Supporting Student Engagement in Foundational Engineering Courses Via the Development of a Laboratory Program

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Introduction

Project scope

The previous laboratory exercise for ZEIT1503 Engineering Mechanics at the University of New South Wales (UNSW) Canberra covered content from the Statics portion of the Engineering Mechanics curriculum (only). In it, students built a static bridge out of balsa wood to support the largest load. This left little problem solving space and did not address mechanical dynamic loads in a practical environment.

This study documents a new laboratory exercise designed by a fourth-year engineering student (Watts, lead author) to include mechanical dynamics content for 2019. In addition, the new laboratory implemented research-based methods to design a laboratory that supports students' learning through active learning techniques.

Several techniques were employed to determine the effectiveness of the new laboratory design. This included pre and post-lab student surveys to query how enjoyable and beneficial they found the laboratory, and to assess how well it achieved the prescribed course learning outcomes (CLOs). Comments from the course convenor will also be considered. This will allow for improvements to be made at the end of the project and support the course staff to make continuous improvements for the future.

Educational Literature on Laboratory Activities in Engineering

Ramsden claims that education is extremely important in the 21st century due to the 'expanding importance of higher education in an economy based on knowledge' given that knowledge growth throughout the world steadily exceeds the capacity to service it (Ramsden, 2003). However, there is no use 'feeding' student's knowledge if they are unable to recall it in the same depth in the future. The level of retention and understanding of content that students will walk away from a class with is highly dependent on the delivery of the course. Hence, the course must be constructed in a way that enables students to learn and retain that understanding.

There are two different types of learning styles that a student may possess or be inclined to use; deep learning, and surface learning (Biggs, 2011). Surface learning refers to a student's ability to understand content on a factual basis and regurgitate information. However, to be able to retain information and problem solve students need to be able to relate content to outside work or past experiences. Deep understanding refers to a students' ability to examine content critically and continue to be able to in the long-term. This is enabled through making course content interesting, collaborative, relatable, with clear goals and through enabling autonomous learning environment. In the university context, particularly in engineering, deep learning is crucial given the nature of the field.

The active learning environment theory describes a means of ensuring student engagement through active participation and interaction with ideas and materials. Active learning theory can be applied to any learning style (Wilson & Peterson, 2006), including different mediums such as: oral, written, practical etc. In case studies this theory enabled all students in the class to engage in deep learning and retain knowledge and concepts beyond the timeframe of the semester (Knight, 2003). This is done by influencing students to:

- spend much of class time actively engaged in doing/thinking/talking.
- engage with peers.
- receive immediate feedback.
- use the instructor as more of a facilitator.
- take responsibility for their individual learning, rather than the teacher.

Laboratory exercises are widely regarded as an effective method of engaging students in active learning (Boud & Dunn, 1986). However, the design of the laboratory must still be done carefully to achieve student outcomes. Balla (1990) reported negative results due laboratory exercises often being unrelated to the theory in classes. Students in similar case studies reported negative attitudes towards the laboratories until their final year when they found the practical experience relevant to design projects (Bliss & Ogborn, 1977). Another common criticism of labs is that the cost-benefit balance of increased staff workload to deliver the labs is often unclear. Ensuring that the labs directly supports the student achievement of CLOs in a measureable fashion can address this (Ramsden, 2003).

A survey of the literature found that an internationally popular laboratory exercises was a ‘Socratic Dialogue Inducing Lab’ (SDI Lab) (Hake, 1992). An SDI lab consists of small, simple experimental or observable activities throughout the semester that reinforce concepts as they are taught. Many regard this technique as their highest preference for teaching practical methods and reinforcing theoretical content in engineering education (Lucke, 2012 and Bayles, 2005).

However, these small simple labs, while good for reinforcing theoretical concepts, fail to promote higher-level problem-solving skills and critical thinking (Hake, 1992). Yet when paired alongside a traditional construction lab focused on deep engagement and learning, provides significantly better results than the SDI lab alone (Peer, 1996).

