Threshold Concept Knowledge in Analogue Electronics: Support and Assessment

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Abstract: In electrical engineering, as in other academic disciplines, there exist special, threshold concepts, where students often get stuck but which once grasped reveal new ways of thinking about a subject. Two surveys, student interviews and focus group discussions, and students' assessment were directed at learning of threshold concepts and their pre-cursors. Results suggest that one of the precursor concepts, current flow, may be a threshold concept in itself. A model of precursor and threshold concepts assessment and additional student-support for learning threshold concepts is suggested.

Keywords: analogue electronics, threshold concepts, learning support, assessment

1 INTRODUCTION

The threshold-concept theory developed by Meyer and Land (2003) has motivated a growing interest in contemporary research on teaching and learning of threshold concepts. According to the theory, in each academic discipline there exist special concepts that once grasped reveal new and previously inaccessible ways of thinking about that subject. Threshold concepts have been linked to ontological shifts (Meyer, Land, & Baillie, 2010), changes in identity, and shifts in subjectivity that come with the reconfiguration of a learner's prior conceptual framework. These changes are central to what it means to become an artist, economist or engineer. Alas, it is threshold concepts that students often find troublesome and where they frequently 'get stuck' (Davies, 2006; Harlow, Peter, Scott, & Cowie, 2011; Meyer & Land, 2005, 2006). Arguments have been made (Meyer and Land, 2003; 2005) that after first encountering threshold concepts, students may spend time in a 'liminal' state prior to crossing the threshold for deep understanding. Until students cross the threshold they are only able to mimic deep understanding and repeatedly fail to solve conceptually identical problems when these appear in new contexts. Thus, it is crucial to uncover why some students find it troublesome to understand and to express knowledge of threshold concepts; likewise, it is important to determine how students undergo a transformational, or even a creative, experience in the liminal space of learning.

Since the formulation of the threshold concept theory, researchers have been focusing on identifying threshold concepts in their field using the attributes identified by Meyer and Land (2003): threshold concepts are *transformative* (they change the learner's whole way of thinking), *irreversible* (they are hard to unlearn, as riding a bicycle), *integrative* (they connect into many diverse niches of a discipline), *bounded* (they mark the edge of a discipline), and they are potentially '*troublesome*' (difficult to grasp; counter-intuitive).

The research reported in the present paper builds on our previous and recent work on the identification of threshold concepts in the first-year electronics engineering and on our investigation of the impact of a threshold concept-informed curriculum and pedagogy on students' learning and retention in electrical engineering (Scott, 2010; Scott, Harlow, Peter, & Cowie, 2010a, 2010b; Scott, 2012). In our previous research five 'key' threshold concepts were identified and two were selected for a renewed curriculum for the first-year paper which was piloted in Semester A of 2010 (Scott, Harlow, Peter & Cowie, 2010a). The outcomes of our mixed-method evaluation study over three years (2010 - 2012) have been used to inform further reviews of the course, including further consideration of the threshold concepts. We have examined the relationships between students' achievement and their perceptions of the challenge of learning and understanding the identified threshold concepts. Additionally, we have explored the affordances of various threshold-concept-teaching opportunities and the students' perceived barriers to learning (Harlow, Peter, Scott & Cowie, 2011; Harlow, Scott & Peter, 2012).

Collectively, the outcome of these investigations has resulted in a revised curriculum to focus on stepping through these targeted concepts using a scaffolded, problem-based learning approach. The findings suggest that the changes in pedagogy, based on threshold concept theory, are worth pursuing as they have the potential to address current concerns around the declining number of tertiary graduates in electrical engineering world-wide (Entwistle, Nisbet, & Bromage, 2004).

Our goal in the present research was to investigate the impact of using the *Immediate Feedback Assessment Technique* (IF-AT) (Epstein et al. 2002) on students' learning of threshold concepts and to tap into students' understanding of threshold concepts and their precursors.

