Engaging students in learning threshold concepts in engineering mechanics: adaptive eLearning tutorials

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Abstract

In learning mechanics fundamentals in engineering, many students struggle with basic concepts, and as a result fail to engage in the more rewarding higher level problem solving tasks where they learn in more depth. A good tutor can walk a student through sticking points and give customised feedback and encouragement. But such individual teacher-student conversations are rare in 1st and 2nd year undergraduate classes with several hundred students and limited numbers of tutors.

Online tutorials and simulations can help, but most do not track in detail where the students going wrong. Nor do they allow the teacher to customize the response as they would in a face-to-face conversation in a tutorial and lab class. The adaptive tutorials using the eLearning platform developed at UNSW are designed to allow the teacher to monitor overall responses in a large group of students and to adjust the teaching, and the feedback given by the online tutorials themselves, to respond to common sticking points. We have been using adaptive tutorials for four years, in 1st and 2nd year engineering mechanics classes within UNSW. We tracked student behaviour in using the tutorials and adjusted the teaching. By analysing student feedback and student performance in assessment tasks, we can show how the tutorials engage students in working through conceptual difficulties.

In 2011, a national project is using a wider range of adaptive tutorials for mechanics courses in engineering across several Australian universities, with different student cohorts and class sizes. Preliminary results show the tutorials compare with traditional teaching and how their use can be customised for students learning the threshold concepts of engineering mechanics in different curriculum contexts.

1. Introduction and context

Students entering Australian universities to study engineering have many different levels of ability, maturity and confidence, and have varying attitudes towards their studies. This is particularly evident when teaching students in large 1st and 2nd year engineering foundation classes. In most Australian engineering schools, the study of mechanics comprises up to 25% to 40% of 1st and 2nd year study respectively. Failure rates of up to 50% are common in introductory engineering mechanics courses and are a continuing concern.

There have been several initiatives aiming to analyse the reasons for the high failure rates, and to find ways of addressing the problem – both by individual engineering mechanics teachers and, increasingly, by the community of engineering educators in Australia. Some of these initiatives have been supported by the Universities and their Engineering Schools. Others have been coordinated and funded as national projects.

This paper presents progress to date on one initiative that began in the University of New South Wales (UNSW), and is now a nationally funded project across several Australian universities. Adaptive tutorials run on the Adaptive eLearning Platform (AeLP), software created in the UNSW School of Computer Science & Engineering. The adaptive tutorials provide interactive learning tools for students to help them practice applying concepts and skills, and the AeLP also has a tool to enable teachers to track where students are having difficulties with basic concepts. The adaptive tutorials have been in use for four years in 1st and 2nd year engineering mechanics in UNSW, and are now being piloted in several other universities.

The current work builds on and complements other work aiming improve learning outcomes in engineering mechanics in Australian university engineering degree programs – in the context of large diverse groups of students, many of whom need more than traditional ‘book and board’ teaching methods to engage them in learning. In the past, perhaps a good tutor would be able to walk a student through detailed sticking points and give customised feedback and encouragement. But such individual teacher-student conversations are rare in 1st and 2nd year undergraduate classes with several hundred students and limited numbers of tutors. Even where individual tutoring is possible, the knowledge about the sticking points remains with the individual tutors students, and is not systematically collected and shared. The Adaptive Tutorials aim to give students guided practice in using engineering mechanics, and at the same time to track and analyse in detail where students are becoming stuck.

2. Literature and prior work

The literature on learning in engineering mechanics in Australia indicates that many students experience substantial difficulties, but offers relatively little explanation of the underlying causes of these difficulties (Dwight & Carew, 2006; Goldfinch et al., 2008a, 2008b, 2009). There are some educational theories that can help identify why this is so, and there are technologies that can assist in addressing the problem.

2.1 The trouble with threshold concepts

The difficulties in explaining high failure rates in engineering mechanics suggests that the students may be struggling with 'threshold concepts' – understandings that transform students' thinking irreversibly. Once acquired, threshold concepts can seem simple and self-evident. Yet without them students will be unable to progress to more complex analyses. Students who fail in engineering mechanics are usually sticking on one or more of these concepts. Typically, it is hard for discipline experts to identify why many students are struggling with apparently simple tasks involving threshold concepts (Davies, 2006; Meyer & Land, 2005)

For the non-expert learner, threshold concepts are 'troublesome knowledge' in that they may initially seem counter-intuitive (Meyer & Land, 2002; Perkins, 2006) A student who is persistent and motivated will eventually reach a breakthrough in understanding. But unless students see the point of the exercise they are unlikely to spend the required time on task to reach the breakthrough point.

