The Adaptive Virtual Workshop: Maintaining student engagement through an on-line adaptive resource for engineering design education

Alexandra, Vassar[a]; Gangadhara Prusty[a]; Lorelle Burton[b]; Jeung-Hwan Doh[c]; Robin Ford[a]; Matthew James[a]; Nadine Marcus[a]; Fidelis Mashiri[d]; Jan H.F. Meyer[e]; Roberto Ojeda[f]; Mohammad Uddin[g]; and Tim White[a].

UNSW, Australia[a], University of Southern Queensland[b], Griffith University[c], University of Western Sydney[d], University of Queensland[e], Australian Maritime College[f], University of South Australia[g]

Corresponding Author Email: a.vassar@unsw.edu.au

Structured Abstract

BACKGROUND

Engineering design is widely considered to be one of the pivotal elements of engineering education. However, design remains a subject that engineering students find the most difficult to grasp. This difficulty stems from the differences in the traditional engineering science-based courses, and the creative skills required for design courses. The traditional science-based courses in engineering provide the students with a clear reference point for right or wrong answers and follow a strategic formula-based approach that can be applied to all similar problems. This is not the case with engineering design, where there are no right or wrong answers, and each problem can have multiple solutions. Despite incorporating long-practiced teaching and learning approaches for engineering design courses, current methodologies continue to suffer from some inherent shortcomings. Due to variability in student response to various engineering design problems, and the 'no right way' to answer problems, educators find it difficult to evaluate student performance in complex design. Additionally, providing performance feedback to students in a timely and efficient manner is extremely costly for complex design tasks, in particular for the large class sizes that are common today. The current multi-institutional project was designed to redress this challenge. The development of Adaptive Toolboxes, consisting of Adaptive Tutorials (ATs) has been undertaken in this research. ATs assemble and integrate the mathematical tools and concepts required to preform a relatively simple but authentic design tasks. The current project builds on previous success in providing tailored feedback to students in mechanics courses, but also providing educators access to complex analytical data based on student responses. The current paper outlines the preliminary implementation of two ATs can be used in teaching engineering design courses at UNSW, Australia.

PURPOSE

The overall aim of this project is to address the current shortcomings in providing timely and efficient feedback to both students and educators in design education. The ability to provide individualised feedback to students can help to ensure student engagement and understanding of the subject matter, and potentially allow educators better flexibility in assessing the overall student performance. The current project investigates the use of ATs in the classroom to support learning (OLT ID13-2837). The effectiveness of such tutorials in supporting online-learning is examined. This study focuses on the design of a flywheel and design of a beam as the two ATs used in this preliminary investigation for the teaching of design in Mechanical Engineering. These ATs provide on-demand access to authentic design experiences with guided support and immediate, tailored feedback for the students. One of the main benefits that could increase student understanding of subject matter is the ability of the tutorials to support the basic difficulties that are seen in design education – current tutorials allow for multiple variable entries, thereby permitting multiple possible solutions and timely individualised feedback to cater for the multiple solutions.

DESIGN/METHOD

This paper focuses on the implementation of the Mechanical Engineering ATs – the design of the flywheel, and the design of a beam at UNSW, Australia. The current experimental approach comprises

both qualitative and quantitative research methods. For the qualitative analyses, survey data was collected to examine the efficiency of ATs in teaching engineering design tasks. Surveys were conducted at the completion of each of the ATs to gauge student experience and engagement with the subject matter. This has included documenting any benefits to learning achieved (eg., better understanding of concepts after completing the AT).

Quantitative assessment was undertaken to understand student performance in each question. Statistical analysis of assessment scores, time spent on each of the questions, number of attempts made for each question have been undertaken to help understand any particular areas of difficulty or concern with the subject matter. Additionally, one-way analysis of covariance (ANCOVA) tests have been conducted to find any significant differences in the pass/fail rates in each of the different courses where the ATs have been implemented, in comparison to the previous year where no ATs were used in the same course.

RESULTS

The aim of the study is centred on improving the student experience in design-based engineering courses, by using online-based Adaptive Workshops. The research found that students were able to better understand the subject matter via the improved feedback loops provided; and both the student and the educator were able to make necessary adjustments to cater for the individual learning needs of students. Additionally, surveys found that students had a better and more enjoyable learning experience through the use of the ATs. However, a third of students have found the ATs hard to navigate, which would effort needs to be invested in improving the navigation aspect of the ATs, so that students can focus limited cognitive resources on the subject matter. These preliminary results are in line with other research that shows students feel that ATs are beneficial to their learning (Khawaja et al., 2013). The results indicated a better pass rate in the subject with the introduction of ATs, also in line with earlier studies that have shown that the progressive introduction of ATs to the course Mechanics of Solids curriculum resulted in the steady increase of pass rate marks in that course (Prusty et al. 2011; Khawaja et al. 2013).

