Threshold Concepts and Introductory Electronics

Jonathan Scott
University of Waikato, Hamilton, New Zealand
jbs@waikato.ac.nz

Ann Harlow
University of Waikato, Hamilton, New Zealand
aharlow@waikato.ac.nz

Mira Peter
University of Waikato, Hamilton, New Zealand
mpeter@waikato.ac.nz

Bronwen Cowie
University of Waikato, Hamilton, New Zealand
bcowie@waikato.ac.nz

Abstract: *Electronics and circuit theory are acknowledged as troublesome subjects when first introduced to students. This leads to low student retention into later electronics courses, especially in universities that offer a common first year where students are free to change streams after the first year. We report on a detailed study of the application of Threshold Concept Theory to an introductory electronics course. We identify some Threshold Concepts, explicit and tacit. We postulate that a high density of Threshold Concepts accounts for the reputation for troublesome learning in, and low retention following, these courses. We further suggest that the bimodal distribution of marks that is commonly observed in electronics teaching is a hallmark of a Threshold Concept. This may have significant impact on assessment.*

Introduction

Students commence study in electronics anticipating that they will momentarily be constructing music players or learning how a cellphone works, but hit a wall of disappointment when they encounter circuit theory. In comparison to mechanical engineers who see and handle the objects of their attention, electronics engineers study the movement of electrons they cannot touch through components they can barely see before they can design anything interesting. It is widely presumed that this lack of physical engagement leads to the disillusion. The upshot of this is that a number of students become discouraged and are less likely to continue with studies in electronics. This problem is well-recognised, and some reasons for it and various strategies to mitigate it have been presented (Tsividis 2009, Tsividis 1998, McKechnie and Kalavally 2009).

In contrast we draw on Threshold Concept Theory to explain the difficulties. We suggest that electronics is very "front-heavy", requiring the student to understand a relatively large number of Threshold Concepts as soon as they commence their study of electronics, and before they are able to progress to more interesting study.

The Course Studied

In our university, first-year electronics, mechanical and software engineering students as well as first-year computer science students are required to take ENEL111, "Introduction to Electronics". Students regard this electronics course as the most difficult of first-year courses. It has a typical enrollment in the order of 140 students, and a student can expect to spend 150 hours of his or her time on the course, including attending classes, doing homework, personal study, etc. It is composed of lectures, tutorials and laboratory (lab) sessions. There are three lectures delivered per week, each student is required to attend one 1-hour tutorial and one 3-hour lab session per week. Material is arranged so that it is presented in lectures first, applied in tutorials, and subsequently applied in the lab classes. Scheduling constraints mean that a given topic is encountered in tutorials 1–4 days after it is discussed in lectures, and is then typically seen in lab classes 4–11 days later. No closer spacing is possible while maintaining the guarantee that the material will be encountered in order.

Tutorials typically have 40–50 students, 4 postgraduate tutors and 1 or 2 academic staff in attendance. Students are encouraged to ask for help after no more than a couple of minutes of being "stuck". The vast majority of students receive attention within a few seconds of putting up their hands.

The lab classes are run with no more than 24 students per class working as 12 pairs of students, and each class is of 3 hours' duration. The total enrollment means that there are 6 separate lab streams that run each week for a total of 18 hours of staff lab time per week. One such stream is pictured in figure 1. Each lab class is attended by two postgraduate students and one or two academic staff. In response to student enquiries or requests, "mini-lectures" of a few minutes duration are delivered on a whiteboard to assist students when there are common difficulties with the lab exercises, see figure 2. The laboratory space houses general-purpose computers and students studying other courses, and is run with as friendly as possible an atmosphere in order that students feel as secure as possible and so free to learn. In summary, the course is demanding but well supported.

Figure 1: View of students attending ENEL111 laboratory class (foreground).

Assessment is based on an examination (exam), tests held during the semester, and upon marks awarded in real time during the lab sessions and awarded based upon lab work books that are written in the lab classes and submitted for marking. Students are allowed to take their lab notebooks into mid-semester tests (called "quizzes") and the exams, and they are allowed to write anything in their notebooks without limit. Textbooks are not allowed in exams purely in order that no pressure be applied to students to purchase any one or more textbooks. In spirit the course is "open book", if not in final practice.

Threshold Concept Analysis

According to Meyer and Land (2006), there are certain conceptual ideas, Threshold Concepts (TCs), that are exceptionally hard for students to understand upon first exposure and yet, once mastered, have the capacity to change students' perceptions of the whole discipline. A TC is different from a key concept

Figure 2: View of an instructor giving a "mini-lecture" using a white board to a small group of students in a laboratory class.

in that the application of the TC is possibly counter-intuitive, bounded or limited in some way. It is therefore considered troublesome knowledge, as it tends to require the learner to be able to suspend what is already known in order to fit the threshold concept into a schema and internalise it. Furthermore, "getting your head around" a TC requires passage through a liminal space, a process that requires time, thought, and intellectual adjustment. A considerable literature on TCs has appeared since their original presentation in 2003 (Meyer and Land 2003). Cousin (2006) provides a very brief introduction.