Ideally, a student and teacher would have an extended 'conversation' in which the teacher sets activities for the student, observes the student responses to the activity, and then adjusts the explanations and activities accordingly. Where there are large diverse classes and therefore limited scope for individual responses to students, one solution is to mediate the conversation through technology (Laurillard, 2002; Prusty, 2010).

2.2 Technological solutions

Students can learn basic skills with the development of a coherent approach to computer-assisted learning and assessment (Hadgraft, 2007). However, although there are a number of initiatives by Universities around the world to use on-line educational tools, few have the ability to provide instant, intelligent (relevant and appropriate) feedback that is adapted to the learner's knowledge level in the way that a human tutor would. For example, there are inventories in the form of quizzes that assess student's ability to work with basic concepts (e.g. see http://www.foundationcoalition.org/home/keycomponents/concept/index.html).

Participating in hands-on or interactive activities can improve the students' motivational levels in learning (Packard et al., 1998, Jorgenson, 2006 and Kessissoglou & Prusty, 2009). Moreover, research suggests that students benefit from an interactive learning environment in which they can have some control of their learning experiences (Chandler & Mayer, 2001). But having students experiment with real world cases can be costly and sometimes even dangerous.

Computer-based games that have been developed for the students in Statics and Mechanics of Materials courses (Philpot et al., 2003) were successful in both improving student performances and dramatically increasing engagement and motivation levels.

The adaptive tutorials developed at UNSW have been set up as a virtual laboratory where students can explore the interaction between variables in a safe and accessible environment.

3. Methods

3.1 Adaptive Tutorials and the Adaptive eLearning Platform

Adaptive Tutorials (ATs) are eLearning modules where an Intelligent Tutoring System adapts the instruction level (difficulty, feedback and activity-sequence) to learners, based on their individual performance. From a pedagogical point of view, ATs are similar to teaching laboratory activities and are analogous to the concept of Tutorial Simulations as described by (Laurillard 2002). They can be described as a pragmatic hybrid between instructivist and constructivist educational theories, trying to strike a balance between guided and discovery learning.

ATs are typically guided, featuring a detailed explanation that leads students through the interaction, while offering adaptive, remedial feedback in response to learners' misconceptions. ATs are also interactive, enabling students to investigate a phenomenon, or a relationship between parameters of a problem in a hands-on manner, thereby encouraging discovery learning. They exhibit three types of adaptivity:

1. students experience adaptive feedback with remediation targeted to their intrinsic misconceptions
2. activities are also sequenced adaptively based on their performance
3. the content of the activities (examples, questions) and the feedback is adapted in response to general patterns in student responses.

Adaptive Tutorials are not "launch and forget" projects. Once ATs are developed, teachers' use the AT-Analyser, which creates a visual trace of student performance, (Figure 1) to scrutinise their students' interactions during the ATs, and to adapt the AT content as needed based on their students' demonstrated misconceptions. Tutorials can then be easily updated to address any misconceptions. This creates a powerful educational experimentation environment where hypotheses about students' learning can be evaluated, adapted and then shared and published. Teachers thus become 'action researchers', confirming or disproving their hypotheses about the best way to help their students learn (see Ben-Naim et al. 2008 and 2009 for discussion).