CONCLUSIONS

The use of ATs in teaching engineering design has resulted in improvements to the way educators are able to analyse student needs. This can further translate to improved student engagement and increased understanding of the subject matter, achieved through the improved, timely and individualised feedback mechanisms. The preliminary results of this research suggest that ATs do not necessarily result in higher student performance can improve overall performance of students in the subject and increase their understanding of the subject matter. Addressing This will in turn allow for better structure to the design of courses and the ability to efficiently understand and address any gaps in student knowledge. Preliminary results indicate that the inclusion of ATs in the teaching curriculum does not necessarily translate to higher marks or deeper student engagement; no statistically significant differences were seen in the final exam results in the subject. However, initial data suggests a higher overall pass rate for the subject with the inclusion of multiple ATs. Overall student feedback has suggested that students enjoyed using the ATs and would like these used more often in their subject. One third of students surveyed found that the ATs give them a better understanding of the subject matter. More research is required to support these preliminary results.

KEYWORDS

eLearning, adaptive feedback, engineering design education

Introduction

Constructing an authentic learning environment for Engineering Design courses can often prove to be a complex task. Whilst Engineering Design is widely considered to be one of the pivotal elements of engineering education, historically engineering design courses are usually introduced only in second year, subsequent to science-based courses, such as mathematics and science (Prusty et al., 2011; Dym et al., 2005; Prusty et al., 2009; Velan et al., 2009; Prusty et al., 2013; Khawaja et al., 2013). This often leads to students experiencing difficulty in understanding and practising engineering design. This difficulty stems from the differences in the traditional engineering science-based courses, and the creative skills required for design courses. The traditional science-based courses in engineering provide the students with a clear reference point for "right" or "wrong" answers and follow a strategic formula-based approach that can be applied to all similar problems. This is not the case with engineering design, where there are no right or wrong answers, and each problem can have multiple solutions. Engineering design requires a shift in student thinking and understanding to incorporate both convergent and divergent thinking techniques. In fact, a study by Dym et al. (2005) has shown empirical evidence that those student design teams that challenged engineering assumptions throughout the design process the most, performed better than students with little variations over the design process – further reinforcing the idea that design requires cycles between divergent and convergent thinking in order to be successful.

Current teaching methodologies for engineering design continue to suffer from some inherent shortcomings. A lack of academics with industry experience, lack of expensive equipment required to undertake mechanics-based design and builds, setup of laboratories and the incorporation of an effective ratio of students to tutors in such a laboratory, makes teaching design a resource-heavy activity. The simulation of actual environmental conditions, for example in a design of a stiffened panel of an aeroplane, is virtually impossible in a traditional laboratory setting. In particular, with increasing class sizes, in most cases with student numbers in excess of 200 in first and second years, the universities are simply not able to provide an authentic engineering design experience to all of its students.

Traditional laboratory-based classes have thus far been a critical part of teaching design concepts to students, and have helped to provide students a sense of 'authentic engagement' (Nedungadi & Raman, 2010). However, in large class sizes, a hands-on laboratory is not always a practical or efficient use of resources. Research shows that computer animations and simulations can provide excellent opportunities for students to increase their subject matter understanding by the manipulation of all variable parameters in animations and simulations (Jimoyiannis & Komis, 2001; Nedungadi & Raman, 2010). In addition, the use of computer-based design experiences can assist educators in evaluating student performance in complex design-based activities. Such software is also able to provide performance feedback to students in a timely and efficient manner – this is extremely costly for complex design tasks, but is essential with large class sizes.

In this way, Adaptive Learning can help to combat some of the current shortcomings in engineering design. One of the most important aspects of adaptive learning is the ability of the system to engage with student's individual learning needs, by allowing them to work at their own pace and knowledge level. The feedback provided to students is adaptive; it is based on their input into the system, and directed as an individualised response to their particular errors. Adaptive Tutorials have been previously and successfully used in Mechanics courses (Prusty et al., 2011; Prusty et al., 2009; Prusty & Russell, 2011; Marcus et al., 2011; Ben-Naim et al., 2009). Based on this success, a multi-institutional project has been initiated to develop Adaptive Toolboxes for Engineering Design courses. Currently, design tutorials in Mechanical, Civil, Aeronautical Engineering and Naval Architecture have been developed and are in the process of being implemented (Figure 1). Adaptive

Toolboxes consist of Adaptive Tutorials (ATs) and assemble and integrate the mathematical tools and concepts required to perform a relatively simple but authentic design task. Used extensively in teaching engineering science, ATs have been shown to improve student performance and better engage with students.

The main aim of this study is to examine the efficacy of using Adaptive Tutorials in Engineering Design and how the use of these tutorials can better inform learning and teaching processes.

