‘Getting stuck’ in analogue electronics: Threshold concepts as an explanatory model

Abstract

Could the challenge of mastering threshold concepts be a potential factor that influences a student’s decision to continue in electronics engineering?
This was the question that led to a collaborative research project between educational researchers and the Faculty of Engineering in a New Zealand university. This paper deals exclusively with the qualitative data from this project that was designed to investigate the high attrition rate of students taking introductory electronics in a New Zealand university.
The affordances of the various teaching opportunities and the barriers that students perceived are examined in the light of recent international research in the area of threshold concepts and transformational learning.
Suggestions are made to help students move forward in their thinking, without compromising the need for maintaining the element of intellectual uncertainty that is crucial for tertiary teaching. The issue of the timing of assessments as a measure of conceptual development or the crossing of thresholds is raised.

Keywords: threshold concepts, liminal space, electronics engineering, teaching and learning

1. Introduction

Retention of students in early electronics courses is a problem acknowledged worldwide. It is a particular problem in universities that have a common first-year programme, because students can change streams (e.g. from electronics to mechanical) at the end of the first year. It is commonly believed that the major reason for the low level of student retention in electronics courses is a lack of ‘visibility’ or lack of ‘concreteness’ about electronics that may be the problem—mechanical engineers can see and get their hands on boats, cars, propellers, cogwheels and so forth from the start, while electronics is too small to see and handle, and its workings can be quite alien to most school leavers. This paper deals exclusively with qualitative data from a study that began by exploring factors that may contribute to the high attrition rate of students in the introductory electronics course (ENEL111) in a New Zealand university taken by most engineering and computer science students. The proposal was that the challenge of mastering threshold concepts could be a potential factor that influences a student’s decision to remain within an electronics engineering programme.