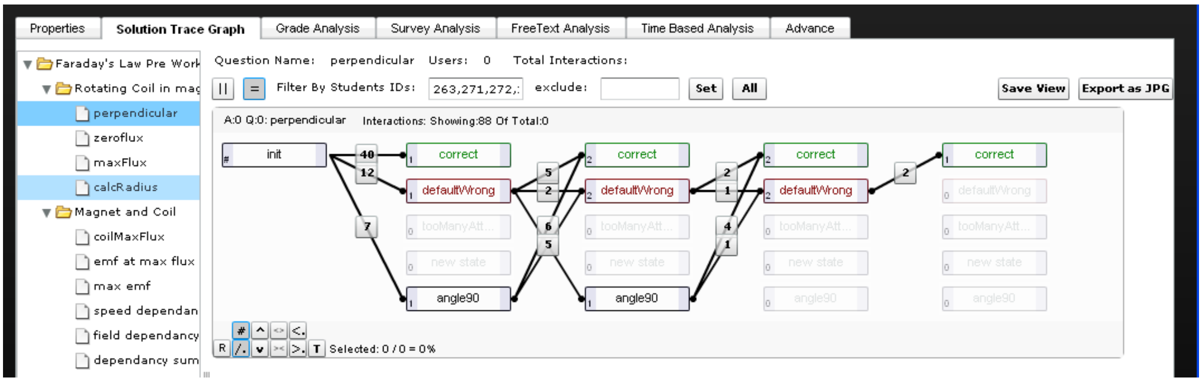

Figure 1: The Adaptive Tutorial Analyser uses A Solution Trace Graph to visually analyse students' solution-traces through the problem state-space

3.2 Adaptive Tutorials in Mechanical Engineering at UNSW

In view of the fact that many 1st and 2nd year undergraduate students struggle with basic concepts in mechanics courses, at UNSW we have been developing, using and evaluating ways of using online Adaptive Tutorials to help students in Engineering Mechanics and Mechanics of Solids courses since 2007 (Prusty et al. 2009).

Adaptive Tutorials, based on the virtual apparatus simulations, have two advantages: (a) students can spend time working through the tutorials and get immediate feedback on how well they are able to understand and apply basic concepts and (b) teachers can track how students are performing in these tutorials in detail, and pinpoint areas where teaching needs to be adjusted.

The ATs were used as a supplement to other teaching, to clarify the fundamental concepts in each course. We implemented three such tutorials in the 1st and 2nd year mechanics courses. Through staged implementation of the ATs, we aimed to find out how they:

- help students learn
- improve performance in assessments across the 1st two years of study
- add to overall student satisfaction with the courses.

Student feedback was collected via a questionnaire that featured within each AT as well as through a formal institutional evaluation.

The ATs, equipped with a rich, highly visual set of interactive tools, such as that as shown in Figure 2, provide intelligent remediation and instant feedback thereby promoting guided user exploration and discovery. With the implementation of AeLP tools, we were able to monitor the progress of students using an analyser tool available within the AeLP platform.

Figure 2: Adaptive tutorial on shear force and bending moment

3.3 ALTC project

In 2010, the Australian Learning & Teaching Council funded a 2 year project to involve wider group of engineering educators in using the Adaptive eLearning Platform (AeLP). The aim is to make adaptive tutorials available more widely for engineering mechanics education. Specifically, the project's goal is to build on the pilot study at UNSW by extending the use of ATs to more engineering mechanics topics and to more institutions in Australia. The process for achieving this will be the following:

1. **Identify the threshold concepts** in engineering mechanics for which new Adaptive Tutorials would be most valuable. This work will be done collaboratively and will involve educational development support in each institution.

2. **Develop the Virtual Apparatus needed**, and then design and author the agreed Adaptive Tutorials. Using educational developers and software developers to work with the academics in the project team, we expect to develop 8 to 10 such ATs within the timeframe and budget.

3. **Set-up an ALTC Engineering Adaptive Tutorials Portal (ATP)**, to facilitate publishing, sharing and reuse of Adaptive Tutorials. The portal will incorporate a web interface to enable teachers to view, copy and adapt existing tutorials. There will also be a web-based tool to enable teachers to analyse students' responses during use of the ATs.

4. **Assure adequate staff training on the AeLP** by means of 2 dedicated training workshops for mechanics educators from a variety of universities and a set of online support material such as wiki pages, screen-casts, and a support forum.

5. **Evaluation** - individual teachers, supported by the project team's educational advisors and with the help of educational developers, will perform pedagogical research into the effectiveness of the AT's. The results will be published in the engineering education community and to cross-disciplinary audiences.

6. **Dissemination** - access to the educational portal will be made available to the Australian Higher Education sector so content could be re-used; publications will also serve a dissemination purpose, as will the training workshops.

4. Results and outcomes

The results and outcomes reported here summarise progress to date on the development and use of the AeLP for learning in engineering mechanics.

4.1 AeLP development and use

Since the original tutorials for mechanical engineering began in 2007 (Prusty, 2009), there has been continuing development of more tutorials, and of the underlying analysis tools. In 2011, a total of ten ATs in engineering mechanics are being piloted and evaluated.

In the original adaptive tutorials, although the feedback could be adjusted, the simulations themselves required programmers to adjust the parameters. The user interface now allows teachers to select and adjust the simulations, which run as an underlying parametised model.

