Developing More Engaging Engineering Practicals

Terry Lucke
University of South Australia,
Adelaide, Australia
Terry.lucke@unisa.edu.au

***Abstract**: This paper reports on changes to two practical projects that were implemented to improve the level of student engagement in a second year civil and mechanical engineering course. The practicals were redesigned so they could be conducted by small groups of students in the classroom instead of in the laboratory. The new practicals were very successful and were observed to promote increased student engagement and effective collaboration between team members.*

1. Introduction

Mechanics and Structures is a second year undergraduate course that is taken by both civil and mechanical engineering students at the University of South Australia (UniSA). The course introduces students to the properties of common engineering materials and the theoretical content is typical of a *Mechanics of Solids* type engineering course. Projects and practicals are used to ensure that students understand how this theory is applied in design practice and to develop students' analytical and problem solving abilities.

Mechanics and Structures is taught through a variety of teaching and learning methods, as well as self-directed study by the students. A new concept is introduced each week through the weekly two-hour lecture and a two-hour tutorial session allows students to apply the theoretical concepts introduced in the lectures. An innovative peer assisted learning program arranges for high achieving students from previous cohorts to help explain the more difficult concepts in the tutorial sessions. Course evaluation survey responses generally reflect the success of the peer assisted learning program.

The average class size for Mechanics and Structures is typically around 100 students with approximately 25% of these students being international students. The class is generally separated into five separate groups of around 20 students each for the tutorial and practical classes.

The learning that takes place in the lecture and tutorial classes is then reinforced by four different practical projects that are conducted in small groups to further extend students' understanding of concepts. The four projects are: the Spaghetti Bridge Competition, the Beam Deflection practical, the Column Buckling practical and the Signpost Design Project. The four practical projects are discussed in more detail in Section 3.

2. Student Engagement

There has been much literature and research presented over the last 20 years that promotes student-centred learning and active learning principles. Some of the more distinguished advocates for these principles include Prosser and Trigwell (1999), Biggs (1996; 2003) and Ramsden (2003). There has been a shift in the focus of teaching and learning in higher education away from traditional teacher-centred activities towards more student-centred learning approaches. Active learning principles recognise that when students are actively engaged with their learning, they are much more likely to understand the concepts. Krause (2005) affirms that student engagement has emerged as a cornerstone of the higher education lexicon over the last decade and this is a key element of UniSA's new Teaching and Learning framework (Lee, 2007).

Student engagement has been shown to promote deeper learning outcomes. Astin's theory of student involvement (cited in Krause, 2005) contends that students learn by being involved. Bonwell and Eison (1991) reinforce this theory by stating that when students are actively involved, they engage in higher-order thinking tasks such as analysis, synthesis, and evaluation. Pascarella and Terenzini (cited in Smith et al., 2005) expand on this idea by stating that the greater the student's involvement or engagement in academic work or in the academic experience at college, the greater his or her level of knowledge and general cognitive development.

Biggs (1999) states that good teaching involves getting students to use higher level cognitive processes by promoting student engagement. Shuell (cited in Biggs, 1999) reinforces this argument by stating that it is the teacher's fundamental task to get students to engage in learning activities that promote the desired outcomes. Teaching activities therefore need to be designed to promote more student engagement and programs need to incorporate more opportunities for students to experience teamwork (Mills and Treagust, 2003). Duderstadt (cited in Smith et al., 2005) goes further to explain that teachers in the 21st Century may need to set aside their roles as teachers in the traditional sense and instead become designers of engaging learning experiences, processes and environments.

It can be therefore concluded from contemporary educational literature concerning student-centred learning that activities that increase levels of student engagement will generally facilitate higher level cognitive processes and should be included in engineering courses where possible.

3. Practical Projects

Mechanics and Structures is taught over a period of 13 weeks. Students are required to attend approximately six hours of classroom activities each week and also expected to spend at least four hours undertaking self-directed study. The six hours attendance consist of a 2hr lecture where the new theoretical content is introduced, a 2hr tutorial session to assist students in understanding the theoretical content and a 2hr practical project session where the theory is put into practice.