Context of Engineering Mechanics Course at UNSW Canberra

Student Learning Outcomes

At the successful completion of this course you will be able to:

CLO1. Explain the basic concepts and principles of Engineering Mechanics using words, diagrams and equations.

CLO2. Apply the principles of Engineering Mechanics to solve engineering problems and critically evaluate your solutions.

CLO3. Apply the principles of Engineering Mechanics to identify ill-defined problems and design practical solutions to them.

CLO4. Communicate your solutions to engineering problems in an appropriate format and using appropriate language (including a technical report).

Figure 1: CLOs for 2019

The course in question, ZEIT 1503 Engineering Mechanics, used to be split into two different courses (Statics and Dynamics). When the courses were combined, the dynamics content was essentially moved into the “Statics” course. Before the merge, the laboratory task was mapped against all CLOs, but this did not remain true when the new material was added. The CLOs for ZEIT1503 Engineering Mechanics are shown in Figure 1. While not explicitly stated, CLO1-3 include both statics and dynamics material. Therefore, the laboratory needed to be updated in order to contribute to the development and assessment of all new CLOs. In addition to supporting the new learning objectives, the new laboratory needed to minimize workload on the staff in order to be cost effective as described above Ramsden (2003).

In addition to the new lab, ‘Socratic Dialogue Inducing’ activities are already incorporated into weekly tutorials for ZEIT1503 Engineering Mechanics as short, open-ended activities to reinforce tutorial work. Therefore, this paper focuses exclusively on the design and implementation of a longer lab project designed to address the additional content and engage the students in active learning.

Finally, many students have indicated that they have ‘built bridges’ in High School (or earlier) and that the prior lab felt repetitive. In response to this, we sought to create a laboratory that allows for a level of autonomy and uniqueness for the student to further engage that active learning environment.

Project Approach

Laboratory design

Three ideas were proposed for the laboratory including a projectile launching mechanism, energy transfer board, and independent problem exercises. All three proposals were formulated as a result of a literature review of similar laboratory exercises done by other universities, accounting for recommendations from each of their experiences. The first proposal would require the students to construct a projectile to hit a given target using a limited amount of materials, similar to that done by Bernhard (2000). The second proposal would run in a similar way to classic Rube Goldberg machines, as it runs on the same principle of consequential energy transfer between systems (Ginsberg, 1984). Rube Goldberg machines have been recently applied to first year engineering courses with success (Berg, 2015 and Mahinroosta 2016). The last proposal would be similar to the SDI labs but on a larger and more exploratory scale, similar to that of a university in Pakistan (Amjad and Ali, 2011). This would consist of various smaller activities and experiments that students perform to give a practical aspect to the methods and specific examples they are learning in class.

After consultation from three reviewers and other stakeholders, including current and previous students, the Energy Transfer Board lab was elected. The main reason for choosing this option was the ability for the students to take ownership of their creation and interact and explore concepts in Engineering Mechanics in a less structured manner. The major difficulty of this option is that it required a higher degree of maintenance and resources for construction as well as continued support. Every effort was made to minimise this risk for 2019, as well as to ensure that improvements are made in Dec 2019 for 2020 based on the findings of this project.

First Design Iteration

The first design consisted of three panels, the first of which was entirely pre-defined, the second was partially defined and the third was undefined. A schematic of the first design of the energy transfer board can be seen in Figure 2. This represents the intended outcome of the path of the ball in module 1 (left). This module would have two balls, dropped one after another in the top left corner funnel, with two balls exiting the last funnel at the bottom right.