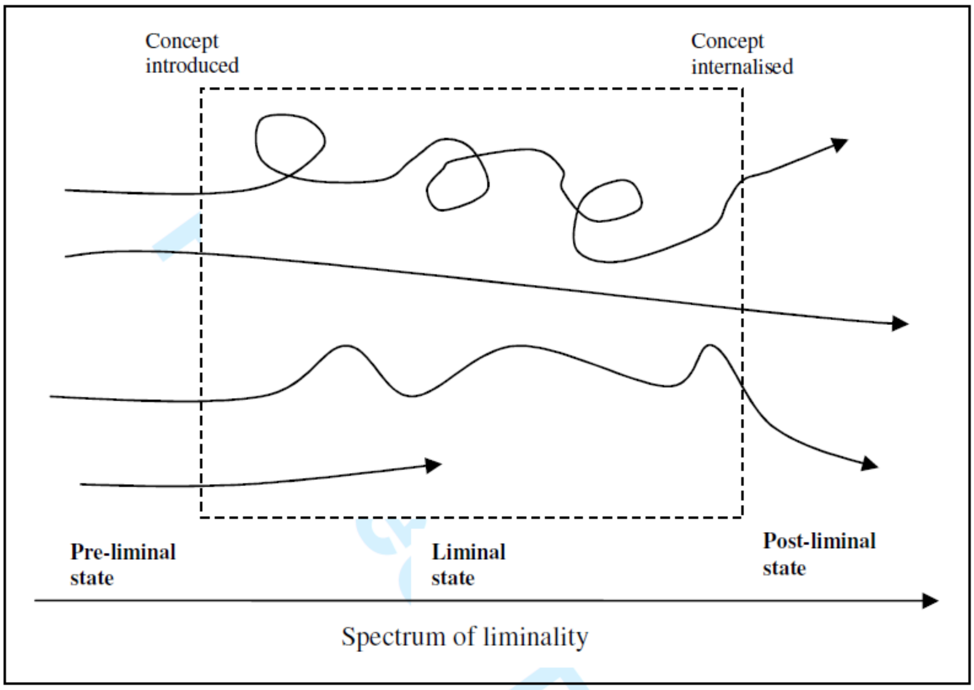
1.1 Threshold concepts defined

Threshold concepts are a relatively new idea that is being talked about in higher education circles and that have been used to link thinking, learning and practice in a discipline. A threshold concept is distinguished from what might be termed a ‘key’ or ‘core’ concept, as it is more than just a building block towards understanding within a discipline. Meyer and Land (2003) identify five characteristics of ‘threshold concepts’. First, they should be *transformative,* in that once understood, a threshold concept changes the way in which the student views the discipline. Second, they should be *irreversible* - given their transformative potential, a threshold concept is also likely to be difficult to unlearn. Third, a threshold concept is *integrative* – in understanding the concept the learner will be exposed to the previously hidden interrelatedness of different aspects of the discipline. Fourth, a threshold concept is *bounded*, that is, it helps to define the boundaries of a subject area. If a threshold concept is relinquished, thinking begins to move outside or beyond the scope of the subject itself. Finally, it is potentially '*troublesome knowledge*' because it may be counter-intuitive so, in grasping a threshold concept the learner may move from understanding in a 'commonsense' way to an understanding that goes against and beyond previous knowledge.

1.2 Progress through a state of liminality

In order to master a threshold concept the learner will most likely travel through a lengthy tunnel of 'liminal space' (i.e. be in a conscious state of being 'on the threshold of') and possibly be in a 'state of flux' (Meyer & Flanagan, 2010) for much of the journey. In effect, the learners experience 'disturbance' (Land, 2010). Foley (2010) suggests that learners in the liminal state are afflicted by uncertainty and when they eventually succeed in grasping the concept the uncertainty is, to a significant extent, dispelled. Flanagan, Hokstad, Zimmermann, Ackermann, Anderson, & Fradinho (2010) define the liminal state as an ever-changing, *non-linear* process, where the learners live with many choices and learn to tolerate uncertainty as they come to grips with understanding, and develop an ability to 'zoom in' and 'zoom out' or think holistically while focusing on a part. It has been suggested that this intellectual uncertainty is a crucial element of tertiary learning and teaching (Royle, 2003, p.52).

Figure 1. How different learners might navigate through a liminal space (Kabo & Baillie, 2009)



According to Perkins (2010a), the liminal space that learners pass through, is where they may 'get stuck' (as the threshold concept theory suggests). In line with the computational perspective and in terms of dual processing models, Perkins invokes the idea that cognition operates in two modes - a) a fast mode, which automatically processes information via a rapid pattern recognition process and a quick, intuitive assembling of interpretations, and b) a slow mode - which is characterised by controlled processing and deliberate figuring out before an outcome is evident. The outcome of the fast mode may be an instantaneous action – the ‘doing’ mode of thinking, while the outcome of the slow mode is the ‘planning’ mode of thinking. Progression towards a state of fast cognition can be seen as a person focuses on the task at hand in more complex ways:

- Thinking *about* – where the focal attention is on learning about the ‘object’, and where thinking involves addressing a fully externalised object.
- Thinking *with* – where attention is divided between the object itself and how to use the object as a ‘tool’ – the knowledge functions peripherally, but still with a sense of presence.
- Thinking *from a sense of* – where attention is freed to make sense of the world from a perspective of knowledge of the object and ways in which the object can be used – where the knowledge in question operates entirely tacitly ‘from the frame’.

Perkins (2010b) cautions that “tool-like use even with practice doesn't always reach the point of complete internalization to fast cognition, nor need it, nor is it necessarily desirable in fact, since with complete internalization one loses reflective contact with and perspective on the knowledge and question. A lot of well rehearsed knowledge hovers between tool and frame and that’s a good place for it.”

Bearing these ideas in mind and building on a small collection of studies of threshold concepts in electronics engineering (Cartenesen & Cartensen, 2010; Foley, 2010), this paper seeks to understand what kind of learning can realise the transformational potential of threshold concepts in electronics engineering. The context for the study was a first year university paper in analogue electronics.

2. The study

The study arose in response to a lecturer’s concern about how to retain students in electronics engineering. When introduced to the notion of threshold concepts he considered the idea made intuitive sense based on his experiences of the challenges students faced in electronics. The research process for the study began with the lecturer’s reflection to identify two potential threshold concepts in analogue electronics using the characteristics described by Meyer and Land (2003) and detailed above. He then revisited his teaching approach in analogue electronics to emphasise, and elaborate on these concepts. He planned his teaching to focus more explicitly on these threshold concepts in lectures, tutorials and labs. The research study focused on the lecturer-identified threshold concepts: Thévenin’s Theorem and Dynamic Resistance.