Figure 1: The range of tutorials designed for teaching Engineering design, including for disciplines of Civil, Aeronautical, Mechanical and Naval

Adaptive Tutorials in Engineering Design

ATs are web-based eLearning modules, where the difficulty, feedback and activity-sequence of the tutorial is adjusted based on a student's performance and profile (Khawaja et al., 2013; Nedungadi & Raman, 2010). Students are encouraged to learn at their own pace and also interact with any tutorial simulations, thereby encouraging discovery-based learning. There are three particular types of adaptive behaviour in ATs:

1) Difficulty is adjusted based on student-specific actions and can be mediated by the educator based on analysis of student response and engagement with the tutorial;
2) Feedback is adapted to each student's individual needs (based on system inputs);
3) Each tutorial has an adaptive 'activity sequence', where students are given a particular sequence of questions or events based on their earlier inputs into the system.

These important adaptive aspects can aid in addressing the current shortcomings in providing timely and efficient feedback to both students and educators in design education. Furthermore, one of the unique features of the tool is its ability to provide analytics to the educators that can help to guide and inform future teaching processes (Ben-Naim et al., 2009; Ben-Naim et al., 2008). The ability to have detailed analysis of each student's level of engagement with the tutorial can greatly assist the educator to better structure their instructional design for maximum use of our cognitive resources. The educator can be provided with detailed analysis of student performance, including the number of attempts made at a question, a detailed breakdown of the kinds of mistakes made in answering the questions and the time spent on each of the questions. Such information is also invaluable to educators in better understanding what threshold concepts there are in the subject matter for students, concepts that represent a transformation in understanding, without which a learner is unable to progress to learning more complex material (Meyer et al., 2003). It is essential for an educator to better understand what threshold concepts are encountered by each individual student in order to then use this information to cater their teaching to better suit the needs of the class and of each individual student in subsequent instructional design. Visual trace graphs of student performance can help to examine in more detail student interaction with an AT and to adapt the content as needed based on student performance. Teachers can in this way find the best possible way to help their students understand subject matter (Ben-

Naim et al., 2008; Ben-Naim et al., 2009). Further clarification on ATs can be found in previous publications (Prusty et al., 2011; Khawaja et al., 2013; Marcus et al., 2011), and further presentation of AT use in engineering design tutorials can be found in recently presented work (Jimoyiannis & Komis, 2001; Nedungadi & Raman, 2010; Vassar et al., 2014).

Method

In this case study, three successive cohorts of students doing their undergraduate Mechanical Engineering degree and in their second year of study undertook an Engineering Design course with either no adaptive tutorials (implemented in 2012), one adaptive tutorial (implemented in 2013) or two adaptive tutorials (implemented in 2014). The first of the AT's involved the design of a beam, where students had to design a cross-section for a column that was holding up a garage. The second of the ATs focussed on the design of a flywheel, teaching students how to design the axle of a stationary bike and an accompanying flywheel. Both tutorials provide many ways in which students can alter their designs, the paths are adaptive, based on student input into the system and allow room for creativity and experimentation with design. The overall assessment of learning and the lecturer taking the course did not change over the course of the three years. Due to the changing nature of university courses, in terms of a course's popularity, the differing capabilities of different students within each course, it is impossible to establish a tightly controlled experimental analysis. We are conducting a quasi-experimental design where we loose some experimental control but gain access to a real-life scenario in the process (Kenny, 1975; Huitema, 2011). In this experimental approach, both qualitative and quantitative analysis were used to establish any patterns of difference in the performance of students, and the overall satisfaction of students with the course in a similar manner to a study of the efficiency of ATs in Mechanical Engineering (Khawaja et al., 2013). Qualitative and quantitative data have been gathered concurrently, thereby the design of the evaluation following a concurrent triangulation strategy, described by Creswell (Creswell, 2009) and implemented in other work examining the use of ATs in the classroom (Prusty et al., 2011; Prusty et al., 2009; Prusty & Russell, 2011; Marcus et al., 2011).

In the quantitative analysis component, the aim was to whether there were any improvements in the marks of students or the overall understanding of subject matter upon the introduction of adaptive tutorials into the engineering design course. Students undertook the ATs at various points of the semester, based on the curriculum and the course plan for the semester. Marks were attributed for the completion of the ATs, which then counted towards the final course mark. Due to the non-randomised nature of the experimental groups, a one-way analysis of covariance (ANCOVA) tests were conducted to find any significant differences in the mean final course marks in each of the years where the ATs have been implemented, in comparison to the previous year where no ATs were used in the same course. The statistical analyses were sought to get a better understanding of the exploratory research questions, which look to test the assumptions that adaptive tutorials can effectively support learning and teaching processes (Khawaja et al. 2013; Prusty et al. 2011; Nedungadi & Raman 2010; Prusty et al. 2009; Velan et al. 2009; Prusty et al. 2013). In this exploratory research, it was predicted that students with previously lower performance should benefit more from adaptive tutorials than students with higher performance profiles. Furthermore, those students that perform well in the AT component of the course, would achieve better results in the final exam. And finally, it was predicted that students would perform better with the inclusion of ATs in the design courses, as compared to the students who did not have ATs included in the design course.