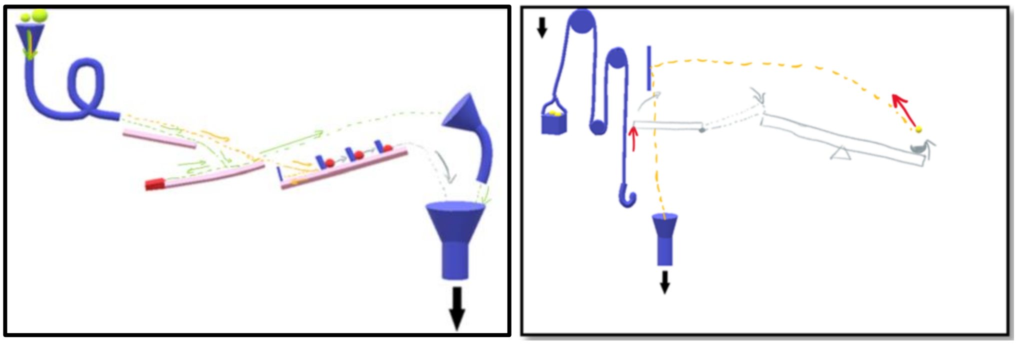


Figure 2: Schematic of the two pre-defined panels for the first design of the lab (Module 1: left, Module 2: right)

The blue objects in this schematic represent fixed objects on the board, the pink objects are adjustable in their angle, and the red/grey objects represent open-design space for the students to come up with a solution for. Students would be provided with a gathering of assorted materials (including springs, ramps, tubes, etc.) with which to construct these open-design areas. The last module (not pictured) of this design of the lab envisioned that students would be given a blank board to create a similar system to deliver a ball from A to B. This would give students the creative licence to explore various concepts in Engineering Mechanics freely, taking ownership and autonomy of their learning.

In the first two modules, students are expected to break down the seemingly complex problem into smaller problems. At this point, these modules only rely on basic understandings of energy transformation, projectile motion, stored energy in a spring, and momentum in collisions. These modules would be very useful in making the third, open-design module less daunting. By achieving a baseline analysis of the first module as a group, this would enable students to have confidence in their abilities to continue with the rest of the laboratory, fostering deep learning styles in an active-learning environment.

Prototypes for small parts of the system were manufactured and tested but major complications occurred during this stage due to manufacturing time constraints and the lack of reliability of the prototypes which posed a threat to delivering the laboratory on time. Through consultation with the course convenor, it was decided to take a simpler approach and revise a second design of the laboratory that would provide less of a manufacturing burden and more reliability for fewer pre-build components for the students.

Second Design Iteration

The prototype for the second design iteration would provide students with more autonomy and creativity within their construction of a lab which is conducive to active learning. This second design consisted of two parts, the first being a pre-made structure as seen in pictures from the trial run on the left in Figure 3. The upper half required the students to perform an analysis to predict the minimum height at which the ball must be dropped, using the least number of stepping blocks, to get the ball into the bucket. The students would be required to then test their analysis by pegging different stepping blocks into the board and explaining any observed energy losses. This guided part introduced the students to the application of basic concepts in Engineering Mechanics to the physical world and principles of friction and chaotic systems, as well as inelastic collisions.

The lower half of the laboratory consisted of a blank board with holes to mount various objects (Figure 3). The students were required to deliver a ball into the bottom left bucket and predict the velocity of the ball out of the system. They were then asked to measure the velocity of the ball upon exit and quantify and explain any discrepancies found and identify where they originated. The students were encouraged to demonstrate as many different kinds of energy transfer as possible given the resources allocated to them. As the lower half was very open-ended and the students were given a few pre-made mechanisms such as a simple pendulum and levers, the laboratory allowed the students autonomy to explore the possibilities and limitations of different concept of Engineering Mechanics in the application.

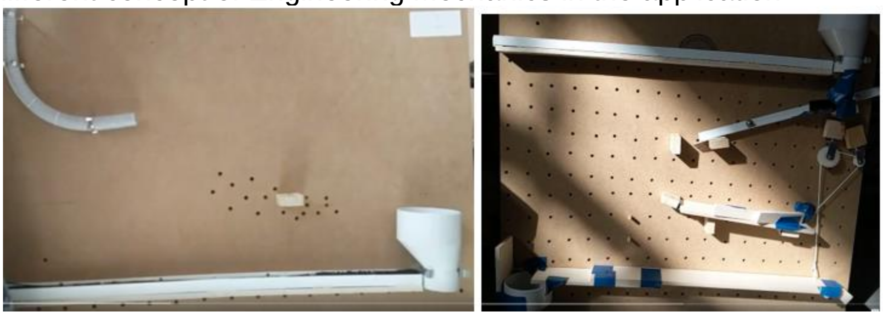


Figure 3: Trial students' solutions (left: part 1, right: part 2)

An initial trial of the laboratory was run on the 23rd of August 2019 with two first year students, who trialled the student interaction component of the practical activity and produced a baseline for reliability and feasibility of the exercise. This group of students were given less than half of the normal time for the laboratory (3 hours) therefore were not required to perform a full quantitative analysis.