There were 140 students enrolled in the first year electronics paper (ENEL 111) that was the focus of the research, 99 of whom participated in various parts of the research study. In addition, the lecturer reflected on his teaching experience with the aid of videoed material from the two lectures he gave on the threshold concepts.

The researcher acted as a neutral observer between the students and the lecturer, gathering and reporting data from student responses to two online surveys (administered early and late in the semester), one set of questions administered during a lecture in week ten, focus groups, and achievement results from labs, tutorials, quizzes and the final exam. The observations, surveys and focus groups 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, with a view to providing data that might help lecturers to understand why students opt out of electronics early in their tertiary education. The focus on the threshold concept teaching sessions was intended to determine whether or not these concepts proved to be particularly troublesome knowledge.

Data in this paper are reported from the three student focus groups held in weeks ten and eleven of the 12-week semester, with 13 volunteering students. Compared to the survey data, focus groups provided opportunities for participants to introduce ideas that are relevant to them and not just the researcher. Perkins' (2010a) ideas on the learning stages where students need most help to pass through the liminal space that characterises the gaining of threshold knowledge were pertinent to the analysis of data collected on the students' experiences and achievement.

3. The findings

3.1 The identification of threshold concepts and revised teaching

The lecturer identified that the ENEL 111 course contained a number of threshold concepts on the basis of his own experience of their transformative characteristics as well as his intimate knowledge of his present day students: including the post-graduate students who helped as demonstrators in the labs and tutorials, and previous year one and year two students. He explained this transformative aspect as being something that could not be unlearned, and once learned was taken for granted.

This study investigated student perceptions of ENEL111 as they experienced two identified threshold concepts. Both threshold concepts require the substitution of a simple model for a complex object subject to a limiting condition. In the case of Dynamic Resistance - the ability to substitute a bias-dependent linear component for a nonlinear one, subject to the application of only small-signal ac signals. In the case of Thévenin's theorem -the substitution of a source and resistor subject to linearity. The lecturer explained the relevance of the Thévenin's concept thus:

> The model concept is common – electrical engineers use the word model to mean a substitution of something that is not really there, like the way Freud does with ego, super ego, id – that's a model of the mind. An engineer would say that Thévenin's theorem is that any circuit can be modelled with a voltage source and a resistor in series. (Lecturer on Thévenin as a model)

In order to facilitate students' learning and achievement, the lecturer decided to signal the importance of his identified threshold concepts more strongly than he had in past years and to spend more time on them, connecting the ideas and using more illustrative examples.

> I have made the lecture demonstration more dynamic – the oscilloscope that projects [on the screen in the lecture theatre] is new, added this year. I can now show them what smallness means – the rule of thumb for electrical engineers is that small signal is 25mV peak to peak – I actually measure that. I look up at the screen and I say, 'You see that thing, it doesn't look like a sine wave now, that is because the tangent and the curve have deviated.' I make that measurement and you can see it. I didn't have the ability to show them before." (Lecturer on ways he has changed his teaching for Dynamic Resistance)

In class, the lecturer proceeded to make the importance of the threshold concepts as explicit as possible by referring to real-life examples, showing what the lab experiments would look like, using a document camera in lectures, repetition of the concept, emphasising significance, leaving extra time at the end of lectures for students to request further information, posting a video of each threshold concept lecture on Moodle, and including examples of the threshold concepts in quizzes, and practice examples. The threshold concept lectures were followed by a series of tutorials and lab sessions that focused on student manipulation of calculations and equipment to practise applying the threshold concepts in both theoretical and practical situations.

3.2 Where students 'got stuck' or were challenged

Foley (2010) suggested three areas of troublesome knowledge where first year electronics engineering students, feel that they get stuck:

- Deciding an approach to analysing a circuit – there are many ways to solve problems.
- Constructing a circuit representation from a statement – it is difficult to decide where to start translating words into a network of components.
- Incorporating a model into a circuit analysis – circuit models and their use are not very intuitive.

Similar to Foley’s findings, we discovered that the same areas of troublesome knowledge occurred for students when they were learning about the two threshold concepts in analogue electronics. Our observations revealed that students experienced varying degrees of conceptual, procedural and technical confusion, as may be seen in the following examples.