There have also been continuing improvements in the analyser tool, to enhance ease of use.

Work is also continuing on setting up an ongoing web service that teachers of engineering mechanics can use to run and adapt the adaptive tutorials for their own students, and to carry out research into student learning in the discipline.

4.2 UNSW engineering mechanics results

There is now 4 years of data on use of the engineering mechanics ATs in the UNSW Faculty of Engineering.

Improvements in student performance

Results support the benefits of ATs for learning as well as for giving teachers control of the learning process. The improved performance of the students in Engineering Mechanics 1 and Mechanics of Solids 1 courses in 1st and 2nd year Mechanical Engineering is presented in Figure 3a and b (as the first author didn't teach the course in 2009, the data is not included in Figure 3a). These data indicate that the adopted teaching strategies are most effective in assisting at-risk students (as top students are already knowledgeable of the topic), which is demonstrated by the reduction in failure rates.

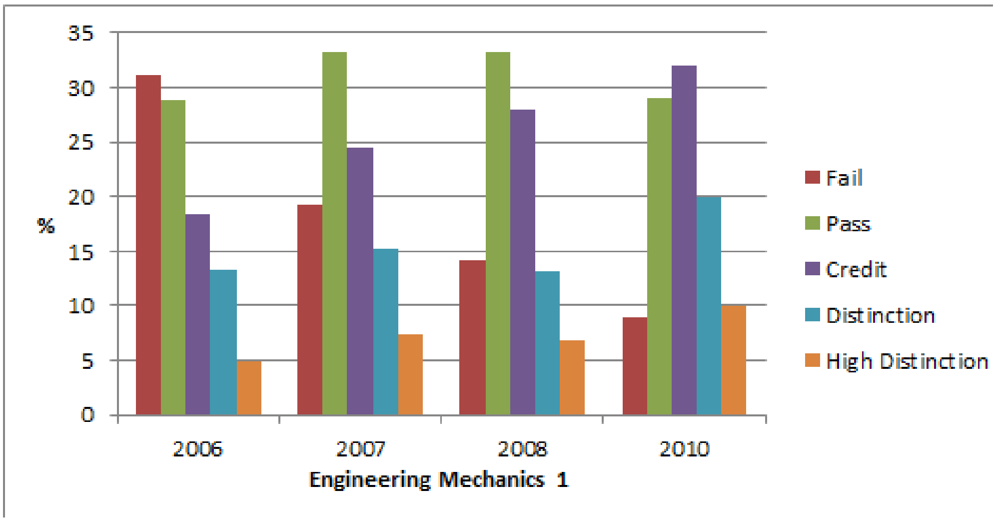

Figure 3a: Student performance in 1st year Engineering Mechanics 1

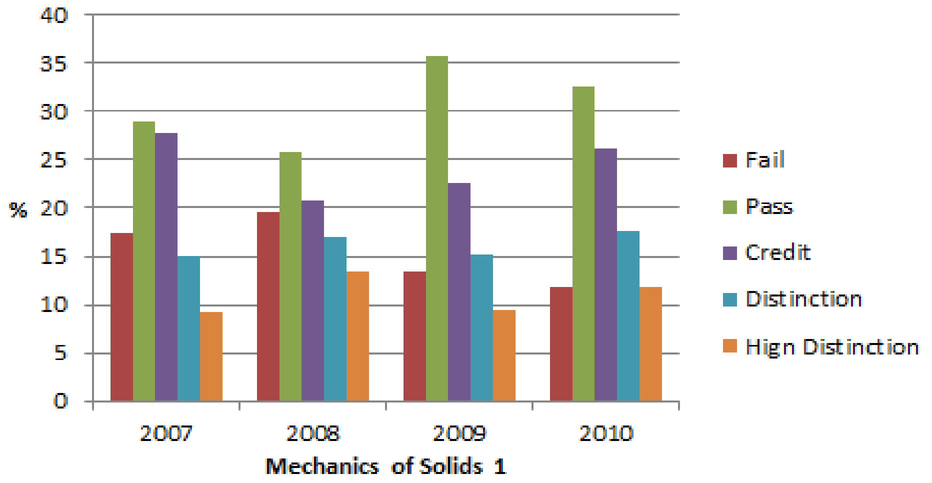

Figure 3b: Student performance in 2nd year Mechanics of Solids

Since the first iteration of the revised mechanics of solids 1 course in 2007, student numbers have almost doubled, student satisfaction rate has increased (Figure 4) and student performance has improved. This is due to the effective staged implementation of my aforementioned teaching strategies.

