Full Paper

Introduction

Design and the application of the design process is a fundamental learning objective that all engineering students must demonstrate during their undergraduate engineering education. In Australia, Engineers Australia's Stage 1 Competency Standards (Engineers Australia, 2013) make explicit mention of design and the design process in two of the sixteen mandatory 'Elements of Competency' (Items 1.6 & 2.3).

At Flinders University engineering students are taught and exposed to design during every year of their undergraduate education. 'ENGR1171 Engineering Design' is part of the common first year and introduces students to an engineering design process coupled with hand drawing/Computer Aided Drawing (CAD) laboratories and a semester long group Design Challenge. The systematic design approach is based on the textbook '*Engineering Design Process*' (Haik & Shahin, 2011). The topic is structured such that theoretical learning is coupled with active, assessed tutorials that complement the material required for the Challenge. Student groups are encouraged to prototype their solution to a given design problem as part of the Challenge.

Being a first year topic, there is also extra emphasis on engaging and retaining first year students. Retention is important both for the institution to maintain student numbers and income, and for students for whom the disruption and cost of commencing and not completing a degree is considerable. There many factors that contribute to student attrition from engineering degrees (Kuley, *et al.*, 2015), one of which is student engagement. While there are many different views on what constitutes student engagement, some of the aspects that engineering students say engages them are 'real-life applications' and being 'hands-on' (Pomales-García & Liu, 2007). Another factor identified in the literature is the role that Faculty can play by being "willing to change the challenge to fit the students", which introduces notions of personalisation (Heller, *et al.*, 2010). Both Faculty and students identify projects as an active form of learning that engages students. (Heller, *et al.*, 2010). So the challenge was to engage students via a design exercise and improve retention.

In 2013 an 'Embedding Transition Pedagogy Principles Across the First Year Curriculum' internal competitive grants program was initiated, offering $4000 to topic coordinators who could demonstrate how one or more of the six curriculum principles (described below) could be embedded into their first year topic. The Topic Coordinator and lead author was successful in securing a grant to purchase a 3D printer and to develop educational resources (a 3D Printing Handbook and a 50-minute lecture) to support its use, to target the curriculum principles of 'transition', 'curriculum design' and 'engagement'. The 3D printer and accompanying resources were used in Semester 1 of 2014 for the first time.

Pedagogical Rationale

The first year experience is critical for laying down the learning platform to see students through to successful completion of their degree and for a lifetime of learning (Kift, 2015). This concern has led to the formulation of a research-based 'transition pedagogy' (Kift & Nelson, 2005) which is:

> *"a guiding philosophy for intentional first year curriculum design and support that carefully scaffolds and mediates the first year learning experience for contemporary heterogeneous cohorts." (Kift, 2009, p. 2)*

In this, Kift (2009) identifies 6 first year curriculum principles: Transition, Diversity, Design, Engagement, Assessment, and Evaluation and Monitoring. The three focused on with this project were:

- Transition: Students have prior experiences of education and need to transition to the university context of learning. They also need to become engineers which involves engaging with, understanding and identifying with the knowledge, practices and culture of the profession.
- Curriculum design:

  "First year curriculum design and delivery should be learning-focussed, explicit and relevant in providing the foundation and scaffolding necessary for first year learning success. This requires that the curriculum must be designed to assist student development and to support their engagement with learning environments through the intentional integration and sequencing of knowledge, skills, and attitudes." (Kift, 2009, p. 41)
- Engagement: Students should be included in learning communities through collaborative environments and given exposure to active and meaningful learning experiences.

Ways were sought to embed these principles by giving students a design project that introduced them to the ways engineers learn and do (e.g. prototyping), was simple and well supported to allow scaffolding, and engaged them in a real-world hands-on group design task that was personal to them: the design of a mobile phone (smartphone) stand that they could keep.

Goal

The aim of the exercise was to determine if having access to a dedicated 3D printer for the topic would encourage engineering students to engage in the topic and to put their CAD modelling studies into practice to produce rapid prototypes of the designs they create. Prototyping is an important aspect of the design process that can provide valuable insight in terms of human factors and fit (Pahl & Beitz, 1996). This is especially so if a particular design and subsequent modelling is limited to the virtual CAD environment. A physical model, even though it may be scaled down, can highlight potential issues with tolerances, fits and assembly processes that are not readily identifiable on screen.