By the term ‘precursor concept’ we refer to an idea that must first be mastered by the student before a particular question addressing a threshold concept can itself be understood. The precursor concept might itself be a threshold concept, but it might equally be simple knowledge. As a trivial example, we might seek to test a student’s understanding of friction in the context of thread and knots by means of a question about the action of an overlocking stitch. Such a question would fail if the student did not know the particular action of an overlocking machine, and what constitutes an overlocked stitch. The knowledge of overlocking is necessary to understand the main question. In this example the dependence is obvious, but particularly when the precursor is a threshold concept that dependence can be less conspicuous. We might postulate that this arises either because the questioner is less likely to register that the student does not understand the precursor idea, or because the deep interconnections of threshold concepts make the dependence distant and subtle. In our work, we have noticed that the danger can lie in assuming that because the student passed a previous course involving the precursor threshold concept that they have passed the threshold, and understand it.

2 METHOD

In the first-year analogue electronics course there are typically 100 to 140 students, some of whom are international students. Students come from a variety of disciplinary backgrounds across the spectrum of science subjects taught at secondary school. There are also students with work experience in technical fields. In the present paper we did not determine if results differed by subgroup as that was not the focus, however, this analysis is definitely in our future plans.

Theories and problems are introduced in weekly lectures which provide motivation and a view of the ‘big picture’. Most of the class time is spent on ‘tangibles’, ‘ponderables’, and ‘visibles’, which are essentially hands-on activities, interesting questions and problems, or simulations, conducted in labs where students have hands-on experiences with equipment to solve problems, and in problem-based tutorials.

For this research we designed two surveys—one at the start of the course and one in the last week of the course—tapping into students’ perceptions of their understanding of taught threshold concepts, and activities that helped them learn. Of the 119 students enrolled in the first-year analogue electronics course, 105 took part in survey 1 and 69 took part in survey 2. Results from these surveys were combined with students’ mid-term and final examinations achievement scores on threshold concept and precursor to threshold concept questions to obtain a better understanding of student knowledge of threshold concepts.

Using various concept inventories that have been created in similar fields (Evans et al., 2003; Hestenes, Wells & Swackhamer,1992), the lecturer built a ‘concept inventory’ to cover the three-year course (Scott, Peter & Harlow, 2012). In order to maximise first-year students’ understanding of threshold concepts the lecturer focused on only two threshold concepts, Thévenin’s theorem and dynamic resistance.

To assess students’ understanding of threshold and precursor concepts the lecturer used IF-AT testing system which provides students with immediate feedback about the accuracy of their answers and allows students to continue answering a question until they discover the correct answer (see Figure 1). Using IF-AT the lecturer created an interactive learning opportunity for students and a more informative assessment opportunity for the lecturer.

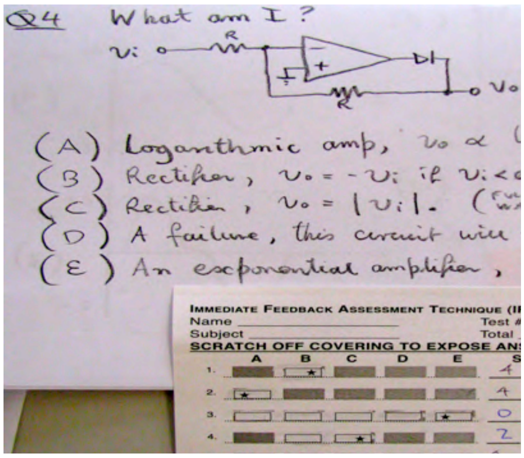


Figure 1: An IF-AT question and ‘scratchie’ card

3 RESULTS AND DISCUSSION

The aim of this research was to address several issues.

3.1 What counts as ‘troublesome knowledge’ in analogue electronics?

Survey data from 69 students provided an answer to this question. Concepts that students found the most troublesome were: dynamic resistance (67%), Thévenin (55%), transistor action (52%), and op amps (51%).