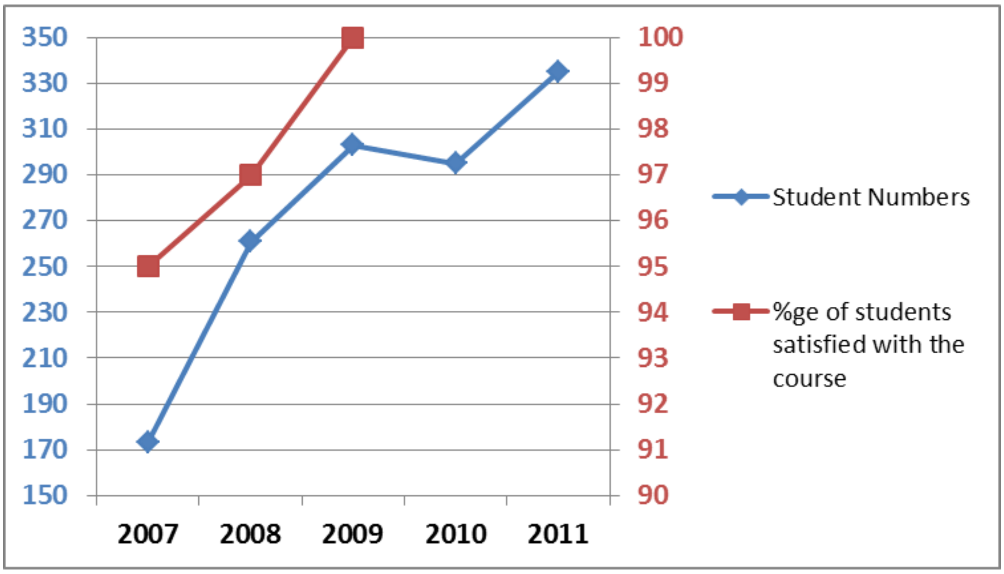

Figure 4: Summary of student numbers and satisfaction

There is also evidence that after the introduction of the adaptive tutorials, there were subsequent improvements in student performances in all the 3rd year undergraduate engineering courses that have Mechanics of Solids 1 as a pre-requisite (Figure 5).

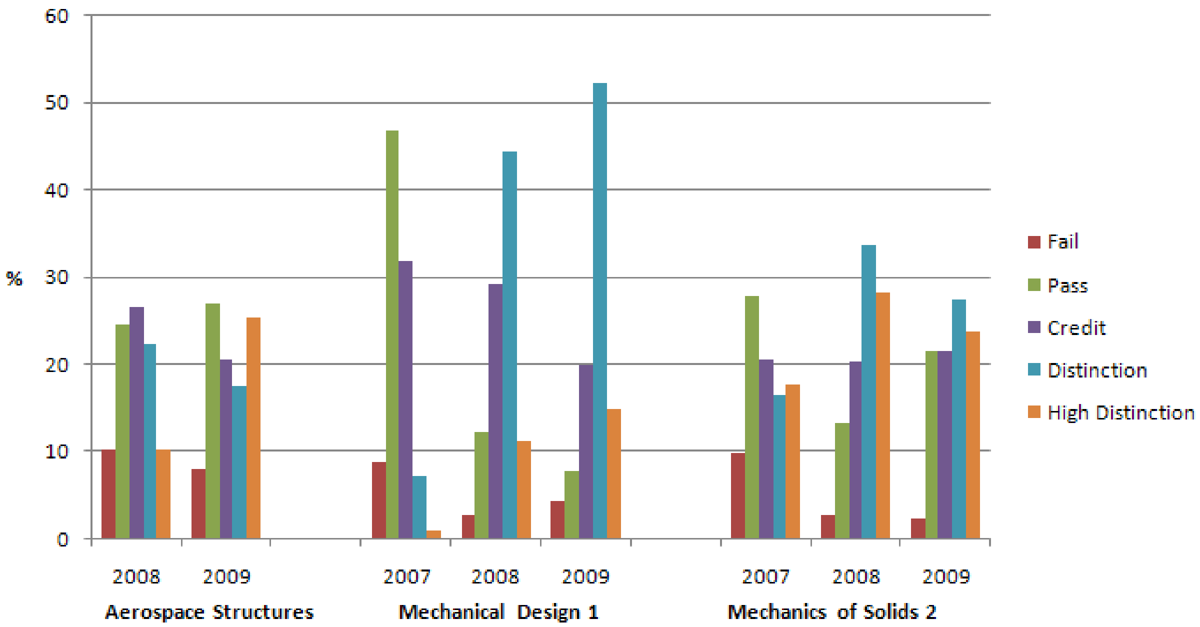

Figure 5: Improved performance in 3rd year courses using engineering mechanics concepts