One of the secondary aims was to see whether it was possible to determine any particular threshold concepts to student understanding in engineering design. This was done by the examination of the time spent on each part of the design cycle questions and the number of attempts made for each question, thereby examining those components of the AT, which can then inform the rest of the teaching aspects. An understanding of what threshold concepts are potentially encountered by students can help to direct learning in such a way, as to reduce external cognitive load and therefore contribute our limited cognitive resources to learning the instructional material itself.

In terms of qualitative analysis, survey data was collected to examine the efficiency of ATs in teaching engineering design in Mechanical Engineering design courses at UNSW, Australia, and the overall student satisfaction with completing ATs.

Results and Discussion

Student Performance

A one-way between-groups analysis of covariance was conducted to explore the impact of ATs on student final course marks. This was done at three different times, prior to any Design ATs being introduced, with 1 AT being introduced and with 2 ATs being introduced. The final course marks show an increase between the cohort of students that did not use any ATs (*M=66.32 SD =15.578*) to the cohort of students that used 1 AT (*M=68.7 SD = 14.953*). This is in contrast again to the following year, where 2 ATs were used in the course where the mean overall mark decreased (*M=64.75 SD=17.495*). According to the ANCOVA, there were no significant differences between the final course marks for the groups with no ATs, 1 AT and 2 ATs, $F(1, 1018) = 1.915$ $p > .05$ $(p = 0.167)$. This implies that the higher number of ATs used in the engineering design courses did not lead to a positive effect on the overall performance of students. This preliminary finding is in line with earlier findings of the use of ATs in Mechanical Engineering (Ben-Naim et al., 2009; Khawaja et al., 2013). However, it is important to note that this was the first time a beta version of an AT was utilised in Mechanical Design courses, and therefore more research is needed to determine the overall influence of ATs on course marks.

The mean final marks exam marks are fairly consistent across the three years, and the standard deviations show a consistent spread of marks across the three cohorts (Table 1). Using a one-way between-groups analysis of covariance to explore the significance between the different cohort exam marks, it was found that there were no statistically significant differences between the three cohorts of students in the final exam marks, $F(1, 1018) = 0.753$, $p > 0.05$ ($p = 0.386$).

Table 1: Statistical Analysis of three cohorts of test scores with no ATs, 1 AT and 2ATs

		Final Course Mark (/100)	Exam Mark (/40)	Beam Design AT Mark (/3)	Flywheel Design AT Mark (/1)
(N = 333)	No ATs (2012)	66.32 (15.578)	24.78 (7.456)	N/A	N/A
(N = 332)	1 AT (2013)	68.7 (14.953)	23.92(7.902)	2.342 (.971)	N/A
(N = 354)	2 ATs (2014)	64.75 (17.495)	24.245 (8.408)	2.38 (.957)	0.676 (.337)

Additionally, the mark distribution across the three different cohorts of students indicated the inclusion of ATs in the syllabus resulted in higher pass rates and slightly lower fail rates, indicating that the inclusion has been beneficial to students to some extent (Figure 2). These preliminary results are not statistically significant and more research is required in the area, once the beta version of the Flywheel Design AT is finalised.

