Adaptive Tutorials to target Threshold Concepts in Mechanics – a Community of Practice Approach

Gangadhara B. Prusty, Carol Russell, Robin Ford, Dror Ben-Naim, Shaowei Ho, Zora Vrcelj & Nadine Marcus
University of New South Wales, Sydney, Australia

G.Prusty@unsw.edu.au; C.Russell@uws.edu.au; robinford1@a1.com.au; dror@smartsparrow.com; shao@smartsparrow.com; n.marcus@unsw.edu.au

Timothy McCarthy & Tom Goldfinch
University of Wollongong, Wollongong, Australia
{timmc, tomgold}@uow.edu.au

Roberto Ojeda
Australian Maritime College @ University of Tasmania, Launceston, Australia
reojeda@amc.edu.au

Anne Gardner
University of Technology Sydney, Sydney, Australia
agard@eng.uts.edu.au

Tom Molyneaux
RMIT University, Melbourne, Australia
tom.molyneaux@rmit.edu.au

Roger Hadgraft
University of Melbourne, Melbourne, Australia
roger.hadgraft@unimelb.edu.au

***Abstract**: We present our work on introducing Adaptive Tutorials in first and second year mechanics courses in Engineering. Adaptive Tutorials are interactive online modules where an Intelligent Tutoring System adapts the instruction level to learners, based on their individual performance. Through an ALTC-funded project, we formed a community of practice of Engineering Mechanics educators from a range of Australian universities. As a team, we began by identifying Threshold Concepts that if they are not grasped inhibit students' learning before developing a set of Adaptive on-line Tutorials to target them. These Adaptive Tutorials were used by students throughout the first half of 2011, and were found to be both engaging and conducive to learning. In this paper, we present our approach and findings and discuss our strategy of giving educators pedagogical control over such advanced technologically-based instructional methods with the goal of increasing adoption and ultimately improving students learning.*

Introduction and background

In engineering curricula, the study of mechanics comprises up to 25% to 40% of 1st and 2nd year study respectively and can be termed as the "iceberg of mechanics" (Fig 1a). Failure rates of up to 50% are common in introductory engineering mechanics courses and are a continuing concern. The persistence of these high failure rates suggests that the students are struggling with the 'threshold concepts' – the understandings that transform students' thinking irreversibly.

A good tutor can 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. Conventional online tutorials and simulations can help, but most do not track in detail where the students are 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 (Fig 1b) are designed to allow teachers to monitor overall responses to large group of students and to adjust the teaching, and the feedback given by the online tutorials themselves, to respond to common sticking points. By analysing student feedback and student performance in assessment tasks, we can show how the tutorials engage students in working through conceptual difficulties.

Based on a successful pilot study and evaluation at UNSW (Prusty et al., 2009, 2011), a team of enthusiastic mechanics educators from a range of Australian Universities (University of New South Wales, University of Wollongong, University of Technology Sydney and University of Tasmania) participated in adopting Adaptive Tutorials into their teachings as a Community of Practice (CoP) (Ben-Naim & Prusty, 2010). This was achieved through the development, use and dissemination of a set of Adaptive Tutorials (ATs) that targeted the identified threshold concepts in the 1st and 2nd year mechanics courses in engineering. The CoP has set out to incorporate Adaptive eLearning technology into the field of engineering education, in a way that can benefit likeminded academics in Australia and beyond.

This paper evaluates how the ATs have been able to help student learning of threshold concepts in engineering mechanics, across a range of contexts provided by the CoP.

Figure 1: (a) Iceberg of mechanics in engineering (b) Snapshot of Adaptive Tutorials

Tackling threshold concepts in engineering mechanics

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.

Threshold concepts

The difficulties in explaining high failure rates in engineering mechanics suggest 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. It is typically hard for discipline experts to identify why many students are struggling with apparently simple tasks involving threshold concepts (Davies, 2006; Meyer & Land, 2005; Prusty, 2010). 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 that 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. Such individual 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, knowledge about the sticking points and how to overcome them remains with the individual tutors. It is not systematically collected and shared. 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).

Adaptive eLearning for both students and teachers

Adaptive Tutorials (ATs) are intelligent tutoring systems in which students typically interact with a simulation towards a task-goal while being guided and remediated. The ATs used in this project run on the Adaptive eLearning Platform (AeLP), which provides two very different types of feedback:

1. students are given guidance and individualised feedback based on their interaction
2. teachers can also receive feedback on their own authoring choices to drive reflection and content adaptation.