Students undertake four separate practical projects during the semester with the larger projects running over a number of weeks. The practical project components of the course are worth 30% of the total course mark with Practicals 1 and 4 being worth 10% each and Practicals 2 and 3 worth 5% each. Students form into groups to undertake the practicals and the typical group size for Practicals 1 and 4 is four students while the number of students in the groups for Practicals 2 and 3 is usually two. The four practicals are discussed in the following sections.

Practical 1 - Spaghetti Bridge Competition

The first practical project conducted in the Mechanics and Structures course is the spaghetti bridge competition. The idea behind this project-based learning activity is that small groups of students combine their knowledge and skills to design and build a lightweight bridge made entirely from spaghetti and glue to carry the heaviest load possible. Prizes are awarded for the winning designs and group members of the winning teams gain extra marks. The top team members are awarded five extra points, the second and third place teams receive four and three extra points respectively and the fourth and fifth place teams gain two extra marks each. A few of the students' course evaluation responses shown below indicate that it is definitely one of the highlights of the course.

Course Evaluation Question: *Overall, what are the strengths of this course?*

Responses: Go the spaghetti bridge! Spaghetti bridge was fun; First prac with the bridge really got us thinking about what would be the best way to design and build it.

The spaghetti bridge practical is an excellent example of the benefits of project-based learning and undeniably demonstrates the benefits of using these principles. Mills and Treagust (2003) affirm that students who participate in project-based learning activities are generally more motivated by them and demonstrate better teamwork and communication skills. The increased student motivation and engagement that this practical generates is clearly evident in the consistently high attendance, participation and grades.

Another observed benefit that the spaghetti bridge project promotes for the team members is a sense of project ownership and belonging. Smith et al. (2005) state that it is vital for students to have peer support and be active learners, not only so they learn the material in a deeper fashion but also so they get to know their classmates and build a sense of community among themselves. During the spaghetti bridge project the students work together closely and intensely for a period of three to four weeks where they quickly learn to negotiate tasks and to get along. Cooperative group work also teaches group members vital social skills (Johnston et al., 1998). This cooperative teamwork spirit is illustrated in Figure 1 which shows students working on their spaghetti bridge projects.

Figure 1 – Engagement and Teamwork during Spaghetti Bridge Practical

The spaghetti bridge competition also promotes engagement with industry and high school students. The competition is now sponsored by a local engineering employment consultancy and the bridge designs are judged by the top bridge engineers in the South Australian Department for Transport, Energy and Infrastructure. A simplified version of the competition is also conducted by high school students on engineering open days at the University.

After completion of the three week collaborative design and construction period, the strength of each group's bridge is then tested, the winners are decided and the industry prizes are awarded. The spaghetti bridge practical has consistently proven itself to be a reliable and effective method of promoting student engagement and overall interest in the Mechanics and Structures course. The effect of this collaborative and engaging project is that within the first few weeks the students generally appear to be engaged, motivated, interested and eager to learn.

In previous years, the next two practicals following the spaghetti bridge were the beam deflection practical and the column buckling practical respectively. Although these are very important concepts for students to understand, these practicals were conducted in the laboratory and were demonstration sessions only. Students were generally observed not to engage well with the practicals during these demonstration sessions and often appeared unmotivated and bored. Students attending a typical laboratory demonstration session is shown in Figure 2.

This year it was decided to try a new approach to increase the level of student engagement with these two practicals. They were redeveloped so that they could be conducted in small groups within the classroom in order to promote the type of collaborative learning group recommended by Johnson et al. (1998) and Mills and Treagust (2003). The following sections describe the new approach taken this year to promote more student engagement with the beam deflection and the column buckling practicals.