Figure 3 shows the students' solution for the first part of the laboratory, having completed the course with one block (with a slight angle) in 30 minutes. The figure also shows the students' solution for the second part of the laboratory, using principles from several areas of first year engineering mechanics. Feedback from the course convenor advised that the rest of the class would be able to complete the assigned tasks well in the time given.

Final Design

From the prototype and initial trial run, slight adjustments were made to the construction of the board and materials given to students as can be seen in Figures 4-6. This included the addition of a ‘catch can’ between the two parts of the board which had a layer of sand so that students could mark and track iterations of the ball falling in the sand and making indentations. This also included the addition of more pre-built contraptions and a wider range of supplied construction materials as seen in Figure 6. Those that are consumable from year-to-year can be seen in the red outline.

Figure 4: Photograph of the final design

Figure 5: Photograph of the materials allocated to each station

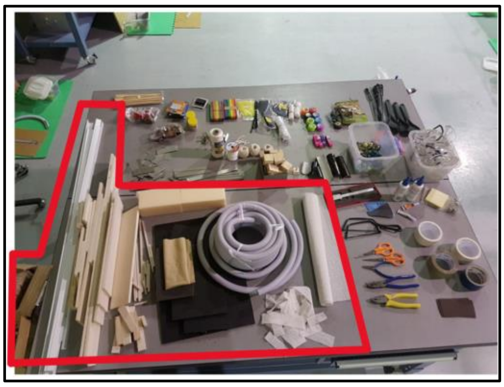


Figure 6: Photograph of construction materials provided to the group

Results

The laboratory ran smoothly from the 16 Sep 19 to the 25 Sept 19. Students constructed many different solutions and creations for the laboratory as observed in Figure 7. There was a variety of materials used and no two group’s solutions looked the same.

Figure 7: Examples of student solutions

A summary of the results from surveys taken of the students before and after the laboratory can be seen in Figure 8. Remarkably, the average responses for all questions were positive in nature and there was a general positive shift towards responses post-lab. The most notable positive shift was to the question ‘I feel able to apply content to real-life problems’ (CLO3). This suggests that the laboratory assisted students to conceptualise the content they had learnt in class, to real-life.

Contrarily, student responses to their ability to ‘Understand principles’ (part of CLO1), ‘Interpreting question’ (part of CLO1) and ‘Solve theoretical problems’ (CLO2) decreased after the lab. This negative shift was unexpected as these three concepts are generally a pre-requisite for being able to apply content to real-life problems, which increased. This discrepancy is most likely due to the time of the semester that the surveys were conducted.

They were conducted towards the end of the semester which suggests that the students may have realised a knowledge gap in their understanding due to the lab, that they were unaware of before. The laboratory exercise may have introduced them to applying the concepts in real-life and in doing so, unveiled some fundamental underlying misconceptions or gaps of understanding that were not recognised previously.

