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Using Hands-on Models to Improve Student Learning Outcomes in Statics

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BACKGROUND

Traditionally, Engineering Statics is one of the most difficult courses that first year engineering students have to deal with. It is also one of the most important and pivotal courses in their development and understanding of basic engineering principles. Poor performance in Statics often has a follow-on effect that causes students to struggle with simple concepts throughout the rest of their studies (Steif, 2004; Molyneaux et al., 2007) or even to drop out of engineering programs altogether (Rezaei et al., 2007; Devine & Kimmins, 2010). The difficulties engineering students have with learning Statics are well recognised and a substantial amount of literature has been published in this area (Steif, 2004; Goldfinch et al., 2008; Dollár & Steif, 2006).

PURPOSE

This paper describes an initiative to improve student learning outcomes in Engineering Statics and Mechanics of Materials by developing a set of low cost, hands-on, interactive models for students to use to demonstrate the underlying theory and to help them to better understand basic engineering mechanics principles.

DESIGN/METHOD

Practical classes were developed that centred on the use of hands-on, interactive models to demonstrate fundamental engineering mechanics principles. Students were asked for feedback on the individual practicals and whether they thought that the practicals were effective in demonstrating the particular underlying principles. Students were also asked to comment on whether they thought that the practicals had actually improved their understanding of the theory and for any suggestions on how to improve the effectiveness of the practical projects. Students' final grades were also compared to those from other engineering institutions in an attempt to evaluate the effectiveness of the initiative.

RESULTS

The new practical classes using the hands-on demonstration models were very successful and students were observed to fully engage with the activities during the classes. Student feedback after using the models was overwhelmingly positive with many students affirming that using the models had helped them to better understand the theory. Some valuable insights into student perceptions were gained through the feedback process and useful suggestions on how to improve the classes in future were obtained. Pass rates for this class were better than average rates presented in the literature (Manteufel & Karimi, 2010; Benson et al., 2010).

CONCLUSIONS

This paper reports on the effectiveness of using low cost, hands-on, interactive models to improve student learning outcomes in Engineering Statics and Mechanics of Materials. Student evaluations on the use of the models demonstrated that they were very effective in explaining the underlying concepts and helped students to better understand the relevant theory. Although there is insufficient evidence available at this stage to make any substantial claims on the pedagogical benefits of using the hands-on models, the level of student interest and engagement during the practical classes was clearly evident and this reinforces previous study results.

KEYWORDS

Engineering Statics, hands-on models, experiential learning, student engagement, learning outcomes

1. Introduction

Much of the pivotal engineering education research in the last two decades promotes student-centred learning and active learning principles. These principles recognise that when students are actively engaged with their learning, they are much more likely to understand the concepts. The more involved and engaged the student is, the greater his or her level of knowledge acquisition and general cognitive development (Smith et al., 2005) and engagement in higher-order thinking tasks such as analysis, synthesis, and evaluation (Bonwell and Eison, 1991). Biggs (2003) explains that the more motivated and scholarly students generally adopt a deep learning approach regardless of the teaching method, while the less scholarly students are more likely to take a surface approach. He maintains that the way to narrow the gap in understanding between these students is to involve them in activities that are engaging and require them to use higher-level cognitive processes.

The value of successful group collaboration project work for students' personal and academic development is seen as being extremely important as it not only encourages the deep learning approaches needed to fully understand the material, but also acquaints students with other class members and helps build a sense of community. Such activities tend to maximise all the group members' learning outcomes and have been shown to promote higher individual achievement than competitive or individualistic approaches (Smith et al., 2005). Ditcher (2001) affirms that employers' expectations have also changed and they now demand engineering graduates that can work cooperatively with others and have good communication and management skills. Teaching activities therefore need to be designed to promote more student engagement and engineering programs need to incorporate more opportunities for students to experience teamwork (Mills and Treagust, 2003).

Engineering Mechanics (incorporating areas such as statics, strength of materials, mechanics of solids and so on) is a core area of curriculum for both civil and mechanical engineering students. It is traditionally regarded by many students as conceptually difficult and theoretical. Consequently the pass rates are unacceptably low (Goldfinch et al., 2008, Divine and Kimmins, 2010, Karim, 2011, Steif, 2004). Although active learning techniques have been acknowledged as effective means of improving student engagement in their learning, pressures of time and economy have led to number of hands-on activities being reduced within engineering programs, or replaced with on-line alternatives (Feisel & Rosa, 2005). However, where personal interaction between students is possible in traditional face-to-face learning environments, the use of small group, hands-on practical/project-based activities, has been repeatedly shown to provide positive student learning outcomes (Bernhard, 2010; Molyneux et al. 2007; Baldock and Chanson, 2006).

