Threshold-Concept Inspired eTutorials in Electronics

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Abstract: Engagement of students in traditional engineering tutorials can be low, especially where the level of preparation varies widely across the student population. Online tutorials are a way of addressing this problem, as they offer the chance for students to work at their own pace, at their own preferred times, while staff can add and update questions, links, and hints in almost-real time. We created such a set of tutorials in an introductory electronics course, incorporating a strong Threshold-Concept focus. The tutorials were coded by one of us (Balsom) in PHP, and this allowed us to extensively and flexibly control reporting to examine student usage. We benchmarked students from year to year, introduced the eTutorials, and measured their impact. We employed surveys and interviews for additional feedback. We quantitatively and qualitatively address the question of how effective the eTutorials were in comparison with well-staffed, well-attended, conventional tutorials addressing the exact same material in the previous year. We also search for correlations between student usage and eventual grade with the aim of early detection of students requiring intervention. The cost is compared with use of commercially-available eTutorials in Physics that are used by a parallel introductory Physics course in the same school.

Keywords: Threshold Concepts, Computers in Education, Intelligent Tutoring Systems

1 INTRODUCTION

Critics describe academics in engineering as "teaching the way they were taught", meaning that the pedagogical style has not changed much, although the material they are required to teach changes relatively rapidly. This manuscript will describe how we addressed this with respect to tutorials, using an electronic, web-based, "eTutorial" system, and how well it succeeded.

Intelligent Tutoring Systems (ITS) are not a new idea, as one might guess from the observation that they rate a Wikipedia entry. [1] These systems have naturally migrated to the web in recent years, and are used for high-stakes and large-cohort situations where they can be very involved affairs. [2] The idea has reached even into the narrow world of electronics, for example see [3]. Good quality systems can be very costly to implement. A similar system built at Auckland University with the aim of managing assessment of large cohorts at reduced cost took five years to develop. [4]

Our aim with the system described here is not so much to provide intelligence but merely to provide examples in adequate quantity with flexible delivery, and some system of reporting so that student progress may be monitored and assessed. Students regularly ask for more examples. Because electronics and circuit theory textbooks assume a high level of mathematical experience and ability, their problem sets are not useful to our students. Even if we had extensive problem sets, limits to contact time prevent having more tutorials or streamed tutorials that might help students get through many more conventional problems.

Our response is to limit questions to the "important ideas", and to have students access these electronically, on demand. Threshold-Concept Theory (TCT) is the tool that allows us to focus on the troublesome, big ideas, referred to as "Threshold Concepts" (TCs). [5–7] Our experience with assessment based on TCs was used to target these important areas using multiple-choice questions in the fashion of a Concept Inventory (CI). [8]

2 The Problem

Prior to 2013, our first-year paper "Introduction to Electronics" (ENEL111) consisted of 3 lectures per week, one 3-hour laboratory session per week, and several flat-classroom, hour-long tutorials of which each student was required to attend at least one per week, throughout a 12-week semester. We carefully selected tutors who knew what they were doing and communicated well. Tutors and academic staff attended tutorials so that plenty of manpower was available. In spite of effort put into tutorials, students regularly concentrated their criticisms on these practice sessions and problems.

These criticisms concerned quantity more than quality, of staff and questions, although students rarely completed all the problems and staff were often idly patrolling tutorials. Few students attended more than one tutorial, although this was encouraged. We observed that students could not suggest anything to improve tutorials that had not been tried. We formed the opinion that students attacked quantity because they did not truly understand what might have been at fault with the quality. Rather than continue with an ineffective strategy, we decided to put all available resources into creating an electronic catalogue of questions, and cancelling the face-to-face, scheduled tutorials. We suspected that the diverse spread of abilities and rates of learning meant that physical, group tutorials were a bad fit, with some students bored and others rushed and lost.

In threshold-concept terms, and with hindsight, we might speculate that those who has passed through the portal would be bored and distracted. Likewise, those entering the liminal space felt lost without knowing what questions to ask, and could not make use of the tutors. The deep contemplation that accompanies passage through the portal is not what a tutorial can supply.

3 What We Did

A trial of web-based eTurorials ran throughout A semester 2013. In parallel, students were assured that they could bring questions up with staff for personal help. Students were encouraged to bring questions to staff during laboratory sessions, and PCs and extra staff were on hand for this purpose. The tutorials were accessed via an easy-to-remember URL, "enel111.co.nz". Authentication was accomplished through Google accounts, so that usage could be tracked. The students were told that there was no penalty for wrong answers, so there was no incentive to create extra accounts apart from the ones provided through the university's enrolment system.[1] All questions are multiple choice. The questions were divided into 12 groups, and a student was allowed access to each subsequent group only after they had answered 5 consecutive questions correctly. Each group contained twenty-something questions, presented in random order, so that it was possible but tedious to get through by guessing over and over again.