Figure 2 – Students Attending a Typical Laboratory Based Demonstration Session

Practical 2 - Beam Deflection

The aim of the original second practical project was to observe and measure the bending strains and deflection of a beam subjected to transverse loading. This practical was conducted in the laboratory instead of the classroom. A laboratory technician set up and ran the practical using the apparatus shown in Figure 3a. Students gathered around the apparatus in a similar manner to that shown in Figure 2 to observe the practical. They then recorded the common results for inclusion in their written report.

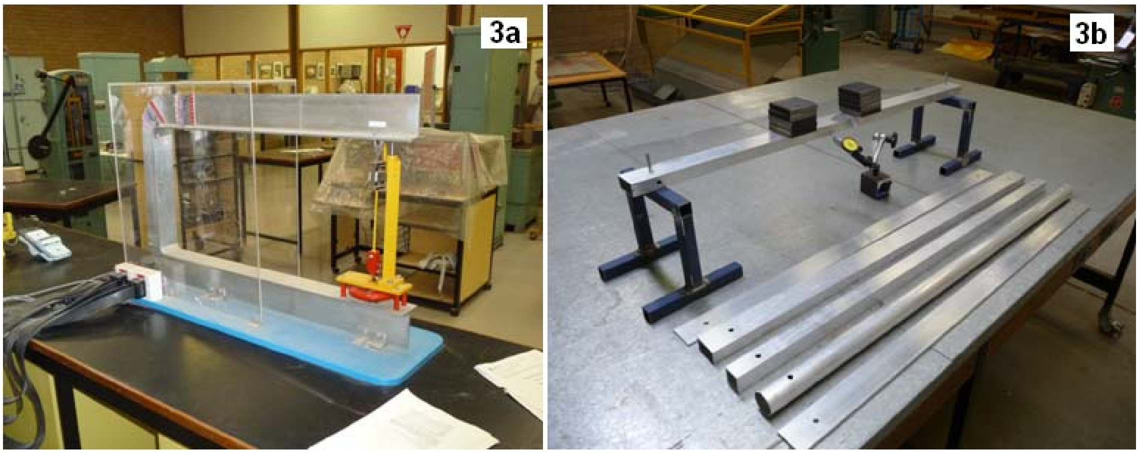

Figure 3a – Original Beam Strain and Deflection Testing Apparatus
Figure 3b – New Desktop Beam Deflection Testing Model

As part of the new approach in developing more engaging practicals, six new desktop beam deflection models were built. The models were designed to be used in the classroom by groups of four students. One of these models is shown in Figure 3b.

The new deflection models (Figure 3b) consist of six different aluminium beam sections which are individually placed onto stands at each end. A plunger type dial gauge is placed underneath the beams and zeroed when no load is applied. Various incremental point and uniform loads are then applied to the beams and students are required to measure and record the deflections for each load increment.

The students also used a set of vernier callipers to measure the dimensions of each of the different aluminium beams. To reinforce the relevance of the practicals the students then needed to use the theory they learned in the lectures to calculate the second moment of inertia for each beam. The effects that varying geometrical properties had on beam deflection behaviour was then observed and discussed in their reports. The practical procedure promoted much more engagement and teamwork as illustrated in Figure 4.

Figure 4 – Collaborative Groupwork with New Beam Deflection Testing Models

The assessment for the practical comprised two components, writing a short practical report and developing an Excel spreadsheet. The report was of a typical engineering type that included the practical outline, methodology and discussion. The students compared measured to theoretical results and discussed the reasons for any discrepancies.

It has been observed that many second year engineering students have little or no experience in the use of Microsoft Excel. It appears that there may be an (incorrect) assumption that most students already know how to use Excel. First year engineering students are often taught to use higher order software programs such as *MATLAB* and *SolidWorks* before being introduced to more basic programs such as Excel even though this program is used extensively in industry. The Excel component of the assessment was therefore included in this practical to introduce the students to the program and help them develop the skill levels expected by industry.