Student engagement and feedback

A snapshot of the student evaluation questionnaire adopted within the ATs (Prusty et al. 2009) clearly demonstrates that the students' like to see many more of such Adaptive Tutorials in a course (Figure 6):

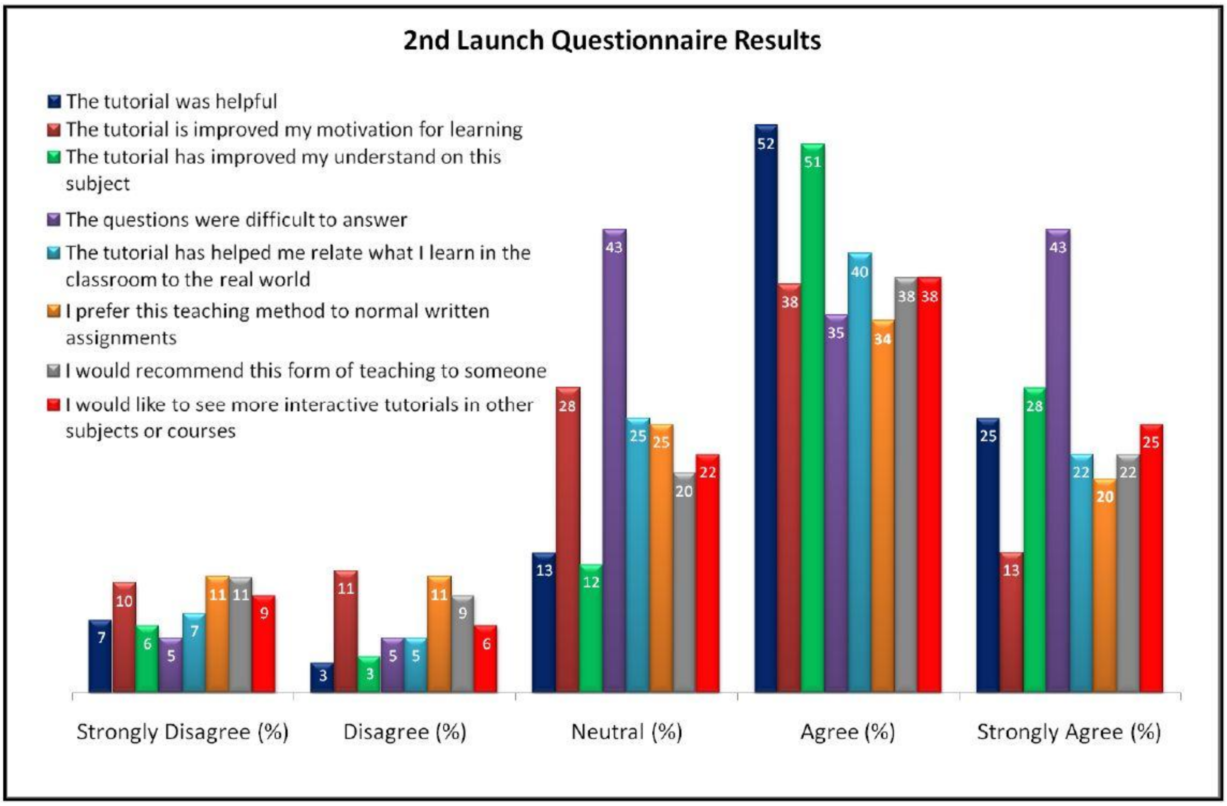

Figure 6: Student response on a typical questionnaire in of the Adaptive Tutorials (Prusty, 2009)

The survey indicated that students were generally very happy with the ATs and with the quality and challenge they provide. It was also indicated that the assessment methods were appropriate given the course aims. Students' comments include:

“Allow more of this kind of interactive lessons to better understand all our lesson. Hope to have more of this kind of online interactive lessons”

“Excellent tutorial. The tutorial has really furthered my knowledge of this topic. I would really like to see more of these tutorials. This tutorial has taught me the basic concepts and ideas I will need to undertake questions of a similar nature in the text book. Very helpful”

“awesome i understand the sign conventions regarding the angles now. thanks.”