Students had difficulty analysing the Thévenin circuit they had set up:

> We’ve drawn the circuit and we’re trying to find out what the internal resistance of the battery is and so we’re still figuring out how – it’s not so much about how to connect it up properly but how to interpret the results we’re getting. (Student in Thévenin lab deciding on an approach to analysing a circuit)

Students were unsure about where to start when they were not given a circuit diagram:

> We always get stuck, because we make a lot of errors. It’s more like we’ve just got to figure out how it’s all got to be set up. It’s easier to do if there’s a diagram (there is a diagram in number two). (Statements from two students in Thévenin lab trying to connect a circuit from a statement)

Even when there was a circuit diagram some students could not make a start:

> 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. 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, 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 difficulty understanding that they needed to be thinking of a simple model:

> These two [students] still haven't got the concept that the battery has a resistance in itself, and they know there is another resistance there, but not that it's already within there. To them a resistor is a component. It's not something that is in the inherent chemistry of how the battery is made. (Lecturer half an hour into the Thévenin lab on incorporating a model into circuit analysis)

In addition to the three areas of troublesome knowledge suggested by Foley, this study found that students sometimes had difficultly linking what they were doing in the lab to other knowledge:

> What I found in the labs (was that I) 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 you're 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)

For this reason, many students felt that they needed more lab time to complete the work.

> Our lab times are from 2-5 and we usually carry on – we are not sure what we are looking for. Even the lab sheets – what are we looking for, where are the questions? They are embedded in the text…(Focus group student)

> 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)

Where students encountered extra difficulty, demonstrators went around each pair of students to clarify the confusion:

> It is a Thévenin problem – we are putting a resistor in there and a voltage in and measuring. It's a bit confusing with AC and DC. They weren't told about that. A lot of them have had the same problem. They won't get anywhere near a right answer if they use DC. (Demonstrator in the Thévenin lab)

In summary there were two issues in the above Thévenin data:

- Firstly, there is the issue of modelling which is crucial for electronics engineering students given the lack of 'visibility' attached to electronics; and
- Secondly, there is the particular issue of Thévenin, which is both a particular example of modelling and a circuit analysis tool.

3.3 Discrepancies between what the students and the lecturer felt were necessary for learning

To test whether there were mismatches between pedagogy and learning, the lecturer reflected on his teaching and students were asked to discuss how they felt about their learning, and about where they 'got stuck' in the process. We examined potential overlaps and discrepancies between the lecturer and students' perceptions.

3.4 Understanding and articulating knowledge

The lecturer wanted the students to gain a good understanding of the threshold concepts and was aware that students had difficulty with Thévenin's theorem, but did not know why this was the case. He was puzzled why students in the quiz, when asked to put in words the rule to find the Thévenin equivalent of a circuit, wrote down an equation rather than a sentence.

It is likely that the reason behind this was a lack of students' understanding of the concept – students memorised the equation but could not explain its meaning. Our observations provided evidence that students were rarely asked to explain their understanding of concepts either to each other or to the support staff in the tutorials and labs.

When students were asked by the researcher to explain Thévenin's theorem it became apparent that although many could not explain it, several students did recognise its importance, and were able to describe it from a sense of how it was used:

> I have found I've had to use Thévenin's equivalent circuit a lot. At any stage you could keep going forwards but without it being prerequisite in the sense that there are going to be questions that will require it. It's both not needed for the entire course and needed for portions of the course. I suspect you could pass without it but it won't just be a question, it will add on to other things. (Focus group student)

Others could just describe it in words:

> Thévenin's theorem is understanding that you can reduce a complicated circuit to a workable equivalent consisting of a resistor, and a power source. (Focus group student)

3.5 'Doing' versus 'understanding' in the lab

The lecturer felt that students took so long to get started in the labs because they did not understand that they needed to be thinking of a model, and did not progress as he had expected. He explained:

> The idea that this is a model of a battery, the idea of a model is hard to get into your head, and I think that a lot of the threshold concepts that I see, in other disciplines are because they are all making a model and that's hard for people to get their heads around. You have difficulty with the idea that something that is completely different can represent something else. (Lecturer talking about getting stuck on Thévenin in the lab)

Students experienced difficulties in linking what they were doing in the lab to previous, other knowledge and they felt they needed more time to complete the lab work.