This paper describes an initiative that was undertaken to improve student engagement and learning outcomes in two new core undergraduate engineering mechanics courses, namely Engineering Statics and Mechanics of Materials. A set of low cost, hands-on, interactive models were developed for students to use in small groups that demonstrated the underlying theory and helped them to better understand the basic engineering mechanics principles.

2 CORE ENGINEERING MECHANICS COURSES

2.1 Engineering Statics

Engineering Statics is a first year undergraduate course that is taken by civil and mechanical engineering students at the University of the Sunshine Coast (USC). The course ran for the first time in 2011 and incorporates typical statics topics such as concurrent and non-concurrent force systems, equilibrium of forces, centre of gravity, friction and hydrostatics forces. It is taught over a period of 13 weeks. Students are required to attend an average of four hours of classroom activities each week and are also expected to spend at least four hours undertaking self-directed study. Attendance consists of a two hour lecture, where the a new theoretical concept is introduced each week, a one hour tutorial session to assist students in understanding the theoretical content and a two hour practical/project session each fortnight where the theory is reinforced by six different practical projects using the new hands-on demonstration models: Force Resultants, Summing Moments, Method of Sections, Centroids, Friction and Hydrostatic Forces.

2.2 Mechanics of Materials

Mechanics of Materials is a second year undergraduate course that is taken by civil and mechanical engineering students. The course also ran for the first time at USC in 2011. The course incorporates topics such as stress and strain, torsion, beam deflection and column buckling. It is taught in a manner similar to Engineering Statics. There are four different practical projects: the Spaghetti Bridge Competition, the Beam Deflection practical, the Column Buckling practical and the Signpost Design Project.

3 HANDS-ON ACTIVITIES TO PROMOTE STUDENT ENGAGEMENT

Students in Engineering Statics and Mechanics of Materials undertake a number of separate practical projects during the semester with the larger projects running over a number of weeks. The practical projects component of the course is worth 30% of the total course mark with the individual exercises being worth 5% or 10% each. The remaining course assessment consists of 10% for a mid-term test, 20% for weekly tutorial problems and 40% for the final examination. Students form into self-selected groups to undertake the practicals. The typical group size for each practical/project is four students. The students were required to submit a short practical report that included their calculations, observations and discussions regarding any discrepancies between calculated and observed results.

3.1 Force Resultants - Statics

The aim of this practical was to investigate and prove the theory that the resultant of a number of concurrent forces acting simultaneously at a single point can be determined by simple addition of the forces graphically, either tip to tail or by breaking the forces down into their x and y components and adding these separately. Students used a simple three force system consisting of a hanging weight, a pair of force transducers and a protractor to demonstrate the theory of concurrent forces and equilibrium (Figure 1a). Figure 1b shows some of the students undertaking the practical.