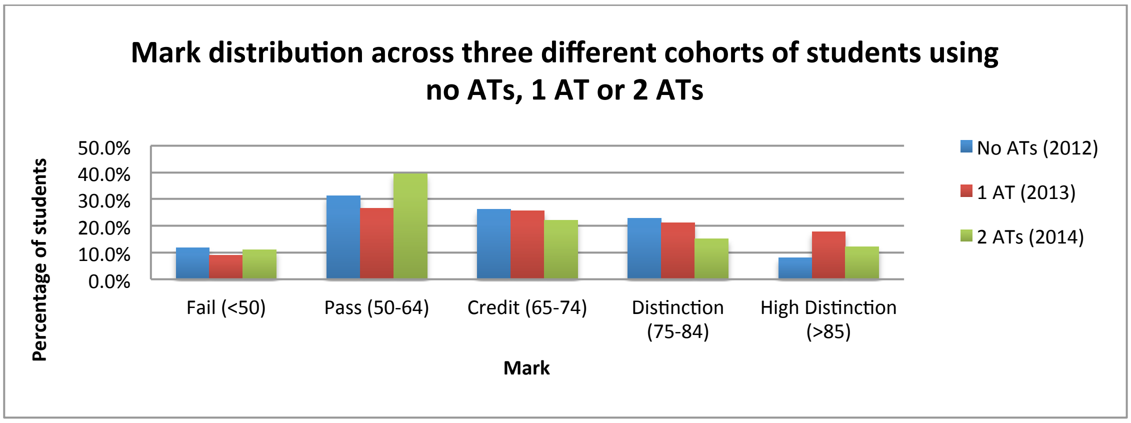

Figure 2: Mark distribution across the three different cohorts of students

Otherwise, no significant differences were seen with the use of ATs in other mark areas, and final course marks were not significantly influenced by the completion of ATs. The analytics of the Flywheel Design tutorial (implemented in Session 1, 2014) were then used to determine whether there were any specific threshold concepts in the design loop that the students encountered repeatedly. Figure 3 shows the Design Loop used to make the assessment, with each question divided into the particular section of the Design Loop that it falls into and some sections of the Design Loop joined together to fit with the tutorial question structure.

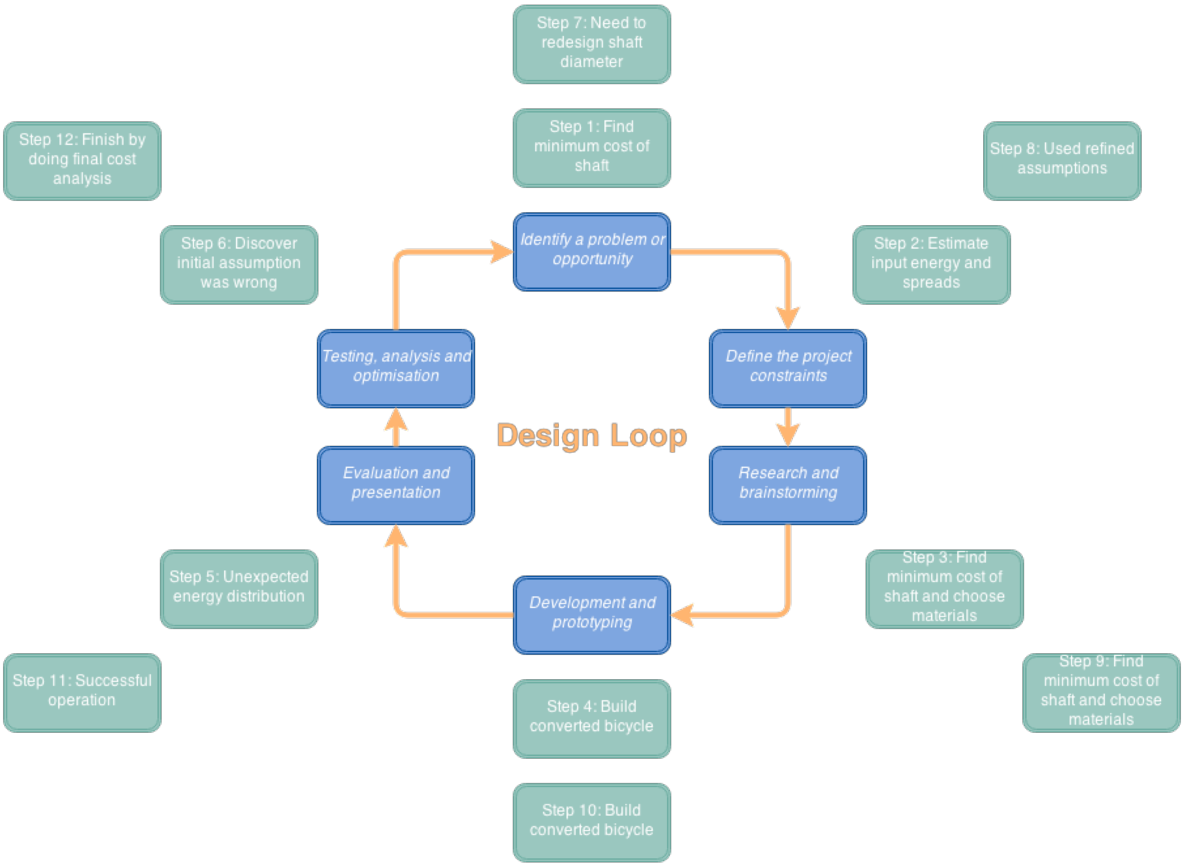

Figure 3: Design loop with questions from the Flywheel Tutorial separated into the branches of the loop

The analytics of the Adaptive Learning Platform found that the 'Development and Prototyping' branch of the Design Loop had the highest mean times to complete and required the highest number of attempts to complete (Table 2). This implies that students found this to be the hardest aspect of the tutorial to master and this could potentially imply the presence of threshold concepts.