It is our assertion that first electronics courses (necessarily) introduce more than their fair share of Threshold Concepts, especially in the analog part. In view of this belief, the electronics course was analysed in a threshold concept light, and various changes made in response to this. We identified 3 TCs in our introductory electronics course, ENEL111, namely

Thévenin's theorem or rather the substitution of a simple model for a complex object subject to a limiting condition, a source and resistor subject to linearity in the case of Thévenin;

Dynamic Resistance (DR) or the ability to substitute a bias-dependent linear component for a nonlinear one, subject to the application of only small-signal ac signals;

Feedback or the control of the gain of a circuit independent of the gain of a different element within the first, outer circuit.

Previously two further TCs had been taught in this course: Phase and phasors that lead to the idea of reactive power, and the trans-resistance phenomenon from which the transistor gets its name. However these were eliminated from the course after the analysis exposed the extent of the demands that were being made on the students.

The identification of Threshold Concepts in disciplines remains a matter of ongoing research.(Davies 2006, Atherton, Hadfield, and Meyers 2008, Rountree and Rountree 2009) This space of this manuscript does not permit reporting the extensive process carried out to identify and justify our identifications. Nevertheless, we have a high level of confidence in our identification of the TCs that are *explicitly* taught, based on their correlation with each of the 5 accepted attributes of TCs as identified by Meyer and Land (2003), and upon our subsequent observation of students at work in the course. We furthermore believe that the learning of electronics implicitly assumes an understanding of a significant number of TCs from study at high-school of mathematics and physics.

Details of the Study

A research study was undertaken, with ethical approval from the university, to find out where students got stuck and to determine whether or not achievement could be related to an understanding of the identified TCs. There were 140 students enrolled in ENEL111, 99 of whom explicitly participated in various parts of the research study. Data ware reported from informal observation and interviews with students during lab and tutorial classes carried out by an independent researcher not involved in teaching the course, from three student focus groups held in weeks 10 and 11, with 13 volunteering students, from two online surveys (administered early and late in the semester, 64 students responding to the first survey and 52 responding to the second survey), and from a course appraisal survey filled on paper out at the end of the course without teacher supervision by 87 students. Focus groups and surveys were designed to identify current teaching practices and to develop a better understanding of how existing systems, processes and practices influenced both students and lecturer perceptions of and attitudes towards electronics engineering education. Lectures explicitly teaching a Threshold Concept were video-recorded and subsequently made available to the students. The lecturer was interviewed before and after reviewing the video material.

Qualitative Observations

There is no doubt the students encountered difficulties when they reached Thévenin's theorem. Students appreciated the effort that had been put into making ENEL111 an engaging paper (course) that would give them a good grounding in electronics, but many found the ENEL111 analogue paper difficult and confusing. No less than 90% of survey respondents (n=52) found the new ideas introduced in ENEL111 difficult to grasp.

A significant fraction of the students had difficulty finishing certain of the labs, and comments collected suggest they are wrestling to understand the material. Students agreed that they would be able to do the lab work in a fraction of the time if they had to do it a second time, but were unable to explain what it was that slowed them down the first time through. Two things were found to be troublesome:

- Students had difficulty mapping between a diagram and a 3-dimensional object such as a circuit wired up on a breadboard. Given a circuit and its matching circuit diagram, they were often hard pressed to point out to a demonstrator the physical connection that corresponds to a given node on the circuit diagram. This situation has been reported before in a TC context by Foley (2010), and is evident from this typical quote:

  > With labs it's just hard to know what to expect before you go to them, and it's not any fault of the teaching, it's... I am just naturally terrible with things like breadboard circuits. It's really hard to follow connections. The most difficult part is to transfer from the circuit diagrams to the reality. The biggest problem is when you have a circuit diagram—it's got a layout that's organised in such a way—it's made so you can look at what it's supposed to be doing. When you try to put it physically, you've just got wires jumping around everywhere, whole lines of connections for specific purposes, like ground... such that it just becomes a mess—you can't make it so it stays in a nice neat layout that you get on paper. *(focus group student)*

- Students had trouble handling data graphs. They had difficulty producing and interpreting graphs of voltage against time, both on paper in their lab notebooks, and on the screens of their oscilloscopes. For example, students found it difficult to decide if the resistance of a light globe is increasing or decreasing as the current and voltage through and across it are increased, given the plot of voltage against current. Similar difficulty was observed if students were asked to move from variables plotted against time to different axes, such as occurs when the XY-function of an oscilloscope is activated. This quote gives the view of the student struggling to use data:

> What I found in the labs was not fully understanding what we were trying to find. Sometimes when you are close to the finish someone tells you and you think "oh, that makes sense, I understand now", but it didn't really sink in the whole time you were doing it because you were wiring things up and testing it, you have all your figures down and they look over your shoulder and tell you youre are on the right track, everything is there but you don't really know what you did, what you are measuring it and what you are supposed to be learning. How does that measurement you have made relate to other learning? *(focus group student)*

We might postulate that these tacit skills—mapping from 2-dimensional diagram to 3-dimensional physical object, and internalising plotted data functions—are Threshold Concepts. When such knowledge is weak or absent and must be picked up on the run, students have less time to concentrate on passing the liminal space associated with the explicit TCs in the course proper:

> With the labs I've found it difficult to get everything done in time. Sometimes you spend more time trying to get the work done instead of trying to understand the concepts. *(focus group student)*

Future studies are required to cast more light on this possibility.

Dynamic resistance also confused the students, although by the time it was introduced it had become more difficult to identify sources of confusion. Typical comments were

> It's that circuit. I have no idea how to explain it. I think the current of the small circuit will be lower. *(Student in the lab who is confused about DR)*

> There's a relationship between resistance, and voltage and current. With a DC and AC circuit. It's creating circuits and hooking up circuits—you can use dynamic resistance to control voltage and you can create dynamic resistance without identifying if you have made a mistake... unsure about this idea! *(focus group student on Dynamic Resistance)*

Some students are better prepared ontologically than others. The quote below expressing surprise and enlightenment was made by a student in a lab class around the fifth week:

> This course is about understanding, isn't it!

This student was a vocal member of a group of students who seem more familiar with the idea of learning as memorisation, compared to learning as ordering and connecting knowledge in order to widen the learner's ability to put that knowledge to novel use. Such students have great difficulty with electronics, because it is not very susceptible to "cramming", and tends to be assessed by means of application of principles to unseen circuits.

Quantitative Results

Of 83 students who responded to the question, 25% said they would continue in electronics, 28% said they would not continue, and 47% were uncertain. There were no significant differences in the final grades obtained between the three groups. Some students in the uncertain category reported that they might make the decision based upon their final grades. This situation presumably provides the incentive for universities to boost retention by making their introductory courses easier.

If concepts either are, or are not, threshold, as Meyer would have us believe, and at a given time any given student either has, or has not, passed through the portal, it is to be expected that within a cohort of students assessed on their understanding of a Threshold Concept there should be a clear division between those who understand and those who do not. A manifestation of this in a numerical assessment involving a single TC would be a bimodal mark distribution. The first quiz in ENEL111 addressed a single TC, Thévenin's theorem. A frequency distribution of marks in that quiz appears in figure 3 as the upper left-hand plot. The graph has a clear bimodal distribution. *This may prove to be an objective, quantitative indicator of a Threshold Concept.* The distribution of the total exam marks does not show a clear bimodal tendency, but then it involves three probable, and several suspected, Threshold Concepts, and has too few samples to detect multi-modality.

Two questions within the exam concentrated upon dynamic resistance and switching circuits, concepts considered to be threshold, and key but not threshold, respectively. The frequency distributions for those two questions appear as the lower plots in figure 3. Neither shows a clear bimodal shape. We attribute this to the "clutter" associated with the presence of many explicit and implicit TCs rather than a weakness in Threshold Concept Theory (TCT).