Because we wanted a high degree of control and the ability to set and change activity-reporting mechanisms, the system was coded from scratch, in-house, over the summer, by one of us (Balsom) using the server-side scripting language PHP[2]. The question sets were taken from existing tutorials, past exams, and additional questions written specifically to ensure a decent choice of questions for this paper. The system logged every authentication, questions faced, times taken to make a response, etc.

Throughout the semester, students were surveyed and randomly interviewed by educational researchers (Harlow and Peter) periodically throughout the semester. Where a student either did not log in, or lagged behind, or streaked ahead of the topics, they were asked for their reasons, i.e., some interviews were not random but targeted. All students were given the possibility of "opting out", but most of the cohort of 125 students agreed to participate. Almost 90 students both opted in and completed the course. The data for those who opted out was deleted from the analysis, except for "bulk" statistics such as total numbers of users logged on at any time, etc.

All students take an IF-AT ("scratchy") type, 10-question test early in the semester. In order to benchmark the cohort, 9 questions used in the 2012 test were re-used verbatim in the test administered in 2013. There was no statistically-significant difference in performance in 2013 compared with 2012. The mean test scores on the identical questions were within 2% of the 2012 cohort who attended regular, classroom-style tutorials. Thus we can say with confidence that the two cohorts were essentially equally prepared for this paper. It should also be noted that we made every effort to change nothing else in the paper apart from the tutorial part, to remove all possible confusing factors that might change cohort performance. Lecture slides, lecturing and demonstrating staff, timing and locations of classes, laboratory equipment and assessments all remained exactly the same as far as we could determine.

The final exam in both cohorts was styled identically, consisting of 40 multiple-choice questions. The questions in both years were heavily weighted to address threshold concepts involved in the paper. The questions were similarly distributed across the topics examined, although no questions were exactly repeated.

[1] A number of "unrecognised" accounts were created. A very small number of these were used extensively.

[2] PHP originally stood for Personal Home Page, but it now stands for "PHP: Hypertext Preprocessor", a recursive acronym. It is free software released under its own license.

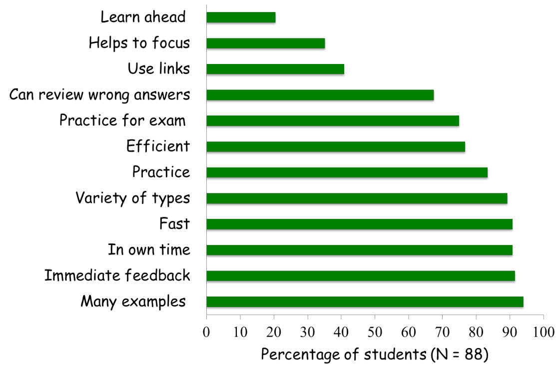

Figure 1: Summary of student perceptions. Bars indicate the value according to the students of an aspect of the new eTutorial system.

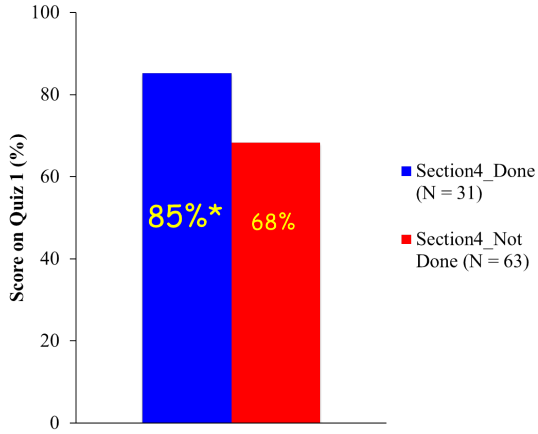

Figure 2: Score in the first test ("Quiz") for groups who had and had not achieved section 4 in tutorials before the first test.