This allows for customised learning for students as well as real-time feedback to teachers that enables them to constantly adapt and refine lesson content for improved student learning. Teacher feedback is in the form of a graphical trace of student performance referred to as the Solution Trace Graph, while student feedback is adapted to their particular circumstance and can vary from being technical clarification of mistakes to actual remediation for concepts not yet mastered (see Ben-Naim, Marcus, & Bain, 2008). The AeLP supports an educational design process in which teachers can author and adapt lessons and feedback to suit their own classes, without having to re-program the underlying simulations and software. In the context of a community of educators with shared challenges, such as common threshold concepts in engineering mechanics, the AeLP enables the community to explore how large numbers of students are tackling common engineering mechanics tasks, and to identify where significant numbers are having difficulty with the concepts required to do these tasks. It also allows for customised lessons to be created to suit each cohort of students.

Evaluation methodology

The Free Body Diagram (FBD) has been identified as one of the more problematic threshold concepts in engineering mechanics. It is a subtle concept; obvious if you grasp it and a complete mystery if you do not. Acknowledging the significance of this concept in the study of engineering mechanics, others have sought to develop interventions that target students understanding of Free Body Diagrams (McCarthy, 2010), and studies focussing on the underlying concepts of FBD's are nothing new (Hestenes, 1992; Lane, 1993). However, providing helpful feedback to those for whom the concept is a blur remains a challenge, particularly when managing large 1st and 2nd undergraduate classes. With this in mind, the ALTC project team developed an adaptive tutorial on Free Body Diagrams and piloted its use in four different contexts in 2011 semester 1. Table 1 summarises the 4 different contexts in which the FBD AT was used at the different universities.

Table 1: Summary of context used in FBD analysis

context	university type	subject	students	use
1	metropolitan, ATN	1st year engineering mechanics for civil engineers	mainly mid-year intake and repeat students (main school-leaver cohort does this subject in semester 2)	revision exercise, for token marks, end of semester, 57/95 completed AT
2	regional	1st year introduction to engineering (statics, dynamics and fluid mechanics)	mixed cohort, some with limited maths background	required students who failed initial test to take tutorials, optional for others, 29/126 completed AT
3	metropolitan Go8	1st year engineering mechanics for civil engineers	mainly mid-year intake and repeat students (main school-leaver cohort does this subject in semester 2)	throughout semester, 84/101 completed AT
4	metropolitan Go8	2nd year mechanics of solids for mechanical engineers	main cohort, students who have successfully completed 1st year engineering mechanics	integrated into teaching and assessment, 10-12% of course marks, 299/326 completed AT

After completing the tutorial, students provided feedback on their experience via a short survey, with multiple choice and open-ended questions. We analysed students' text comments, coding responses as indicating whether the AT was effective for their learning or ineffective, and also coding for particular reasons cited. An analysis of student responses in relation to performance will be reported separately.

Outcomes and discussion

Student responses to the tutorials varied across contexts – see Table 2.

The text comment patterns correspond well with the multiple choice responses (not reported in detail here because of lack of space). See Table 3.

Table 2: Numbers of comments about effectiveness for learning, and mean scores

	A : FBD-effective	B : FBD-ineffective	mean scores for students who completed (see Table 1 for context)
Context 1 FBD	22	30	33%
Context 2 FBD	12	3	21%
Context 3 FBD	28	24	42%
Context 4 FBD	145	58	61%

Table 3: Reasons given for effectiveness, ineffectiveness or suggestions for improvement:

	FBD effective	FBD ineffective	FBD how to improve
engaging	31	0	4
immediate feedback	23	0	2
understanding concepts	19	0	0
simple or easy to	17	0	0
interactive	12	0	0
develops skills	10	0	1
self-paced	9	0	1
saves time	8	0	1
flexible	6	0	2
revision or reinforcement	6	0	0
visual	6	0	0
real or practical	4	0	0
scaffolding	4	0	1
prefer other methods	0	23	1
confusing or hard to understand	0	22	10
not enough feedback	0	18	7
hard to use	0	14	5
frustrating	0	6	2
pointless or useless	0	6	0
time consuming	0	5	0
mistakes in tutorials	0	3	2
unfair	0	2	0
unengaging	0	1	0

Summary of student results

Students in contexts 2, 3 and 4, on balance, found the free body diagram tutorials helpful for learning. Both 1st year civil engineering cohorts were less enthusiastic in their comments than the other two contexts. The most positive response was from context 4 – a large cohort in their 2nd year of study, where the tutorials were integrated into the course assessment.

The analysis of comments corresponds well with the multiple choice responses, which indicates that those who chose to comment are a typical sample (i.e. not biased to those who liked or disliked the tutorials). Those students who found them helpful indicated that they were more engaging (e.g. used words like 'fun' and interesting'). Immediate feedback seems to be particularly helpful. Those students who did not find them helpful said they preferred other methods, found them confusing or hard to understand, or wanted better feedback. Several of these students mentioned specific areas of the tutorials that could be improved.