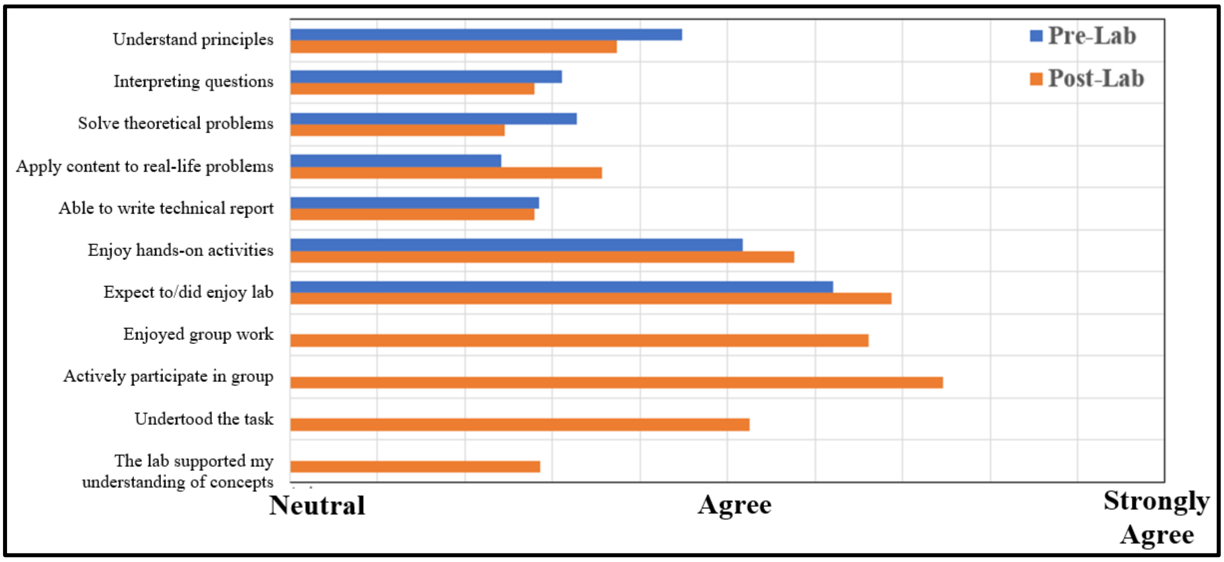


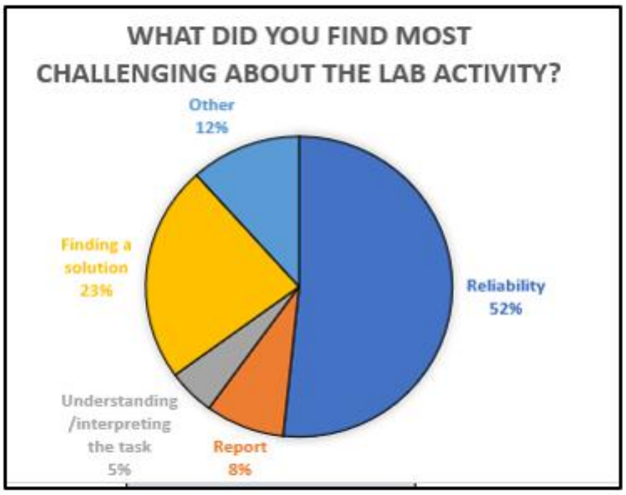
Figure 8: Summary of surveys of students before and after the laboratory

In terms of the success of the laboratory, these are positive remarks as the students gained a greater understanding of the application of engineering mechanics to real-life problems and the use of assumptions to predict mechanics in the real world. The laboratory may have consequently also identified shortfalls in understanding for students, which is also beneficial for their success in the course moving forward.

The exclusive post-lab questions revealed that group participation and enjoyment levels were very positive. It was noted that [I] 'actively participate in group' [work] had the lowest standard deviation of all the questions, showing that most of the class strongly agreed that they actively participated. The class as a whole strongly enjoyed and actively collaborated throughout the laboratory which suggests that the lab did engage the students and provided an active learning environment.

The last question was interesting as it had one of the lower average response and had the highest standard deviation. 'The lab supported my understanding of concepts' [in class] is arguably the most important question as it is vital that the lab supports the classwork to be a successful laboratory. The answer was still positive in nature however the higher standard deviation suggests that students had a lot of mixed feelings about whether the laboratory was applicable or not. It is likely that the reason there were such mixed reviews about the applicability is as the students had not had time to reflect on the laboratory yet as they had not written the technical report at the time of the post survey. As the famous philosopher John Dewey writes; "We do not learn from experience…. We learn from reflecting on experience." Revisiting the content and explaining and analysing the laboratory in the report may have provided students more of an opportunity to review the content of the laboratory in a theoretical manner. This would enable them to make the link between real-life and theoretical problems. However, this data may also indicate that the laboratory was poorly timed with learning the dynamics content in class in the semester.