Table 2: Adaptive eLearning Platform Analytics for the Design Loop

		Mean Time To Complete (min)	Mean Attempts at Question
(N = 15)	Identify a Problem or Opportunity and Define the Project Constraints	2.567 (1.791)	1.25 (0.071)
(N = 26)	Research and Brainstorming	2.968 (2.537)	1.798 (0.892)
(N = 5)	Development and Prototyping	6.443 (0.845)	2.731 (1.262)
(N = 5)	Evaluation and Presentation and Testing, Analysis and Optimisation	3.47 (3.108)	1.567 (0.235)
TOTAL		3.934 (2.458)	1.911 (0.939)

Other ways in which the Adaptive eLearning Platform can help examine where students are encountering problems is with the use of the Solution Trace Graph (Figure 4), which provides a visual summary of the overall student performance (Meyer et al., 2003; Ben-Naim et al., 2009). The solution trace graph in Figure 4 shows that a third of the students got this particular question wrong on first attempt; and then just under half of those students got the question correct on their second attempt. The access to this information can help to inform instructional content as needed and can therefore allow for educators to obtain feedback in real-time from a large group of students. This can greatly reduce the load on the academic, and also improve the course content in real-time as needed, as opposed to waiting until the end of semester to gather course and student performance data.

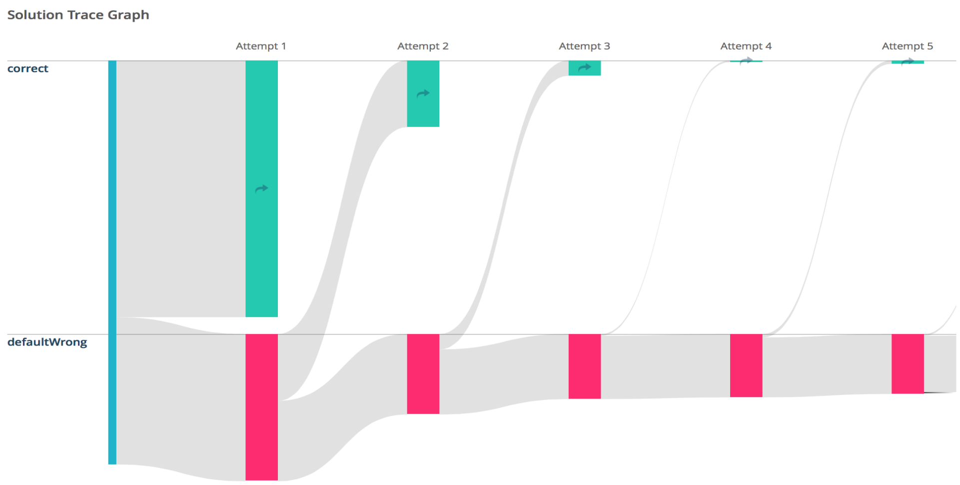

Figure 4: A snapshot of the Solution Trace Graph

Student Feedback

A survey was conducted with students after the completion of the Mechanical Engineering Flywheel Design and Beam Design tutorials in 2014. Some of the questions that students were asked are whether they found the tutorial to be easy to navigate and learn from, whether they would prefer using ATs for other courses and whether they found the AT useful to learning more about Engineering design. Due to the beta nature of the Flywheel Design AT, there were a number of negative comments due to the technical issues encountered by students, which were resolved to be bugs in the coding aspect of the tutorial and not the tutorial material itself. However, this caused some frustration to those students who encountered the bugs and therefore influenced their engagement with the tutorial in a negative manner.

An important aspect of all ATs, in terms of the cognitive load placed on student learning, is that students find them easy to navigate and easy to learn how to use the interactive aspects of the tutorial. This ensures that cognitive resources are directed only to learning the material presented in the tutorial, as opposed to also being used for learning how to use the tutorial itself. Indeed, 37% of students either strongly agreed or agreed that the tutorial was easy to navigate and therefore did not detract from their learning the intended material. A total of 31% of students were neutral on whether the tutorial was easy to learn. Almost one third (32%) of students surveyed found that the AT was not easy to navigate (Figure 5).