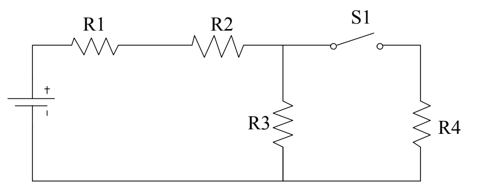
> *Dynamic resistance of diodes is difficult. It is the resistance of diode is changing as you change the current and voltage, which is not normal. I think it is probably because when I look at the question, they say ‘go and use the source and the voltage…’ To my mind <u>I see several things that could be the source voltage,</u> so for example I could be using a dc source and an ac, and I think ‘is it supposed to be the dc or the ac one I am supposed to be using?’(year-one student explaining why he found dynamic resistance troublesome)*

Support from staff, particularly in the lab and tutorials, was judged to be helpful by all students. Students, in particular those who did well in the course, liked the lecturing style (66%), and both those who did well and those who did not do well in the course liked the IF-AT tests (57%): perhaps for different reasons. Working in pairs was appreciated the least by students who had done well in the course (29% of A-level students) in contrast to other students, especially those who had not done so well (i.e., 54% of B-level students, 56% of C-level students and 71% of D-level students). More fully-worked examples, particularly in lectures, were appreciated and requested by all students. Some students (19%) noted that there did not seem to be a reliable textbook that they could mine for examples of the conceptual problems they found to be troublesome.

3.2 The assessment tool

The idea that assessment should be able to identify variation in progress (Meyer and Land, 2008) inspired our search for a way to assess threshold concept understanding for the purposes of re-teaching or extra tuition for those who need it.

Data from the mid-semester assessment was used in this analysis. The assessment that was designed in 2012 using the IF-AT method was able to isolate sources of conceptual difficulty that related to students' prior knowledge. Without specific prior knowledge (e.g., holistic current flow, graph interpretation and 3D representation) students could not be expected to understand the more complex modelling required by Thévenin's theorem (Scott & Harlow, 2012). In addition to poor basic understandings, (e.g., holistic current flow, graph interpretation and 3D representation) students who had difficulty with or guessed the answers to the threshold concept questions had little idea of the inter-relationships between concepts (e.g., some students could not relate the pictures of equipment to a drawn circuit diagram). By assessing understanding of the pre-cursor concepts and of the threshold concept in the same test it was easy to identify students who might have guessed the answer to a threshold concept question.



When the switch S1 closes in the circuit above, the current in R1 will: a) Increase, b) Stay the same, c) Decrease, d) Fall to zero, e) There is not enough information in the question to tell.

Figure 2: Example of pre-cursor exam question that assesses student understanding of current flow

Seventeen students who failed to correctly answer precursor questions (i.e., did not get full marks) but answered the threshold concept question correctly, (i.e., got full marks) were interviewed to gain insight into their understanding of threshold concepts. In all cases, the students who had failed to answer the pre-cursor questions correctly had guessed the more difficult threshold concept questions or used a process of elimination. The results suggest that these students neither understood the threshold concepts nor the pre-cursor concepts.

Without the necessary prior knowledge, these students would have likely failed to complete the course successfully—even if they passed the course there would be a high probability that they would continue their studies without understanding the threshold concept. As Meyer and Land (2008) put it "the necessary pre-liminal ontological shift for the programme was not deemed to have taken place." (p.75).

In 2008, Meyer and Land suggested that traditional assessment should be abandoned since students may often get the right answer yet retain fundamental misconceptions. Instead, assessment should reflect the way students make an ontological shift when they grasp a threshold concept (i.e., when students internalise knowledge and think from the point of view of an expert). Still, in designing such assessments the question remains: How do we know that our students have 'got it' or when they 'became unstuck'?

3.3 Entry-level physics

For this analysis we have combined data from 105 students who completed survey 1 with their achievement on the final exam questions and their final grade for the course. Results revealed that students with NCEA Level 3 physics on average achieved at a similar level in the final exam as those those who did not have NCEA Level 3 physics, $t(97) = 0.85, p > 0.05$.