This is further supported by students' additional comments in the surveys as seen in Figure 9. None of the students most challenging aspects of the laboratory suggested that the laboratory did not support deep learning. The majority of the responses (52%) surrounded students' frustrations with not being able to get their systems to work consistently. The course convenor has expressed that this is not something to address in future as the unreliability of the system "introduces students to losses and inconsistencies in real applications of engineering mechanics." The clear delivery of the laboratory instructions and technical writing support will instead be focussed on.



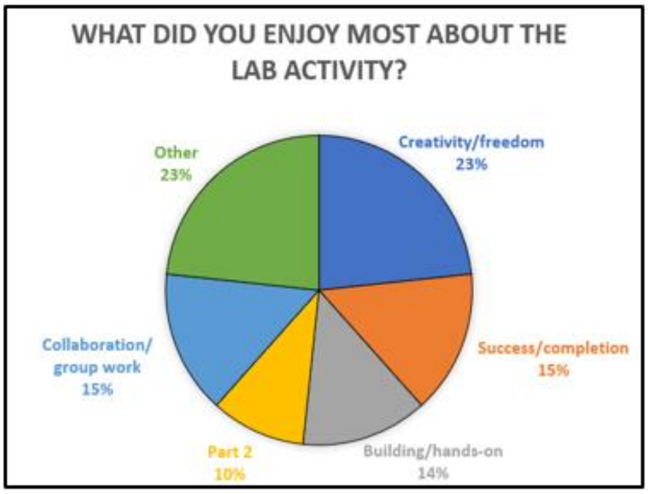


Figure 9: Charts of response themes to the additional, open questions in the surveys

The largest positive feedback about the laboratory was due to the creativity and freedom that the laboratory enabled the students (23%). 'Part 2' (10%) and 'building/hands-on' (14%) also refers to the open-design part of the laboratory. This suggests that the design change from the first to the second iteration, to make the laboratory more 'open-design' was a good choice. Therefore, showing that the students enjoyed being able to autonomously explore the concepts themselves. This was supported by 15% of the comments based around the students enjoying when their creations worked suggesting emotional investment in the activity. This was also noted in the course convenor review as they said; "The best thing was that you knew when someone got it to work – it was obvious! They achieved something, there was such a loud roar, they were so emotionally invested and were clearly engaged. How often do you see that in a lab?"

The review with the course convenor showed that the students did in fact do quite well in understanding, interpreting and solving problems in engineering mechanics (CLO1, CLO2, CLO3) despite students' conceptions about their understanding. This suggests that some of the negative shifts comments on previous are due to students finding a gap in their knowledge that they were not previously aware of. They reported that the "students were clearly engaged, playing with stuff in constructive ways" and that "they were describing things well – they had the appropriate language when describing principles and concepts which is very important for going forward. They are learning the language of engineering which is great." Ultimately the course convenor will keep the laboratory as is for future years, with minor changes to be made to the laboratory manual, and technical report guidance to further support CLO4.

Conclusion

The implementation of the new laboratory exercise for ZEIT Engineering Mechanics at the University of New South Wales is more beneficial to students than previous years as it explores a larger range of principles in Engineering Mechanics. The new laboratory provided students autonomy and an opportunity to be creativity to promote an active learning environment and long-term, deep understanding of engineering mechanics principles.

Educational data collection revealed that students performed well in writing technical reports for the laboratory therefore th e observed drop in perceived ability can be attributed to students realising a gap in their knowledge after the laboratory. This realisation is in fact positive as it will assist students in identifying weak spots in their understanding of the course as a whole.

Some students felt unable to write the technical reports. As such, more guidance and explicit laboratory guidelines will be implemented for future years.

The laboratory will be kept for future years but may be implemented in conjunction with the previous laboratory and later in the semester so that students are able to learn the majority of dynamics content before the laboratory. This means that the course convenor will be able to make the laboratory tasks more complex and to challenge students' understanding more.

Copyright statement

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