“This tutorial was clear and helped me understand the concepts of Mohr's circle to a much better degree than before. I highly recommend it.”

“Very good representation. Very helpful for my studies and understanding of Mohr Circles”

“It would have been better had i listen to you and completed this before my block test “

“Good for continued learning and to help with understanding - ie. getting more feedback then possible with general hand in assignments “

“This tutorial is great, I wish to see more course use something like this or at least put this kind of method in almost every chapter “

“Fantastic program I was really struggling with the force analysis, however this program has instilled confidence for understanding real-life application of engineering and mechanics”

“I highly recommend this tutorial. It has a very appealing practical approach yet at the same time helps me in improving my conceptual understanding of the topic at hand especially regarding the shear force and bending moment. The free body diagram on the side is also very helpful. Two thumbs up!”

These comments provide clear evidence that the ATs resulted in an engaging learning process that stimulated the students to learn and achieve.

4.3 Threshold concepts – initial list

An initial meeting of the ALTC project team in June 2010 identified several basic engineering mechanics methods that significant numbers of students across all the represented universities are struggling with. They drew on a previous project funded by the ALTC to compile initial list threshold concepts in engineering mechanics. The project team then went on to develop a series of tutorials for piloting in 2011. These are:

- resultant of forces, moments and couples
- 3-D force systems
- trusses
- friction in machines
- first and second moment of area
- internal forces in a beam
- shear force and bending moment
- stress and strain
- combined loading
- Generalised Hooke’s Law
- Mohr’s Circle for stresses in 3D
- Mohr’s Circle for strain in 3D.

The tutorials on these topics were set up to capture and give adaptive feedback on some of the constituent enabling concepts that the team had identified. Some of these were common across all tutorials – errors in orders of magnitude, inconsistent application of sign conventions, units and dimensions.

4.4 ALTC project in 2011

At the time of writing, 10 adaptive tutorials are being piloted across 6 universities, and will be evaluated both pedagogically and for technical usability. The 2011 study is evaluating:

I. how different cohorts of students, in different curriculum contexts, engage with the ATs

II. how the ATs benefit learning of key threshold concepts in engineering mechanics
III. how easily and effectively the teachers are able to use the information generated by the ATs to adapt their teaching.

A mix of quantitative and qualitative data is required to answer these questions. Specifically, the research will:

- track student use of the tutorials in different cohorts (Qs I and III)
- collect survey data from student participants, on their perception of the tutorials (Q I)
- compare patterns of assessment results from similar curriculum contexts, without and with the use of tutorials (Q II)
- interview teachers to gather data on how they responded to the tutorial – in terms of ease of use, value for student learning and information for adapting teaching (Q III).

In each class in which they are used, the ATs will be integrated with cycles of assessment and feedback. Typically, they will be available online to all students and strongly recommended to those who perform poorly in early tests. The universities include large metropolitan universities like UNSW, which has Australia's largest Faculty of Engineering and has a high proportion of overseas students in the undergraduate cohorts. It also includes small regional universities with a higher proportion of local students from rural backgrounds, such as the University of Tasmania. Preliminary evaluation results will be available by July 2011 and the final evaluation report by December 2011.

5. Discussion of implications

There is convincing evidence that adaptive tutorials are already helping to address the challenges in teaching engineering mechanics to large and diverse groups of undergraduate students in the UNSW context. The current pilots cover a wide range of other Australian university contexts in which engineering mechanics is taught, and should provide evidence on whether this approach is likely to improve engineering mechanics learning elsewhere.

What is perhaps of broader significance is that there is a growing system, including communities teachers and web service technologies which are together:

- sharing and codifying knowledge of learning and teaching in engineering mechanics in a scholarly way
- identifying where, why and how students are having difficulties in learning engineering mechanics
- building resources that can help teachers and learners address these difficulties more effectively and efficiently in large and diverse undergraduate classes.

The underlying challenges are not unique to engineering mechanics study in Australia. The combined approach of building communities with technologies has relevance for other contexts.

6. Acknowledgements

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