Rapid prototyping in the form of 3D printing has become significantly cheaper and accessible in recent years (Campbell, *et al.*, 2012). Desktop printers are now within financial reach of the 'home hobbyist', and if not, 'Fab Labs' and some city councils are establishing community areas that encourage the 'maker movement'. Anecdotally, our engagement with industry partners and colleagues has highlighted the value of producing engineering graduates who are experienced and knowledgeable when it comes to 3D printing for design and prototyping purposes.

Approach

Students were exposed to the theory and practice of 3D printing in the form of a 50-minute lecture in week 5 of the topic, and a 3D printing assignment was due 5 weeks later, at the end of week 8 of the semester (after the mid-semester break). The assignment required students to design, model and 3D print a stand for their smartphone device. Students were encouraged to be creative with their design (form) as long as it supported their phone in portrait or landscape mode (function) and printed in less than 60 minutes (design constraint). A 13-page 3D Printing Handbook was distributed electronically, which provided further information on 3D printing along with additional internet links and resources.

Leading up to the assignment the 2-hour weekly CAD class was used as an opportunity for students to refine their design and seek assistance from their Instructor if required. Students were required to submit a *.thing* file for their design as well as an accompanying document that indicated the specifications for their design (such as the number of shells, the amount of infill used, and the layer height for their model). Both files were submitted electronically via the University online learning platform. Students were also required to state the estimated print time for their design, as indicated by the 3D printing software. The 3D printer that was used was a *Replicator 2* from *MakerBot*® Industries (Brooklyn, NY, USA).

At the conclusion of the assignment an evaluation of the 3D printing assignment was conducted via an online survey. Survey questions focussed on three areas: increased engagement, improved understanding, and the overall 3D printing experience. The questions were:

Q1. Before studying this topic, had you ever used a 3D printer before? Yes/No

Q2. Did you enjoy the 3D printing assignment (making your own smartphone stand) this year? Yes (and why)/ No (and why)

Q3. Did having access to a 3D printer for the topic make you: more inclined to prototype, less inclined to prototype, or have no effect on your interest to prototype the idea for your group's design assignment?

Q4. Which 3D printing resources were most helpful to your learning? (tick more than one if appropriate)

- The 3D Printing Handbook
- The lectures notes on 3D printing from Damian
- The links at the back of the 3D Printing Handbook
- Online (YouTube) movie files of 3D printing
- Your drawing/CAD demonstrator
- Other

Q5. Do you have any suggestions on how to improve the 3D printing handbook? If so, please list them below:

Q6. Based on your experience this year using 3D printers, how likely are you to use a 3D printer again in the future for any further design prototyping? (5-point Likert-type scale)

Q7. Did the 3D printing assignment improve your understanding of the Engineering Design topic? (5-point Likert-type scale)

Q8. Did the 3D printing assignment improve your understanding of *AutoDesk Inventor*? (5- point Likert-type scale)

Q9. Do you feel you were more engaged with the topic due to the 3D printing assignment? (5-point Likert-type scale)

Results

In 2014, 92% (n=132) of students completed the 3D printing assignment due in week 8 of the semester, and 59% (n=78) of those that completed the assignment also responded to the survey. In 2015, 98% (n=198) of students completed the 3D printing assignment due in week 9 of semester, and 29% (n=57) of those that completed the assignment also responded to the survey. The lower than expected survey response in 2015 could have been due to the fact that the University was also formally evaluating the topic through an online survey at the same time, which may have caused confusion or 'survey fatigue' for the students (administering an online 'Student Evaluation of Teaching' for a given topic every second year is standard practice at Flinders University). The same survey was administered for both years, meaning 135 responses were received. The results that follow represent responses from both years.

Only 12 students (9%) had used a 3D printer before the assignment, with almost all responders (99%) indicating they enjoyed making their own phone stand. For both years, the most valuable resources for students to complete the assignment, in order of importance, were their CAD Instructor, the 3D printing lecture and notes, and the 3D Printing Handbook (the latter two were both produced specifically for the topic as part of the grant funding). 73% of students believed that having access to a 3D printer made them more inclined to create a prototype for their group Design Challenge, yet in 2014 only 40% of groups made a prototype of some sort. However, this represented an increased number of prototypes compared to previous years, when access to a 3D printer wasn't available.