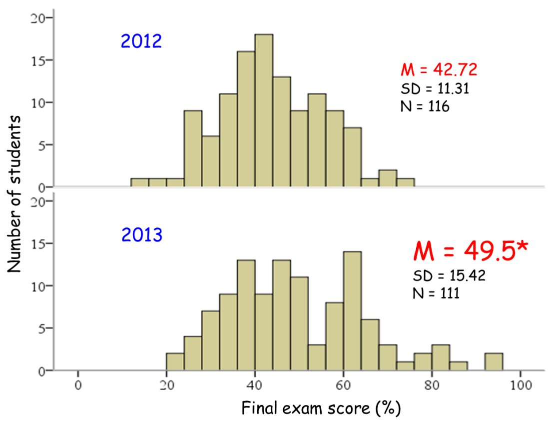

Figure 3: Final exam results in 2012 (conventional tutorials) and 2013 (eTutorials).

4 Outcomes

4.1 Qualitative

Surveys confirm that the students responded well, in spite of the "debugging" that ran in parallel. Figure 1 summarises the student's opinions of the eTutorial system. Some aspects were not valued so much as others, but in general they liked the approach. The level of dissatisfaction perceived by the researchers, who had interviewed students in both the face-to-face and eTutorial years, was drastically reduced. In figure 1 only the "Use links" factor represented a (known) shortcoming of the system, namely that question-specific online references to relevant instructional material was weak because we had not had the time and manpower to put that in place properly.

Data from student surveys also revealed they felt there was insufficient a number of examples for them to use for practice. This outcome should be taken in context: We provided about 20 questions in each of 12 sections, representing 4–5 times as many questions as were available through the old, paper-based tutorials! Nevertheless, we accept that more questions ought to be added as the system grows, even though this would make scoring 5 correct answers in a row a bit more difficult, because of the reduced likelyhood of seen questions reappearing.

Interviews and surveys prove that the eTutorials have improved engagement. The eTutorials accommodated different rates and styles of learning.

4.2 Quantitative

Data collected by us show that learning has significantly improved, and we are inclined to attribute this to the eTutorial system. Figure 2 shows that students who progressed through the eTutorial stages in a timely manner performed better. Of course, this does not prove cause, as the kind of student likely to learn well may also be more likely to carry out suggested tasks. The final exam in 2013 showed that student academic achievement is improved, with mean year-on-year assessment improving 7% with eTutorials compared to the previous year. Figure 3 presents the exam results. As the mean final examination mark improved with no other change to the course, and the two cohorts entered with little difference found in our benchmark test, we suggest that the switch in tutorial approach really is responsible for the "increase in the reduction of ignorance". This is not really surprising, for example in [9, 10] it is reported that an adaptive e-learning tutorial system lowered student failure rate in year 1 and year 2 mechanical engineering courses.

We have also conducted an initial analysis of the extensive reporting data logged by the system in an attempt to find useful correlations that might identify students at risk, or at least give a helpful view of progress. Figures 4 and 5 attempt to provide "activity" and "performance" snapshots, at the times of the first test and the final exam. The "activity" plots present a series of vertical lines, one line per student per section of the tutorial questions. The density of these images is an indicator of overall effort or at least time put in. Current flow, section 2, is considered to be a TC that students should have seen before, while section 4 is a TC they have probably not encountered before. It is not surprising that the upper plot of figure 4 shows much more activity in section 2. We might have expected to see even more in section 4, but activity did not appear until after the test (figure 5), when a lot of people realised they had a problem. By then our intense lab and lecture work was addressing that TC.

The "performance" (lower) plots are less clear. They show, in effect, how often questions were answered correctly on first attempt. This seems to reflect learning style more than ability, and we found no informative or pleasing correlations.

Figure 6 shows another attempt to seek a useful "fingerprint" of student activity. The image tells us that students hit the tutorial system in response to upcoming assessments, rather more so after the first one, and typically in intense bursts. We made no observations that have not already been reported out of usage statistics in similar systems. [4] We were not able to find any statistically-significant property of individual traces that shed light on the student. For example, students who performed well or poorly overall did not have distinctly-different contributions to the cluster in the figure. However, it does give a picture of the cohort and we intend to search in the future to see if it paints the same picture.

5 Cost

Approximately 600 hours of programming time and 100 hours of time spent entering questions has been spent on this project as of the completion of the trial semester. This work was carried out between mid-November 2012 and the end of May 2013. This represents a relatively small development period for a major piece of software that has proven itself in actual customer use. This cost could be compared with that spent by a Physics course that runs in parallel with ENEL111. The physics course uses a commercially available, online tutorial system. This costs some $37 per student. With course numbers ranging from 120 to 150, this represents something like $5,000 per annum. If performance was comparable, it would take 10 years for the investment to pay back. It is also interesting to note that the system saves something like $2,000–3,000 per year in casual demonstrator's salary, implying a commensurately shorter payback period.