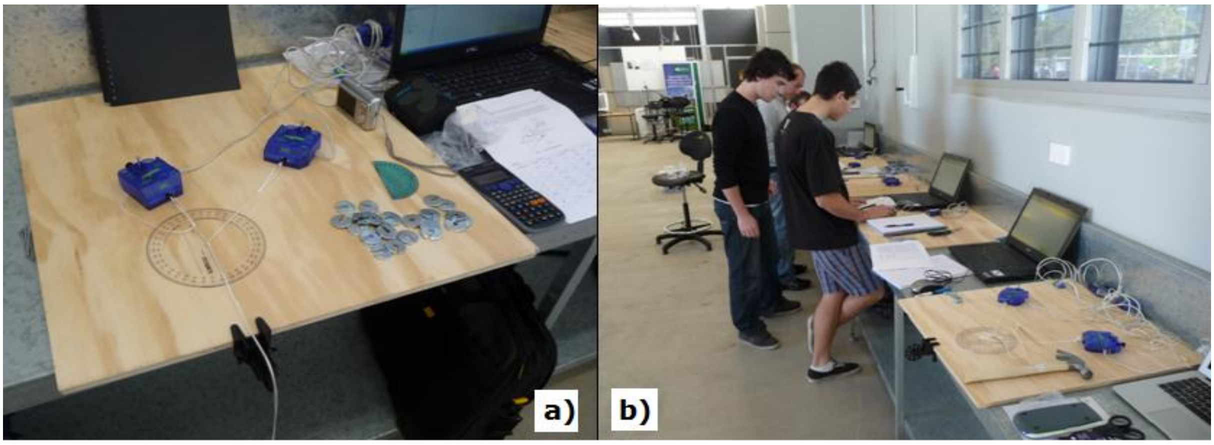

Figure 1: Force Resultants Practical

3.2 Summing Moments - Statics

The aim of this practical was to investigate and verify the theory that the support reactions of loaded beams can be found by summing the moments about each of the supports separately. Students were firstly given a worksheet showing 10 different beam loading cases. Once the students had used the theory to calculate the reactions at the supports, they were then given a loading set consisting of a pair of small kitchen scales, a simple beam and a quantity of M24 steel nuts to use as weights (Figure 2a). The students then replicated each of the 10 loading cases using the loading set and recorded the actual support reactions on the scales (Figure 2b).

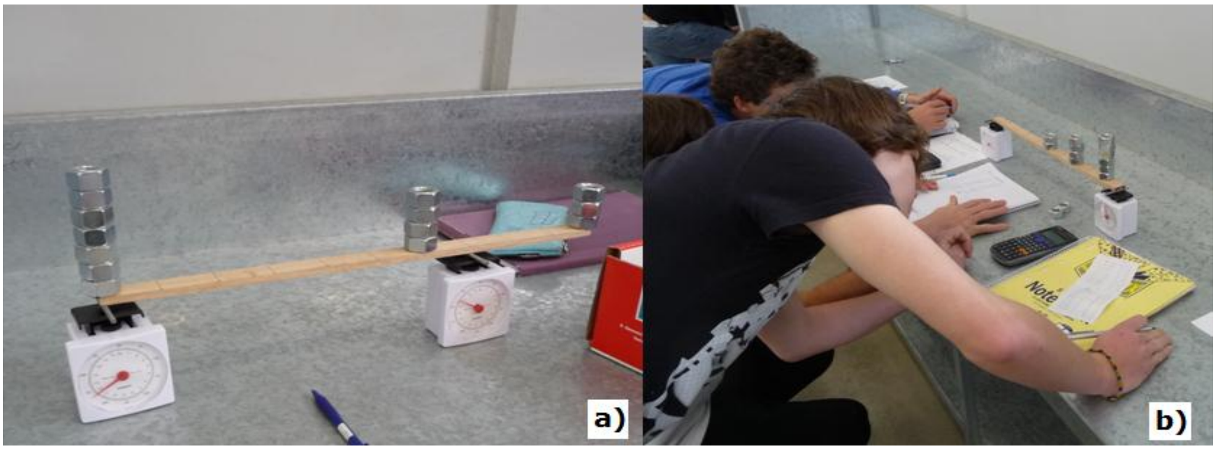

Figure 2: Summing Moments Practical

3.3 Method of Sections - Statics

The aim of this practical was to investigate and verify the theory that the axial loads produced in truss members due to an applied load acting on the truss can be found by using the Method of Sections. Several truss configurations were assembled using the children's building set, K'Nex. The truss was first weighed and the support reactions were determined. An imaginary "cut" was made be removing the appropriate truss members and the truss was then supported on a Statics Board using magnetic pulleys and weights. The amount of load required in each axial member to produce equilibrium conditions was then determined using the hanging weights.

3.4 Centroids - Statics

The aim of this practical was to verify the theory that the Centroid of an object constructed from a combination of simple shapes can be found by summing the 1st Moment of Area of the shapes and dividing this sum by the sum of the areas of the individual shapes. Students were firstly given a worksheet showing three different combined shapes and they were required calculate the position of the Centroids for the shapes (Figure 3a). Once the students had used the theory to calculate the position of the Centroid for each of the three shapes, they were then required to draw and fabricate them using cardboard. They then used the simple pin and plum bob method to locate the actual position of the Centroids (Figure 3b).

3.5 Dry Friction - Statics

The aim of this practical was to investigate and verify the theory of dry friction. Students first calculated the theoretical force required to move a block of wood along a track made from three different materials at different angles of inclination. They then tested the theory with the track horizontal, by attaching a string to the block, which passed over a pulley and had hanging weight attached that produced enough a lateral force to move the block.