The students were required to enter the dimensions of the different beams into Excel cells and then calculate the second moment of inertia value for each beam section using only functions of these cells (numerical values were not acceptable). They were also required to develop charts in Excel to compare theoretical beam deflection values to the observed values. The students responded very favourably to this part of the practical and appeared to engage well with the program. The quality of the submitted spreadsheets (and reports) displayed much creativity and achievement. This introduction to Excel was then further developed in the following two practicals.

Practical 3 - Column Buckling

The aim of the original third practical project was to observe and measure the buckling behaviour of columns under different end fixing conditions. A laboratory technician set up and ran the practical using the apparatus shown in Figure 4a. Students gathered around and observed the practical and then recorded the results for inclusion in their report.

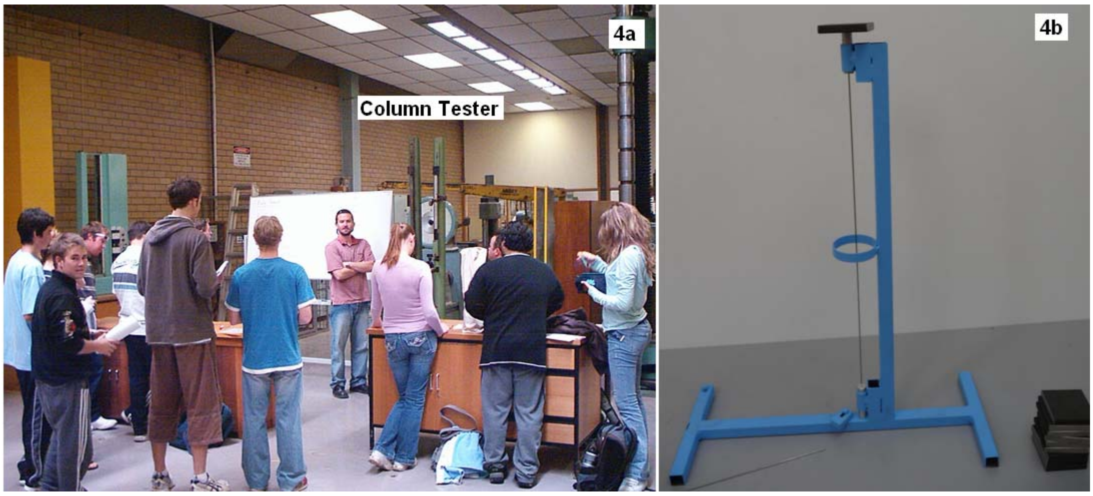

Figure 4a – Students Observing Original Column Buckling Testing Apparatus
Figure 4b – New Desktop Column Buckling Testing Model

Six new desktop column buckling models were built as part of the new approach in developing more engaging practicals. The models were designed to be used in the classroom by groups of four students. One of these models is shown in Figure 4b.

The new column buckling models (Figure 4b) consist of a stand where various lengths of 2.4mm diameter extruded wire are tested for buckling behaviour. Three different materials are tested, namely stainless steel, mild steel and aluminium. The model allows for different end-fixing conditions to be replicated in order to observe the effect these have on the buckling behaviour of the different materials. The lengths of wire are placed in the model and loads are applied axially to the wire by stacking weights on top of the wire holder. Figure 4b shows the first weight being applied to one of the wires. A vernier calliper is then used to measure the deflection within the middle ring. Figure 5 again illustrates the degree of engagement and teamwork that this practical produced.

Figure 5 – Collaborative Groupwork with New Column Buckling Testing Models

The assessment for Practical 3 was similar to that for Practical 2 and also involved writing a short practical report and developing an Excel spreadsheet. The students developed charts in Excel and compared the theoretical deflection values to the observed values. The students again responded very favourably to this part of the practical and much creativity and pride was demonstrated by the quality of the submitted work.