The system as implemented allows questions to be added and removed by the staff running the paper. This

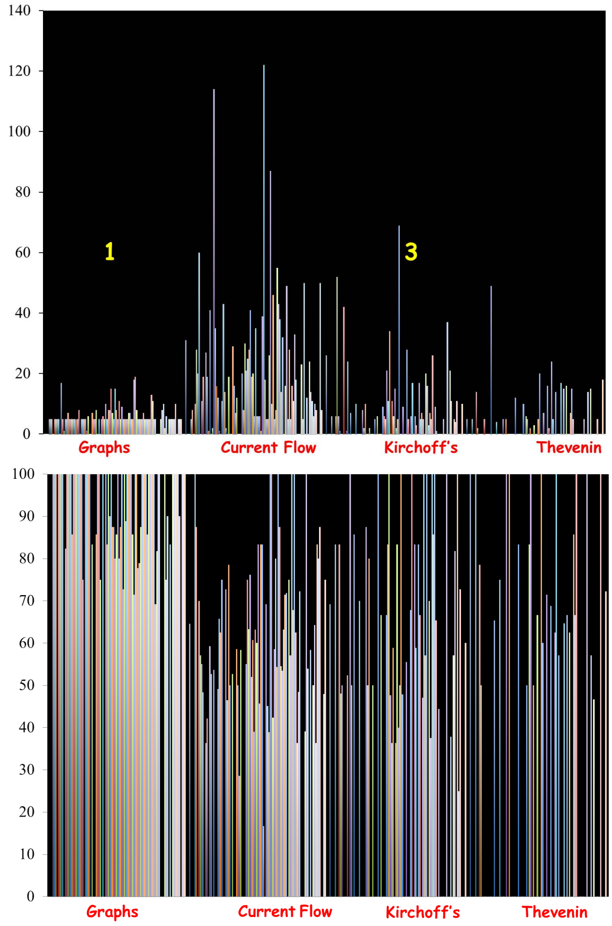

Figure 4: Summary plots of student *Activity* (upper) and student *Performance* (lower) in tutorials before the first test. Y-axis for activity is the number of attempts made on questions in a section, y-axis for performance the percentage of correct answers in the attempts made on questions in a section. Yellow numbers are the "section" in the program, of which there were twelve in total.

flexibility means that it is readily kept current. Finally, this system provides for a good level of monitoring, and if required, assessment of the students. We would argue that the investment will be very worthwhile even if the system is used purely for this course alone for only a few years. We hope it will see wider use.

6 The Future

Feedback from students repeatedly asks for the eTuts to be accompanied by relevant links to online sites such as the Khan Academy, Wikipedia, appropriate engineering web sites, etc. We plan to allow & encourage students to submit such links. We will moderate links and add questions.

While it is great so far, the system needs some enhancements. These include question-specific links to online re-

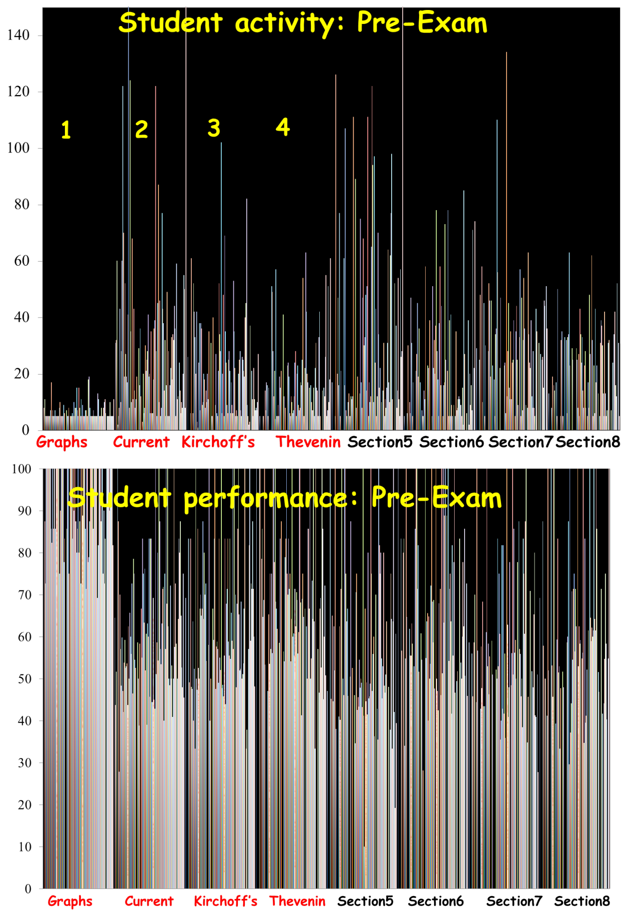

Figure 5: Summary plots of student *Activity* (upper) and student *Performance* (lower) in tutorials at the time of the final exam.

sources; hints if you are stuck; more detailed reporting of student activity; more questions in the database; and transfer of the system to Waikato University servers. We plan to carry out these improvements subject to funding. As of the writing of this manuscript we have funding to cover work up to the start of 2014.