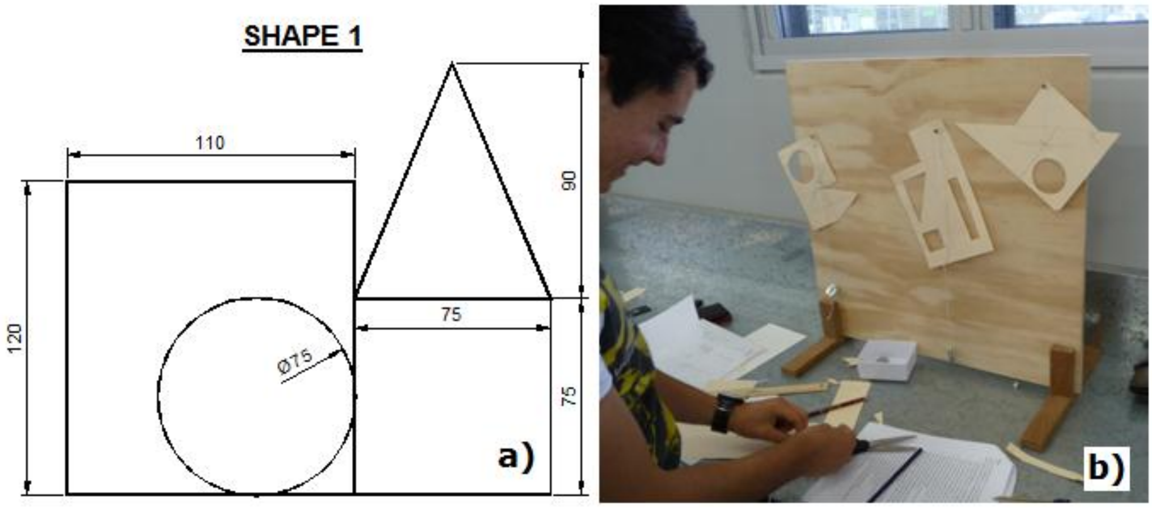

Figure 3: Centroids Practical

3.6 Spaghetti Bridge Challenge – Mechanics of Materials

The first practical project conducted in the Mechanics of Materials course is the spaghetti bridge competition. 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. The design objective is to achieve the highest ratio of applied load to bridge weight. After completion of the three week collaborative design and construction period, the strength of each group's bridge is tested, with prizes awarded for the winning design and the most aesthetic design. 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. This cooperative teamwork spirit is illustrated in Figure 4a which shows one student group working on their spaghetti bridge project and one of the bridges being tested (Figure 4b).

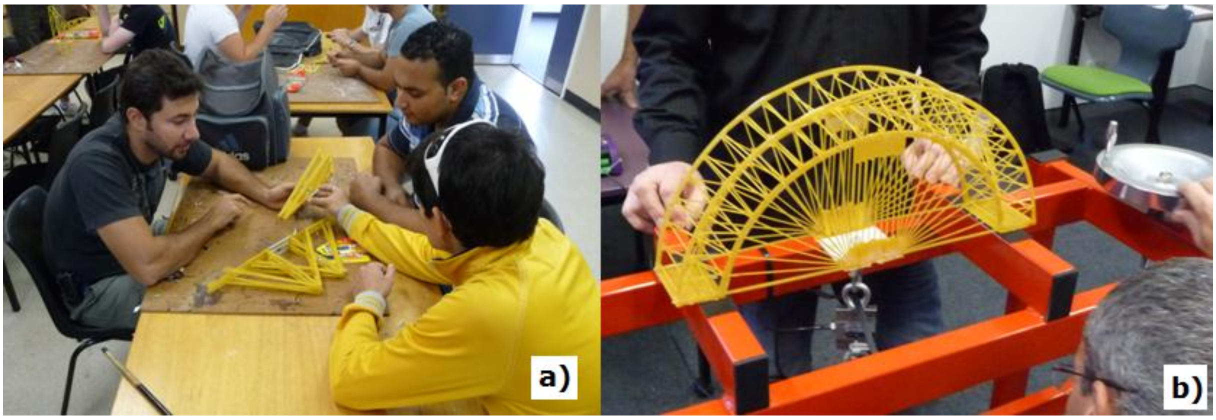

Figure 4: Spaghetti Bridge Challenge

3.7 Beam Deflection – Mechanics of Materials

The aim of this practical was to investigate and verify the beam deflection theory when subjected to lateral loadings. Deflection models were constructed that consisted of five different aluminium beam sections of the same length (1m) that are placed onto support stands at each end, one at a time (Figure 5a). A plunger type dial gauge was placed underneath the beams to measure deflection. Various incremental point and uniform loads were applied and the deflection readings were then compared to those obtained using the theory. Figure 5b shows some of the students undertaking the beam deflection practical.