Similarly, high school physics did not ensure the correct answer to a precursor question—only 71% of students *with* NCEA Level 3 physics answered the precursor question correctly, and a lack of high school physics did not prevent students answering correctly the threshold concept questions—75% of students *without* NCEA Level 3 physics answered a threshold concept question correctly. Note that students who achieved NCEA Level 3 physics may not have necessarily studied electronics as part of their high school physics. Regardless, results indicate a need for a lecturer to dedicate initial lecture(s) to precursor ideas, such as current flow, and to assess if students have grasped these basic ideas some time prior to mid-semester examination.

3.4 Pre-cursor concepts

For this analysis we have combined data from 67 students who completed survey 2 with their achievement on the final exam questions.

At the end of the course, 62 students rated their understanding of current flow, a precursor concept for Thévenin's theorem, as good or excellent while only five students felt that they did not understand this concept. However, the results of their achievement data revealed that many students did not understand the idea of holistic current flow, even at the end of the course. Namely, on 10 exam questions, out of 15 that required an understanding of current flow, a greater proportion of students provided an incorrect answer than a correct answer regardless of how students rated their understanding of current flow (e..g., have trouble understanding current flow vs. no trouble understanding current flow). For example, of 62 students who said that they had *no trouble* understanding current flow a significantly greater proportion gave an incorrect answer to six questions requiring an understanding of this concept.

The findings show that it is essential that assessment (particularly if the assessment consists of a multi-choice test) consists of both the precursors and the threshold concept questions as this combination would provide the most comprehensive view of the students' grasp of threshold concepts.

3.5 Perceived understandings

For this analysis, data from 64 students who completed survey 2 were combined with their achievement on the final exam threshold concept questions requiring an understanding of Thévenin's theorem and their total year grade. Thirteen students rated their understanding of Thévenin's theorem as excellent or very good, 27 students rated their understanding as good, and 24 rated it as limited or none.

Analysis of students' achievement on the threshold concept questions revealed that on 3 out of 5 questions a significantly greater proportion of students who rated their understanding of Thévenin's theorem as excellent or very good more frequently answered those questions correctly than the other two groups of students (100% vs. 52% and 87%, $\chi^2(2) = 14.53$, $p < 0.05$; 71% vs 33% and 42%, $\chi^2(2) = 5.55$, $p = 0.06$; and 93% vs 78% and 42%, $\chi^2(2) = 12.74$, $p < 0.01$). However, regarding the other two Thévenin questions in the examination there were no significant differences in the proportion of correct answers for the three groups of students. For one of the questions, all three groups of students had a high proportion of correct answers (93%, 93%, and 100%) and for the other, all three groups had a very low proportion of correct answers (29%, 15%, 17%).

Results (see Table 1) suggest that although a perceived understanding of the threshold concept was not a good indicator of a student's overall grade for the paper, it was a good indicator of how well students answered questions involving the threshold concept (Thévenin's theorem).

	Perceived understanding of Thévenin		
	A group	B group	C group
	Excellent, very good	Good	Limted, none
Average grade	**73%**	60%	64%
Thévenin exam questions correctly answered	**88%**	54%	57%

Table 1: A group more frequently answered Thévenin questions correctly than B and C group

3.6 Interim assessment

For this analysis, mid-semester achievement and final examination achievement data from 119 students were combined. The results revealed that there was a a small but significant correlation between students' achievement on the mid-semester assessment and their achievement on the final examination $r(119) = 0.4$, $p < 0.05$. and between their mid-semester assessment and their overall grade $r(119) = 0.5$, $p < 0.001$. Thus, mid-semester assessment (interim assessment) was only an indication of potential examination marks. Lab-book marks were more indicative of high/low total grades than interim assessments.

These findings may have implications for the type of assessment used during a course. Formative assessment using an IF-AT test was trialled with year two students as a learning exercise. Students worked in groups of three or four debating their understandings and producing a group answer. This exercise was followed by the lecturer going over the most difficult questions, making sure that the threshold concept questions were explained in detail. Students found this way of assessment for learning to be both engaging and useful.