Overall, the student perception of effectiveness corresponds with the scores for the tutorial. Not surprisingly, more of the 2nd year students (context 4) both found the tutorials helpful and gained higher scores on average.

This initial analysis indicates that, for this particular adaptive tutorial, the subject and cohort appear to be more influential than the mode of use or the type of university. The 1st year, 1st semester civil engineering classes were both unenthusiastic about the tutorial, although it was deployed differently in each case. Entry qualifications are similar for both cohorts – ATAR>91. The 1st year regional university class and the large 2nd year metropolitan university classes in mechanical/general engineering both gave more positive responses. However, the 1st year 'remedial' context users score poorly, though they appreciated the tutorials.

Future work

The civil engineering student cohorts (contexts 1 and 3) both included a significant proportion of students who were repeating the subject. The results may therefore indicate that those students are struggling with basic threshold concepts underlying the free body diagram adaptive tutorial, which had not been catered for in the initial tutorial feedback. The frequent comments that the tutorial was confusing, hard or didn't give enough feedback support this view. Further analysis of the solution trace graphs for these students may show exactly where there is a need for more detailed feedback. Future analyses will also focus on a comparison of pre and post-test performance and understanding. Now under development are overlays of common mistakes made in the Adaptive e-Learning tutorials to help in visualising where student misconceptions are occurring. Figure 1 shows the free body diagram of a rear wheel drive car which is pushing into a wall. The correct solution on the left shows the external forces acting on the car as it pushes into the wall. The figure on the right shows the range of incorrect answers submitted by students with the colour intensity of the arrows indicating their distribution, the darkest being the most common incorrect solution. What this diagram shows with great clarity is the confusion of forces acting on the free body with forces exerted by the free body. A clear and quantified example such as this one is a very powerful tool for identifying common misunderstandings and providing students with improved feedback. Examples of potential feedback which can be developed for this particular AT example are shown in Table 4.

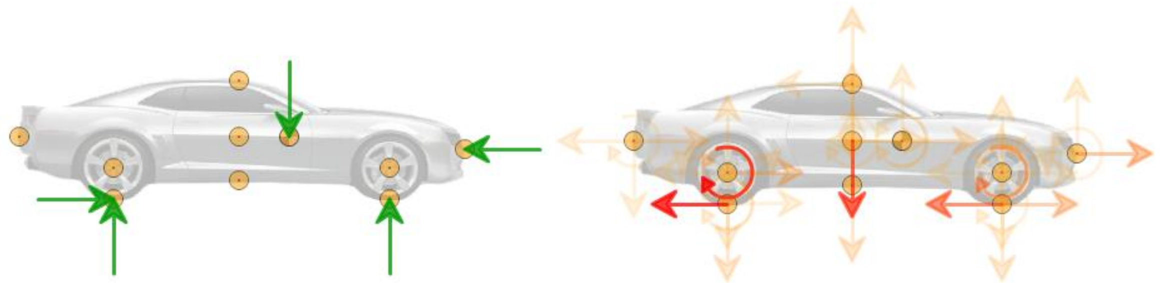

Figure 1 FBD of a car pushing into a wall. Left, Correct, Right, students' incorrect responses.

Table 4: Categories and examples for car FBD

Category	**Context**	**Example of error**
Check the question	Engineers must reliably meet the requirements of a specification	Centre of gravity in the wrong place or directions of forces not matching the directions of axes.
Precision	Care for detail required	Force angle out by 1 degree.
Internal/external forces or couples	An FBD should show only external forces.	Showing internal forces, e.g couple shown at rear wheel
Action/reaction confused	An FBD should show the forces acting on the isolated object.	Traction force at the rear wheel shown in the wrong sense i.e showing the reaction force on the ground instead.

Conclusions and implications

Overall, this exercise has shown the value of taking a community of practice approach to piloting and evaluating the adaptive tutorials within different learning contexts. It enabled us to identify patterns that inform us how and when the tutorials can be used and how to adapt the feedback given to students at different levels. Overall, for the free body diagram adaptive tutorial, we were able to show:

- The tutorial works well for 2nd year students, where it is reinforcing earlier learning and is integrated with assessment.
- The majority of students find the tutorials engaging.
- 1st year student cohorts with a significant proportion of repeating students need more scaffolding and detailed feedback than the tutorial currently provides.

The next stage of this study will analyse in more detail the solution trace graphs from the free body diagram and other adaptive tutorials, and relate them to student scores and the student feedback. The results will guide further adaptation of the feedback given within the tutorials, in particular for 1st year students, who may be struggling with threshold concepts that we have not fully identified.

There are also plans to develop an overlay tool to automate the visualisation of patterns in student decisions in the ATs. Currently these have to be assembled manually.

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