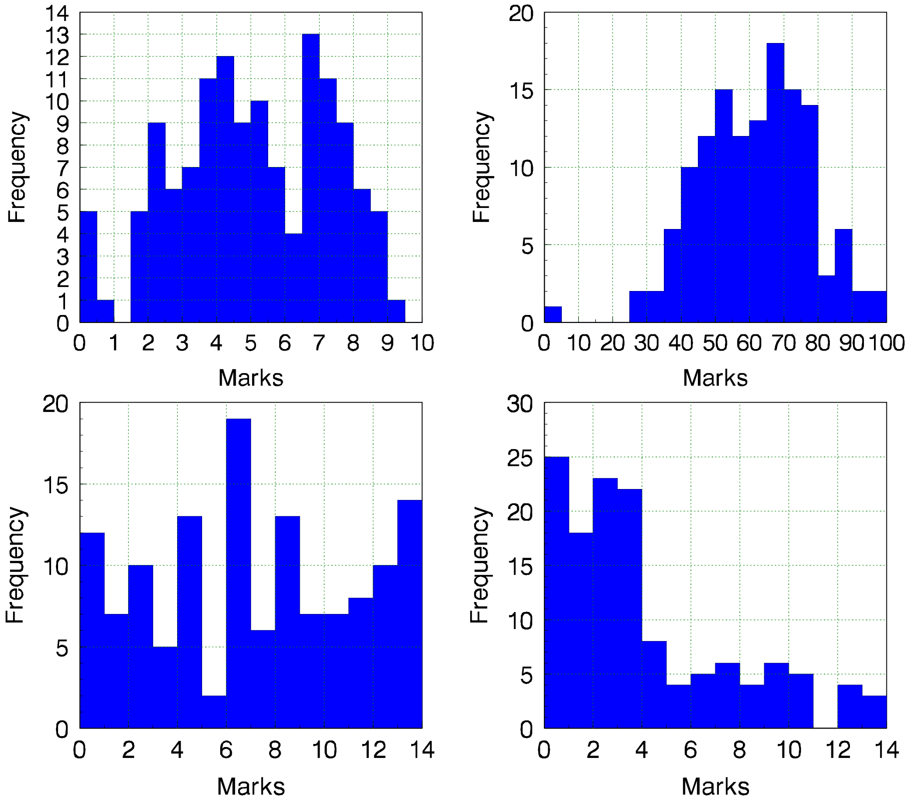

Figure 3: Frequency distribution of marks in the first quiz (upper left graph), the combined exam (upper right graph), and two analog questions within the exam (lower graphs). The question associated with the lower left distribution concentrated upon dynamic resistance, the question associated with the lower right distribution concentrated upon a switching circuit.

The students were asked about their degree of previous exposure to electronics, both formally at school or work, and informally at home. We found that there was no significant correlation with any marks except for the switching-circuit question that we believed to test key, but not threshold, concepts, where the previous exposure was associated with a significantly higher score.

Discussion

Did the TCs pose troublesome knowledge for the students? From a Threshold Concept perspective, electronics as it is customarily taught appears to be very dense in its early stages, accounting for its reputation for diffculty. This situation may be exacerbated by the novelty to many school leavers of a course that depends so little upon memorization and so much on understanding, threshold or otherwise. A decline in educational standards in mathematics and physics at high school has been documented by Brown (2009) while Ainley, Kos, and Nicholas (2008) report a decline in participation. This decline in secondary-school output is blamed for poor performance of students entering EE programs, and indeed those who passed level 3 physics achieved significantly higher grades in the final examination. However, it may equally be a result of reduced familiarity with underlying threshold concepts tacitly learnt by preceding generations while tinkering (Tsividis 2009), as was evidenced by the fact that students with a greater prior experience in electronics had significantly higher mean scores on the key, but not threshold concept, question in the final examination. The difficulties experienced by the students have been described and are similar to those difficulties described by other researchers in the field of electronics engineering (Foley 2010). They are also indicative of the length of time that students must spend in the liminal space in order to gain a full understanding of a TC—something which may not be possible for many students in one semester.

Was achievement related to an understanding of TCs? This study did not establish a clear relation between understanding of TCs and student achievement as measured by the final examination questions. However many insights were gained into students TC understandings in relation to their academic and relevant practical background. When a bimodal distribution occurs in a course assessment, it is tempting to conclude that the group in the lower normal distribution represents those who do not understand and should perhaps not pass. To be precise, this lower group comprises those who have yet to get it, who have not yet traversed the liminal space associated with a TC. Since this process takes time, there is no reason to assume that these students will not pass through in due course and eventually get it. One of the researchers was involved in debates with colleagues at examiners meetings in the 1980s and 1990s, where it was lamented that the pass mark could not be rightfully placed in the saddle between peaks of the distribution purely for reasons of the employers statistical requirements. This paradox is resolved through the delay that it is now acknowledged to take for students to adequately understand TCs. Reports periodically appear revisiting this situation, though the emphasis has moved to concerns with retention rather than rejection (Corney 2009).

Conclusions

This paper has defined and presented evidence of student understandings of TCs in a first year analogue electronics course. The TCs were found to contain troublesome knowledge, however student achievement could not be reliably linked to their TC understandings. There are suggestions that universities make electronics more attractive by postponing hard concepts until later years. This approach has been taken in some Computer Science curricula where TCs associated with memory and hardware are left until second or third year, a policy that has received stiff criticism from Rountree and Rountree (2009). Likewise, we do not subscribe to this approach, for either computer science or electronics, in view of the implications of TC theory and our own experience.

The division of students into two camps, sometimes referred to as the “got-its” and the “didn’t- get-its”, may not accurately reflect any inherent ability or mindset, but as the division between those who have passed through the portal and exited the liminal state, and those who have yet to do so or, of course, who may never do so. The final examination questions may have been too complex to offer a unique explanation of student TC understanding. A better understanding of the importance of TCs and their assessment may be gained through further consideration and improvement of the examination questions. In addition, further research into student achievement in later years may reveal that one semester was insufficient for students to get the TCs.

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