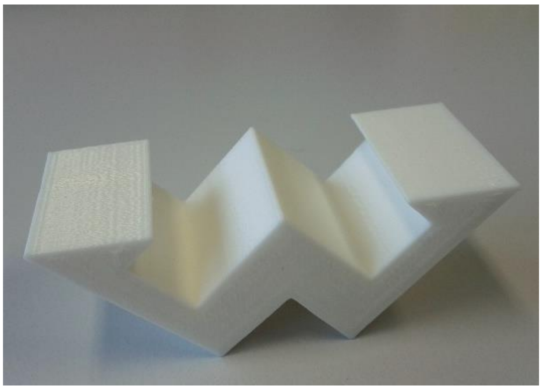
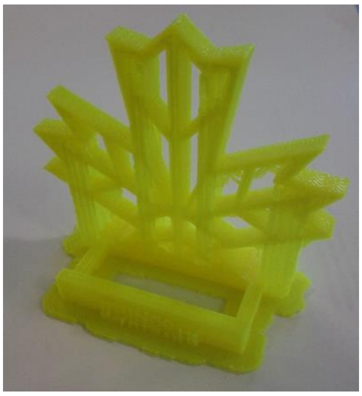
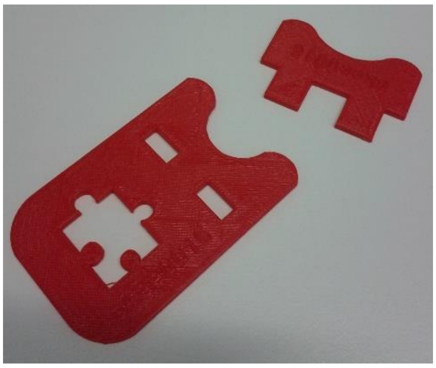
93% of respondents felt that the 3D printing assignment 'really improved' or 'improved' their understanding of the topic; 95% said it 'really improved' or 'improved' their understanding of *Autodesk Inventor*; and 93% reported that they were 'a lot more engaged' or 'more engaged' with the topic due to the assignment. Additionally, CAD instructors who taught across the 2013- 2015 period perceived a significant increase in the CAD modelling skill level of the 'average student' at the end of semester but an analysis of the CAD test results from 2011-2015 did not show a statistically significant difference between the average results over the years.

To determine the impact the 3D printing assignment had on student engagement and hence retention within the topic the number of students who sat the final test for the topic was investigated. In terms of assessment, a hand drawing exercise is administered in week 5 or 6 of the topic and a CAD modelling test using *Autodesk Inventor* is the last assessable item in week 14. In 2014 (the year the 3D printing assignment was introduced) the percentage of students who completed the hand drawing exercise but ***did not*** sit the CAD test decreased to 4.2% (n=6) of the cohort, compared to 6.7% (n=9) in 2013 and 5.3% (n=6) in 2012. In 2015, 5.9% (n=12) of the cohort completed the hand drawing exercise but did not sit the final CAD modelling test, which was a slight increase compared to 2012 and 2014 but less than the 2013 cohort. Over the four-year period, the average attrition rate for the topic as defined above (that is, students who were paticipating in the topic in week 5 or 6, but not in week 14) was 5.5%.

Examples of the 3D printed phone stand designs that the students produced are shown in Table 1. In 2014 almost all students chose to design a single piece for their phone stand, whereas in 2015 significantly more students chose to design a multi-piece phone stand that could fold up and pack away, minimising the volume of the overall design (see Table 1 for examples). As explained by a few students, this meant the stand could be disassembled, put into their pocket and taken to work/school where it could be reassembled and used, rather than left on their desk at home as it was too bulky to transport (see (e) and (f)).

Another design aspect that was noticed with the 2015 cohort in particular was the allowance/provision for adjustment in terms of how a phone was supported vertically, depending on the viewing angle that was most desirable. This is illustrated with design (d), where the 'man' can be moved forward or back along the base, depending on the desired angle.