4 GENERAL DISCUSSION

The findings show that it is essential for students to have a good understanding of the precursor concepts and that these need to be assessed early in the course. The understanding of basic concepts cannot be underestimated for learning more complex concepts. In fact, given the results reported here, it is possible that holistic current flow may actually be a threshold concept.

With different learners taking different routes and time to fully grasp the threshold concept, whereby they are transformed from thinking like a novice to thinking like an expert, the questions of how we might assess this process arise. Will passing a test, or the final examination at the end of the course mean that those who passed have grasped the threshold concept? Given that it is well established that learners may spend a considerable length of time in an unstable, transformational conceptual space before they fully grasp troublesome knowledge, should we even be considering assessment of a threshold concept in a student's first year?

From our findings over two years we have come to an understanding that students who are introduced early to a threshold concept will take on board whatever aspects of that threshold concept that they can, based on their prior knowledge, their propensity for follow-up study, and their ability to articulate their understandings. They find that encountering the threshold concept again and again, across different and appropriate contexts allows them the necessary time and space to follow through the logic yet again, to recall aspects of what they did the previous time, to recognise that a problem needs an application of the concept, and eventually to 'come to know' or to 'own' the knowledge so that they wonder why they found it so troublesome at the start (Harlow, Peter, Scott & Cowie, 2011). This process is not necessarily linear, and it may take well into the second year before 'the penny drops' or 'the light-bulb glows'.

There are a few things that are difficult like Thévenin, that is highlighted as being tricky and he spends quite a few lectures just so that we can pick it up. When we first did it I had no idea, and thought, "Sure, I'll take your word for it." But now I can do most of it on my own. I would recognise it now – it's hard, but I can do it. It is just remembering how to simplify the circuit down, because everything has its own set of rules – like whether it's in parallel or series, there is a lot to remember. Once you pick it up it's OK, but when you are learning it is a struggle. (year-one student explaining why it took time to grasp Thévenin)

This is particularly relevant to the chosen threshold concept, in this case, Thévenin's theorem, as students were introduced to it when first learning circuit theory early in year one, and it was not until year two when transistors were introduced that many students said 'Thévenin clicked'.

5 FURTHER WORK

The design of a comprehensive test is now ending its first year of trialling and to date the lecturer has found it extremely difficult to ensure a reliable and valid test of student understanding. The lecturer is continuing to refine the questions in his assessments and to devise ways of correlating the threshold questions with the precursor questions. He hopes to show that assessment of the more troublesome areas in analogue electronics is all that is necessary to know if a student has had a transformative experience and will re-enrol as a successful student in year two. The key to unlocking what the students are actually doing when they select an answer has been found by interviewing students, which may not be practical without the researcher's help. So the next step is to refine the questions more so that each response gives an indication of where the student has gaps in his knowledge. This may be done in conjunction with ensuring that each threshold concept question is associated with a precursor question, and only when both are answered correctly, does the student receive full marks and is deemed to have understood the troublesome knowledge.

While the lecturer concentrates on refining the assessment tool for year one students, our research focus to support a summer scholarship student to on develop online tutorials in the areas that students are known to have difficulty understanding. An electronics engineering graduate student, who has shown an interest in student learning by demonstrating in labs and tutorials since the start of this project, will be working to design and then monitor online tutorials for students who, regardless of their achievement grades all say they want extra worked examples to help them learn. Some of the findings of the way students prefer to work will be taken into consideration in the design of the online tutorials. Student access data will allow us to track student learning behaviours which may inform an improved teaching and assessment approach.

6 CONCLUSION

Our work has been conscious of making the threshold concepts the 'jewels in the curriculum' (Land & Meyer, 2008). They have helped the lecturer to bring into focus the destination points for students, but as threshold concepts are known to take time to be understood, students continue to have difficulty with them in the first-year course. We are coming to the conclusion that there is a need for more support for precursor knowledge in electronics to be taught at the year one level.

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