design project, drawing upon the issues encountered in the workshops classes and where students appear to have struggled most. Once these issues are ironed out, it is envisaged that the student experience will be even more positive.

Due to the large amount of time invested in developing the design project, it is unlikely that the major project goals will change for subsequent iterations. This may lead to students copying previous student work in the years to come; indeed the focus groups expressed some concern with the open-endedness of the project and this could pose as a 'solution' for some students in the future.

It is felt that the improved engagement with the subject and familiarity with critical tasks such as regular reflection, teamwork, providing feedback and self-assessment will likely have a flow on effect to academic performance in subsequent subjects in the chosen engineering pathways. It will be a matter of future investigation to assess in some way the flow on effects to later year subjects in terms of levels of 'generic skills' such as teamwork and improved communications skills through presentations and report writing. We will need to wait for students to progress through the degree program to look for any such evidence.

6   CONCLUSION

Incorporating the development of graduate competencies, specifically generic skills, into a first-year design subject is not a trivial task. In undertaking this process, many lessons were learned that will act as recommendations for those educators who wish to follow down a similar path. It is anticipated that more detailed conclusions can be

made about the effectiveness of the new design subject and point to improvements that can be made for future iterations once more detailed surveying is performed in the subject and its follow on subjects.

REFERENCES

[1]   Walther, J., Radcliffe, D. F. (2007). The competence dilemma in engineering education: Moving beyond simple graduate attribute mapping. *Australasian Journal of Engineering Education*, *13*(1), pp. 41-51.

[2]   Male, S. A., Bush, M. B., & Chapman, E. S. (2009). Identification of competencies required by engineers graduating in Australia, Proceedings of the 20th Annual Conference for the Australasian Association for Engineering Education*,* Adelaide pp. 882-888.

[3]   Passow, H. J. (2012). Which ABET competencies do engineering graduates find most important in their work?. *Journal of Engineering Education*, *101*(1), pp. 95-118.

[4]   Engineers Australia (2014) Australian Engineering Competency standards. Retrieved April 7, 2015, from https://www.engineersaustralia.org.au/about-us/program-accreditation#standards

[5]   Mills, J. E., Treagust, D. F. (2003). Engineering education—Is problem-based or project-based learning the answer?. *Australasian Journal of Engineering Education*, *3*, pp. 2-16.

[6]   Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist*, *26*(3-4), pp. 369-398.

[7]   Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem-and project-based learning. *Journal of the Learning Sciences*, *7*(3-4), pp. 271-311.

[8]   Prince, M. (2004). Does active learning work? A review of the research. *Journal of engineering education*, *93*(3), pp. 223-231.

[9]   Buskes, G., Shen, B., Evans, J., & Ooi, A. (2009). Using active teaching workshops to enhance the lecture experience. In *20th Annual Conference for the Australasian Association for Engineering Education, 6-9 December 2009: Engineering the Curriculum* (p. 67). Engineers Australia.

[10] Biggs, J. and Tang, C. (2007). *Teaching for quality learning at university*. UK/New York: McGraw Hill.