Table 1: Examples of the 3D printed phone stands the students made for their assignment

 (a)	 (b)
 (c)	 (d)
 (e)	 (f)

The survey provided two open ended questions to solicit more detailed or specific feedback about the assignment. On the question of '*Did you enjoy the 3D printing assignment (making your own smartphone stand) this year?*', an indicative response was:

> "*I enjoyed it as it didn't feel like an assignment, it felt more like I was designing a tool for myself. The fact that I was able to print it and get it back, meant I wanted to put in extra effort to make sure it would look good on my desk, and work well for my phone*".

This reinforced the thinking behind asking the students to design something that they would then go on to use afterwards (a 'personalised' assignment) rather than a 'widget' for academic and assessment purposes.

Many students commented that it was fun, and that:

> "*…it made the learning experience feel more 'real' and the effort/time taken to figure out the CAD program, worthwhile*".

Discussion

Overall, the assignment proved to be one that students enjoyed and engaged with, providing them with an opportunity to apply and scaffold their theoretical learning and understanding to design and produce a stand for their smartphone. A key element of the assignment was the personalisation of the deliverable, with many students commenting that they put more effort into the design and quality of the assignment because of the fact they would keep and use it after it was marked and returned.

Results do not indicate that the assignment altered overall student retention across the topic as the proportion of students completing the final CAD test in the last teaching week of the semester fluctuated across the four years investigated. However, a recent *Australian Learning and Teaching Council* (ALTC) study highlighted that most student attrition occurs over the first two years of study for an engineering degree (14-35%), when 8 different Australian institutions were studied (Godfrey & King, 2011). This attrition range is much greater than the attrition reported for the topic earlier (5.5%), although the definition of attrition does vary. The fluctuation seen across the years regardless of the presence of 3D printing implies that other factors impact on student retention and these should be the focus of future efforts. The results do indicate high levels of engagement with the topic as evidenced by the student comments and the sophistication of the designs.

One of the benefits of the assignment was the students' increased confidence with using CAD, as noted by CAD Instructors. The images in Table 1 provide an insight into the variety and complexity of student designs. A key aspect that the 3D printing assignment brought to the topic was an improved understanding of physical constraints on a model, the process of assembly, and the difficulties of fits and tolerances. Improved skills and understanding were reflected not only in the 3D printing assignment submissions but also in the quality of CAD designs and prototypes made for the semester long Design Challenge – which is a formal assessment of the students' understanding of the engineering design process. An increase in the number of 3D printed prototypes was evident for the Design Challenge in 2014 and 2015 compared to previous years.

After completing the topic in first year, most students go on to study the second year topic 'ENGR2781 Mechanical Design Project'. This involves the students competing in Engineers Australia's 'Warman Student Design & Build Competition', which requires students to design and build an autonomous robot to solve a particular challenge. Students are expected to prototype their early designs using 3D printing and laser cutting techniques, meaning the second year topic is a logical application and extension of the engineering design process.

Additionally, students have demonstrated an ability to transfer their learning across topics, into non-design focussed topics. Topic Coordinators from subsequent semesters have reported an increased number of students who 3D printed their prototype design, most notably for the *Engineers Without Borders Challenge*, which is taught within 'ENGR1401 Professional Skills'.

Conclusion

A 3D printing assignment that encouraged students to make a stand for their smartphone device as part of a first year design topic was shown to engage and motivate first year engineering design students. This is in alignment with Godfrey and King's recommendation to '*ensure that the curriculum explicitly engages and inspires students with engineering thinking* *and doing*' (Godfrey & King, 2011). Key learning outcomes from this exercise were that it used 'current', modern technology that is still in the headlines on a regular basis, and that the personalisation of the assignment made the students put in more effort to achieve a better quality outcome. First year students demonstrated an ability to transfer and apply their learnings to other non-design focussed topics.

This project generated a mini 'module' of information and teaching material around 3D printing, providing resources that have been shared with other Faculty and University staff, outside of the target audience. The 3D Printing Handbook, which is revised year to year, now serves as the basic introduction to 3D printing in the new Digital Fabrication Laboratory 'maker-space' at Flinders' new Tonsley Campus. It is also used in other engineering topics to support student learning.

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