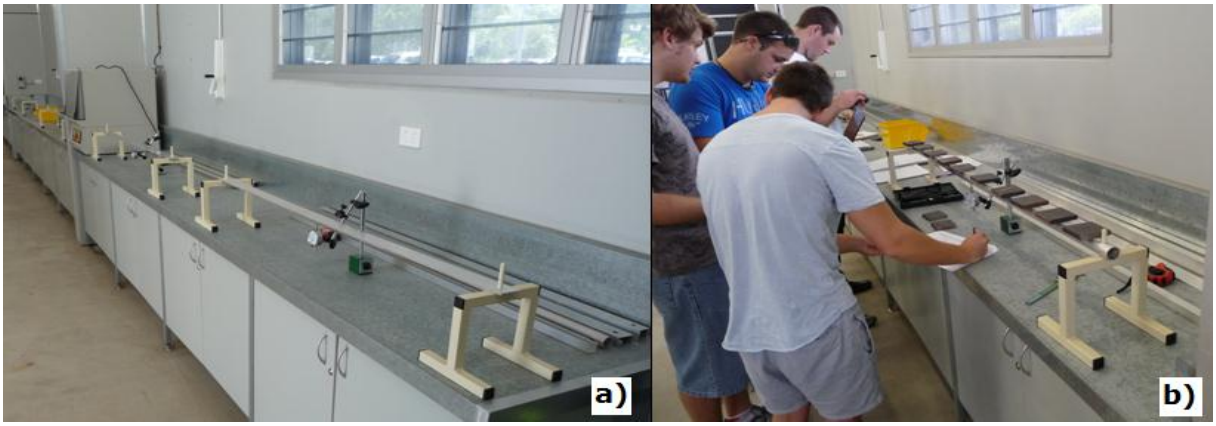

Figure 5: Beam Deflection Practical

3.8 Column Buckling – Mechanics of Materials

This practical was developed to investigate the behaviour of slender members under axial compression from above. The models allow for different end-fixing conditions in order to observe the effect this has on the buckling behaviour. Loads are applied to the wire by stacking weights on top of the wire holder (Figure 6) and the deflection readings were compared to those obtained using Euler bucking theory.

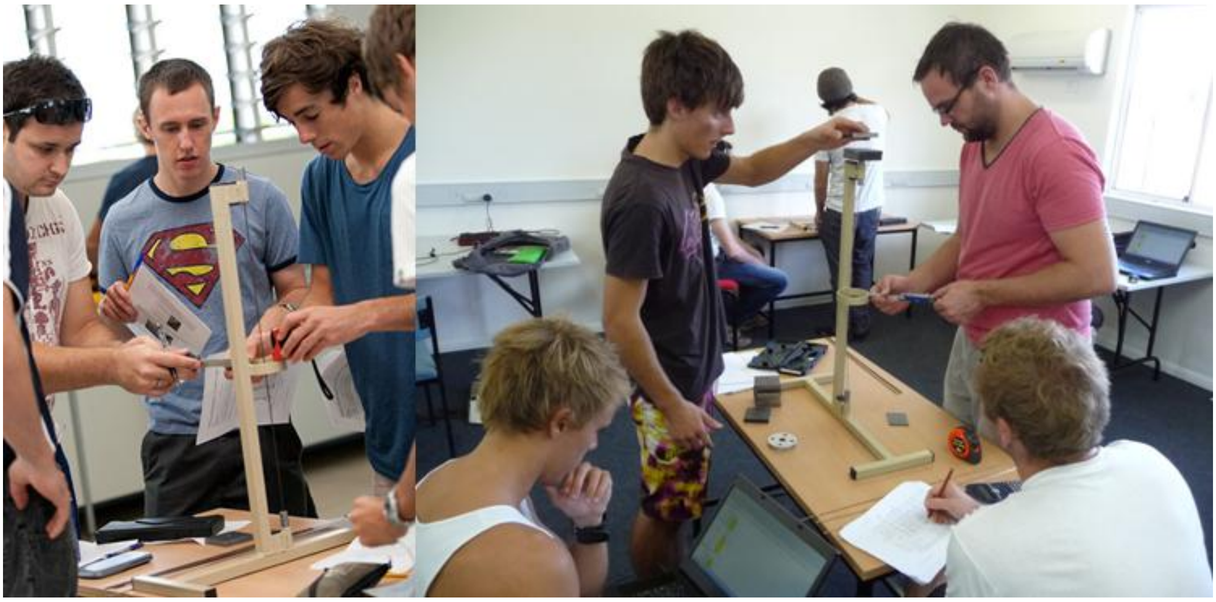

Figure 6: Column Buckling Practical

4 Project Evaluation and Discussion

A range of evaluation methods have been used to gauge the effectiveness of the new practicals in achieving increased student engagement, including classroom observation, standard course evaluation instruments, student surveys and analysis of attendance and assessment results.