7 Conclusion

Electronic tutorials suit larger student cohorts, and cohorts with wide levels of readiness, meaning the early years of popular courses. We have shown that they are very effective. They are not as cheap as conventional tutorials unless there are large numbers of students and the curriculum is reasonably stable.

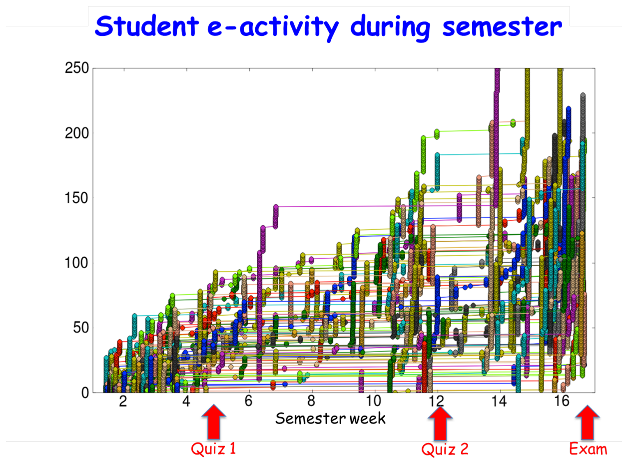

Figure 6: Examination of activity, measured as cumulative question attempts as a function of time throughout the semester. Each line is one student, each dot one attempt. The plot provides a visual summary of the bursts of activity. A horizontal stretch of a line signifies a period of inactivity.

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References

[1] Wikipedia: `http://en.wikipedia.org/wiki/Intelligent_tutoring_system`

[2] Ivon Arroyo, Carole Beal, Tom Murray, Rena Walles and Beverly P. Woolf, "Web-Based Intelligent Multimedia Tutoring for High Stakes Achievement Tests", *Proceedings of the 7th International Conference on Intelligent Tutoring Systems*, 2004, pp468–477, Springer.

[3] Mu Xiaoyan, D. Walter, Xu Huihui, P. Walter, and C. Berry, "Work in progress - video-based lab tutorials in an undergraduate Electrical Circuit course", 39th IEEE Frontiers in Education Conference, (FIE '09), 2009 , pp1–2.

[4] Smaill, Chris, "The implementation and evaluation of OASIS: a web-based learning and assessment tool for large classes", IEEE Transactions on Education, 48(4), pp658-663, 2005.

[5] Scott, J. & Harlow, A., "Identification of threshold concepts involved in early electronics: Some new methods and results", *Australasian Journal of Engineering Education*, Vol. 18, No. 1, 2012. `http://hdl.handle.net/10289/6343`

[6] Harlow, Ann, Jonathan Scott, Mira Peter, and Bronwen Cowie, "'Getting stuck' in analogue electronics: Threshold concepts as an explanatory model", *European Journal of Engineering Education*, Taylor & Francis Group, 2011. p.1-13.

[7] Harlow, A., M. Peter and J. Scott, "Threshold Concept Knowledge in Analogue Electronics: Support and Assessment", paper 1, *Proceedings of The 19th Electronics New Zealand Conference* (ENZCon), Dunedin, New Zealand, 10-12 December, 2012. `http://hdl.handle.net/10289/7203`

[8] Jonathan Scott, Mira Peter, and Ann Harlow, "An Electronics Threshold-Concept Inventory: Assessment in the face of the dependency of concepts", *Proceedings of the 1st IEEE Teaching and Learning in Engineering conference (TALE)*, Hong Kong, 20–23 August, 2012, T1C-2.

[9] Prusty, B., "Teaching and assessment of mechanics courses in engineering", *Third Biennial Threshold Concepts Symposium*, The University of New South Wales, Sydney, Australia, 1–2 July 2010,

[10] Prusty, B., Ho, O. and Ho, S., "Adaptive tutorials using eLearning platform for solid mechanics course in engineering", 20th Australasian Association for Engineering Education conference, University of Adelaide, 6–9 December, 2009.