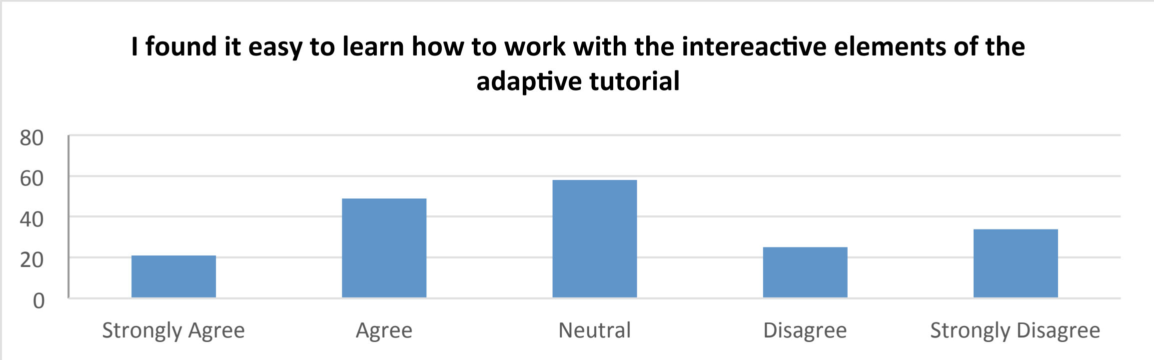

Figure 5: Student survey response for the (2014) Flywheel AT implementation

Overall, the qualitative feedback received from the students implies that students enjoyed using the ATs and found it useful to learning about Engineering Design. Just over half the surveyed students (52%) would like to use ATs in other topics, in comparison with only 22% of students who would prefer not to use the adaptive tutorials again (Figure 6). The majority of students (55%) also found the adaptive tutorial (Flywheel Design) useful in learning Engineering Design Concepts; one fifth of the students (21%) did not find the tutorial useful in learning Engineering Design Concepts (Figure 6). Overall, these findings indicate that students were somewhat satisfied with the use of adaptive tutorials in Engineering Design and found them to be an enjoyable experience. Due to the beta nature of the AT, some technical difficulties would have influenced student responses. Further research is required with the final version of the tutorial, where no technical difficulties will influence student perception.

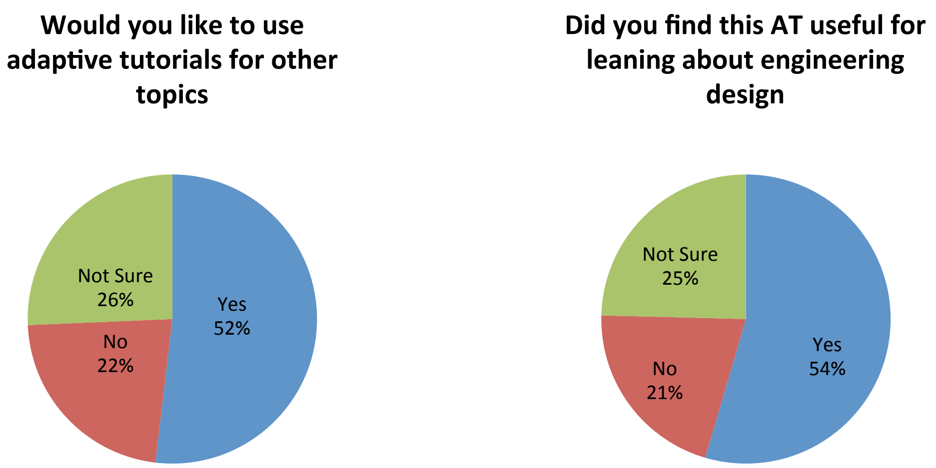

Figure 6: Student survey response for the 2014 Flywheel AT implementation

Conclusion

The construction of authentic learning experiences in Engineering Design courses is a complex undertaking, and is often influenced by physical and financial constraints. To combat these issues, an Adaptive eLearning Platform was developed, which is capable of providing students an adaptive and customised learning environment. As part of the Adaptive eLearning Platform, ATs were constructed to better support the teaching of design in engineering and to facilitate positive learning experiences and/or outcomes. Thus far, only the beta version tutorials developed for Mechanical Engineering have been implemented in class, with the other Engineering disciplines to follow in Semester 2, 2014. A more complete analysis of results can be undertaken once the other Engineering Design tutorials are implemented within their courses. The current study is restricted only to the implementation of ATs in Mechanical Engineering Design.

It is difficult to establish rigorous controls in an experiment that involves testing in a real environment. It is not possible to control for the varying skill sets of students across the three years of the course being run or the changes in the students' personal learning environments. However, there were no major changes to curriculum, teacher, or teaching methods in the Mechanical Engineering Design course. The current findings indicate that the addition of ATs into the teaching of Engineering Design does not necessarily equate to higher student marks or deeper student engagement in the subject matter. The current data showed no differences in exam performance with the introduction of ATs into the curriculum of teaching. However, the rate of students passing the course increased with the addition of ATs into the curriculum. Furthermore, an in-depth analysis of student performance in the ATs in real time does have the benefits of being able to inform further instructional design and a focus on particular threshold concepts for students. Overall, student feedback suggests that students enjoyed completing the ATs and would like them used in their other courses, once technical difficulties have been rectified. However, almost a third of students (32%) found ATs hard to navigate and therefore further effort needs to be invested in making the ATs easy to use and navigate, thus ensuring that all the majority of cognitive resources are spent on learning the material.