4.1 Classroom observations and Students' comments

A significant increase in the levels of student engagement was observed during the new practical classes (Figures 1-6). The small student groups appeared to work very well together with all group members taking responsibility for their roles in the practicals. There was much interaction and discussion among the group members and they appeared to enjoy the practical exercises. This is reinforced by some of the student feedback.

- *I believe that this practical has helped me grasp the concept of summing moments to find reactions. I feel that it has enhanced my learning experience and should continue to do so further into the semester.*
- *I have found this practical has helped reinforce the concept of sections quite well, and I really enjoyed being able to make my own truss section to see how forces worked. This practical was a great challenge, lots of fun. More like this!*
- *This practical, I felt, was an excellent demonstration and proof of an, at times, seemingly abstract and arbitrary theory. (Centroids)*
- *This experiment did help me understand the concept of friction, in the fact that it is now apparent that surface area does not affect friction. Although it seems like it should, I have now witnessed it and can fully believe that it does not affect* F_{max}.

The spaghetti bridge practical is an excellent example of the benefits of project-based learning. The increased student motivation and engagement that this practical generates are clearly evident in the consistently high attendance, participation and grades. Another observed benefit is a sense of project ownership and belonging. It has proven to be a reliable and effective method of promoting student engagement and overall interest in the Mechanics of Materials course. The students continue to comment on the competition throughout the rest of their studies.

- *This prac was a great challenge and lots of fun. More like this!*
- *The spaghetti bridge prac helped me understand heaps of mechanics.*
- *Go the spaghetti bridge prac!*

4.2 Course evaluation instruments

A standard course evaluation instrument called a student feedback on course (SFC) is used for all courses taught at the University of the Sunshine Coast. The SFC has 16 questions in total and the last question: *Q16: Overall, I was satisfied with the quality of this course*, is of particular significance. The average 2011 SFC evaluation results for Engineering Statics and Mechanics of materials were 4.2 and 4.8 respectively (on a 5 point scale with 5 = strongly agree with the statement and 1 = strongly disagree). The results for Q16 for the courses were 4.1 and 5.0 respectively. While these student evaluation results are extremely encouraging for courses run for the first time, other studies have pointed out that it is difficult to directly relate positive student feedback to measurable improvements in learning outcomes (Goldfinch et al., 2008).

4.3 Evaluation of Final Grades

The final grades for students in both Engineering Statics and Mechanics of Materials were substantially better than typical results presented in the literature for similar foundation mechanics courses (Table 1). Although there is very limited data available on engineering student pass rates, Table 1 shows pass rates for USC Engineering Statics and Mechanics students compared to similar international foundation mechanics course student pass rates. This better than average result could be attributed to the increased level of interest and student engagement that these hands-on practicals produced. There are many variables that could influence the results from one student cohort to the next and these would have to be taken into account to enable a realistic comparison. Nevertheless, the results are most encouraging.

Table 1. Comparison of Overall Student Pass Rates

Course	Institution	Year	Pass Rate
Engineering Statics	University of the Sunshine Coast (Australia)	2011	78%
Mechanics of Materials	University of the Sunshine Coast (Australia)	2011	95%
Engineering Statics	The University of Texas at San Antonio, USA (Manteufel, R. and Karimi, 2010)	2004-2009	62%
Engineering Statics	North Carolina Agricultural and Technical State University, USA. (Waters and Rojeski, 2005)	2004	57%
Vector Statics	California State Polytechnic University (Rezaei et al., 2007)	2001-2002	56%

5 CONCLUSIONS

This paper reports on an initiative that was undertaken to promote student engagement in order to improve learning outcomes in two new core undergraduate engineering mechanics courses. A set of low cost, hands-on, interactive models were developed for students to use in small groups that demonstrated the underlying theory and helped them to better understand the basic engineering mechanics principles.

A comparison of student pass rates for the two new USC courses demonstrated that the pass rates were higher than those achieved in similar international foundation engineering courses. Although these results are very encouraging, there is as yet, still insufficient evidence available to make any substantial claims on the pedagogical benefits of using the hands-on, interactive models. However, the degree of student engagement and involvement while undertaking the practicals was clearly 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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