Practical 4 - Signpost Design

The final practical project combines all the theoretical and practical knowledge that the students have acquired throughout the course. This practical requires students to develop a comprehensive spreadsheet in order to determine the most economical steel tube section to support a cantilevered roadside signpost subjected to wind loadings. This practical builds on the Excel skills that were gained in Practicals 2 and 3. Observation of students' behaviour while they were undertaking this practical has shown that it also promotes student engagement and collaborative teamwork.

Results and Discussion

The level of student engagement with the new practicals was observed to improve significantly and this is clearly evident in Figures 4 and 5. The nearly 100% attendance rate recorded for the new practical classes is further testament to the increased level of interest that these practicals generated. There were also considerably more course evaluation responses that specifically mentioned the practicals this year than in previous years. Some of the responses to the same question about the strengths of this course are shown below:

Responses: *1. Practical elements were good; 2. the practicals were relative to course work; 3. practicals were interesting & helped develop my understanding of concepts; 4. hands on practical work along with well constructed lectures and tutes; 5. good teaching, relevant practicals; 6. practicals were interesting and enabled us to practice what we have learnt.*

The overall quality of the work submitted this year by the students for the two new practicals was observed to be of a much higher standard than for previous years. Although the new practicals were clearly successful in improving the level of student engagement, teamwork and understanding, this was not noticeably reflected by any large increase in individual practical marks. This is possibly because the marks allocated for each of the new practicals was only 5% of the total course mark. This may be an issue that requires further investigation in the future.

Figure 6 shows the number of students that did not submit a practical report for one of the four practicals over the last three years. Although the data could be interpreted to show that there was more engagement and student ownership of Practicals 2 and 3 this year than in the previous two years, there is not enough evidence to verify this claim. The results of course evaluations over the next few years should, however, supply enough data to properly analyse these results.

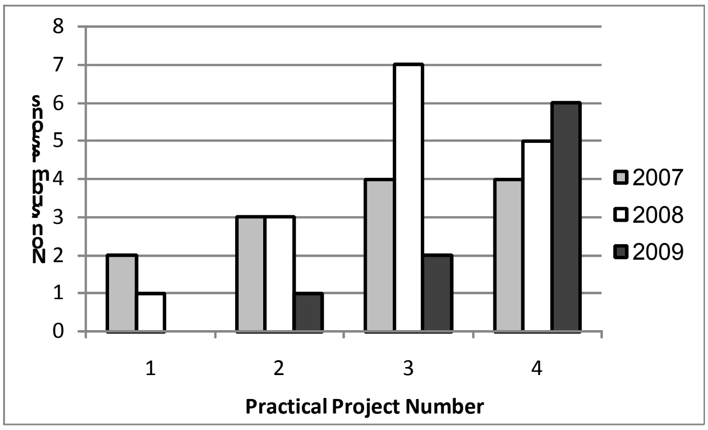

Figure 6 – Number of Students that did not Submit a Practical Report

Interestingly, Figure 6 also shows that the number of students that did not submit this year's Practical 4 report was higher than the previous two years. This may be because this year I updated student marks online after each practical or test was completed and several students may have decided that their standing was high enough to pass the course and therefore they did not bother with the last practical. This requires further investigation.

While no formal student evaluation procedures have yet been undertaken to specifically analyse any differences between the level of student engagement in this year's compared to previous years' practicals, the increase in student interest and involvement that was observed during the classes was very promising. Furthermore, the responses mentioned above to the overall course evaluation indicated how much many of the students enjoyed the practicals this year.

Conclusions

This paper reports on changes that were implemented to two practical projects in a second year civil and mechanical engineering course to improve the degree of student engagement. Although there is insufficient evidence to make any substantial claims on the pedagogical benefits of the redeveloped beam deflection and the column buckling practical designs, the increased level of student engagement and involvement observed during this year's practicals was evident. This paper illustrates that with a few materials and a little imagination, engineering practicals can be designed to promote more engaging and rewarding student learning experiences.

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