The preliminary use of the ATs in Mechanical Engineering design did not negatively affect student learning. Overall, there is partial evidence that including ATs in the teaching of engineering design courses can lead to higher pass rates for students. A key strength in using ATs in design courses is its access to student analytics, which can provide educators with important information about student threshold concepts and inform further instructional design to ensure that students are able to undertake design courses with more ease and apply their skills in solving realistic problems.

References

Ben-Naim, D., Marcus, N. & Bain, M., 2008. *Visualization and analysis of student interactions in an adaptive exploratory learning environment,* In Proceedings of the 1st International Workshop in Intelligent Support for Exploratory Environments In: The European Conference on Technology Enhanced Learning (EC-TEL'08).

Ben-Naim, D., Bain, M. & Marcus, N., 2009. A User-Driven and Data-Driven Approach for Supporting Teachers in Reflection and Adaptation of Adaptive Tutorials. In T. Barnes et al., eds. Proceedings of Educational Data Mining 2009: 2nd International Conference on Educational Data Mining. Cordoba, Spain, pp. 21–30.

Creswell, J.W., 2009. *Research Design*, SAGE.

Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D., Leifer, L.J., 2005. Engineering design thinking, teaching, and learning. *Journal of Engineering Education,* 94(1), pp.103–120.

Huitema, B., 2011. *The analysis of covariance and alternatives: Statistical methods for experiments, quasi-experiments, and single-case studies*. Wiley 2nd ed., p 567.

Jimoyiannis, A. & Komis, V., 2001. Computer Simulations in Physics Teaching and Learning: a Case Study on Students' Understanding of Trajectory Motion. *Computers & Education*, 36(2), pp.183–204.

Kenny, D.A., 1975. A quasi-experimental approach to assessing treatment effects in the nonequivalent control group design. *Psychological Bulletin*, 82(3), p.345.

Khawaja, M.A., Prusty, B.G., Ford, R.A.J., Marcus, N., Russell, C., 2013. Can more become less? Effects of an intensive assessment environment on students' learning performance. *European Journal of engineering Education*, 38(6), pp.631–651.

Marcus, N., Ben-Naim, D. & Bain, M., 2011. Instructional Support for Teachers and Guided Feedback for Students in an Adaptive eLearning Environment. In Eighth International Conference on Information Technology: New Generations (ITNG).

Meyer, J., Land, R. & Project, E., 2003. *Threshold Concepts and Troublesome Knowledge - Linkages to Ways of Thinking and Practising*, In Improving Student Learning - Ten Years On. C. Rust (Ed), OCSLD, Oxford.

Nedungadi, P. & Raman, R., 2010. Effectiveness of adaptive learning with interactive animations and simulations. 6, pp.V6–40–V6–44.

Prusty, B.G., Ho, O. & Ho, S., 2009. Adaptive Tutorials Using eLearning Platform for Solid Mechanics Course in Engineering. In Paper presented at 20th Australasian Association for Engineering Education Conference. University of Adelaide.

Prusty, B.G. & Russell, C., 2011. Engaging Students in Learning Threshold Concepts in

Engineering Mechanics: Adaptive eLearning Tutorials. In International Conference on Engineering Education (ICEE2011). Belfast, Australia.

Prusty, B.G., Russell, C., Ford, R., Ben-Naim, D., Ho, S., Vrcelj, Z., Marcus, N., McCarthy, T., Goldfinch, T., Ojeda, R., Gardner, A., Molyneaux, T., Hadgraft, R., 2011. Adaptive Tutorials to target Threshold Concepts in Mechanics - a Community of Practice Approach. In Proceedings of the 22nd Annual Conference for the Australasian Association for Engineering Education. Freemantle WA, Australia, pp. 305–311.

Prusty, B.G., Vrceli, Z., McCarthy, T. Gardner, A., Ojeda, R., Russell, C., Khawaja, A.M., Marcus, N., 2013. *An Adaptive e-Learning Community of Practice for Mechanics Courses in Engineering*, Australia: Australian Government, Office for Learning and Teaching.

Vassar, A., Prusty, B.G., Marcus, N., Ford, R.J.A., 2014. The Virtual Design Workshop: an Online Adaptive Resource for Teaching Design in Education. In Paper presented at 6th International Conference on Computer Supported Education (CSEDU 2014), pp.452-458

Velan, G. Ben-Naim, D., Kumar, R., Bain, M., Kan, B., Marcus, N., 2009. Adaptive tutorials using virtual slides to enhance learning of microscopic morphology. In G. Richards, ed. Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education. Chesapeake, VA, pp. 759–763.

Acknowledgements

This project is funded by the Office for Learning & Teaching, an initiative of the Australian Government Department of Education, Employment and Workplace Relations (Project OLT ID 13-2837).

Copyright statement