3.6 Understanding what to do in the lab

Although students appreciated the lab sessions and were engaged in practical work over extended periods in the 3-hour lab sessions, there were comments about insufficient direction ranging from requests for learning objectives to be made explicit, through clearer instructions, to more timely mini-tutorials. This comment came from a student who would have liked to have more information about the reasons for tasks and how the lab problems fitted with other learning:

> I don't think they fully explain what you are actually supposed to achieve in the labs. If they ran over the sort of results you wanted I think we would get a lot more benefit from it. Like 'hey we are going to look at diodes.' It is not

> explained, it's 'connect this and connect that and watch what happens.' I think 'well, I don't actually know what I am supposed to be seeing.' Trying to join the dots (Focus group student)

More detailed lab handouts were suggested by some students:

> When they go to draw something on the board, it's handy to have it explained but if it was already printed out it would save them drawing it. They still need to get up and explain it, but it would be very handy for us and for them if it was printed on the sheet in front of us. (Focus group student)

The lecturer did not believe that extra direction would be useful. He felt that there needed to be a challenge for students – they needed to take a risk to enter the liminal space of uncertainty, to figure out together with their lab partner what the question was actually asking and which concept was needed to obtain a solution, as this student realised was happening:

> Nobody tells us what to expect. Basically there are no clear learning objectives outlined, so you don't know what to expect when you go in, and you are not told, you have to interpret it yourself, it takes half an hour before you figure out what you are doing. The learning objectives are there – they are enmeshed in the problem, but they are not given to you, you have to figure it out. (Focus group student)

Students were given hints in the lecture about what would be required in the lab session, and they had worked on solving similar theoretical problems in tutorials. However, the demonstrators, who were PhD students, felt that one of the threshold concept questions in the lab was rather difficult for the students to understand, when they suggested that the lecturer gave students a 'step-by-step instruction sheet' he felt this would constrain students, especially in their thinking to a 'recipe' since there was usually more than one way to solve the problems. He explained why it was essential that students had a good understanding of the concept to be able to do the lab problems. These comments raise the issue of whether the purpose of the labs is to develop, confirm or extend students' ideas.

The lecturer also believed that it was better to wait until several students got stuck in the same place before giving the mini-tutorial in the lab – a just-in-time approach that allowed those who had already passed this point to continue without being shown the way forward. He would draw progressive circuits on the board, reducing the degrees of freedom for possible solutions to help students to answer the question, talking about what he was doing as he drew. Some lab supporting staff felt that there were certain constraints to this 'just-in-time' approach, for example, time to get around all the working pairs of students, and understanding students' backgrounds:

> They often don't really realise what they are looking for in the graphs that they draw. So you have to go through – you are actually better to take them up to the board and say 'OK, guys, this is what you're going to do and this is what you have to watch out for.' Otherwise you spend time with each one of them…(Lecturer/Demonstrator on spending time with each student)

In summary, Table 1 shows the differences between what the lecturer expected and how the students felt about their work:

Issue	Lecturer's point of view	Students' point of view
Understanding and articulating knowledge	Students need a good understanding of the threshold concepts. Students need to be able to articulate their understandings.	Students tended to memorise equations. Students appeared to recognise the importance of the threshold concepts. Students were not specifically asked to articulate their understandings to each other or to staff while doing tutorial or lab work.
Doing versus understanding in the lab	Students took too long to get started in the lab. Students did not understand that they need to be thinking of a model.	Students had difficulty linking lab problems to previous knowledge. Students needed more time to complete lab work.
Understanding what to do	Students need a challenge. Students need to figure out with each other what each question is asking and which concept is needed to obtain a solution. Lecturer gives hints in lecture as to what the lab work will cover. There is no one way to solve the lab problems.	Students were engaged throughout and appreciated lab sessions. Students felt there was insufficient direction in labs: - make learning objectives explicit - give clearer instructions - more timely mini-tutorials

Table 1. Mismatches between pedagogy and learning

4. Discussion

4.1 The liminal space

The experiences in the lecture, tutorial and labs are intended to help the students to move on to *thinking from a sense of* (frame), where the concept (object) and the use of the concept (tool) are internalised resulting in empowerment, whereby the student can recognise and apply the concept in authentic situations in the manner of fast cognition. Just like Eckerdale, McCartney, Moström, Sanders, Thomas and Zander, (2007), our study found that students experienced many of the proposed features of liminal spaces, such as taking a significant time to get started, oscillation between states such as anticipation and anxiety, emotional involvement, and mimicry of the new state, as this student comment shows:

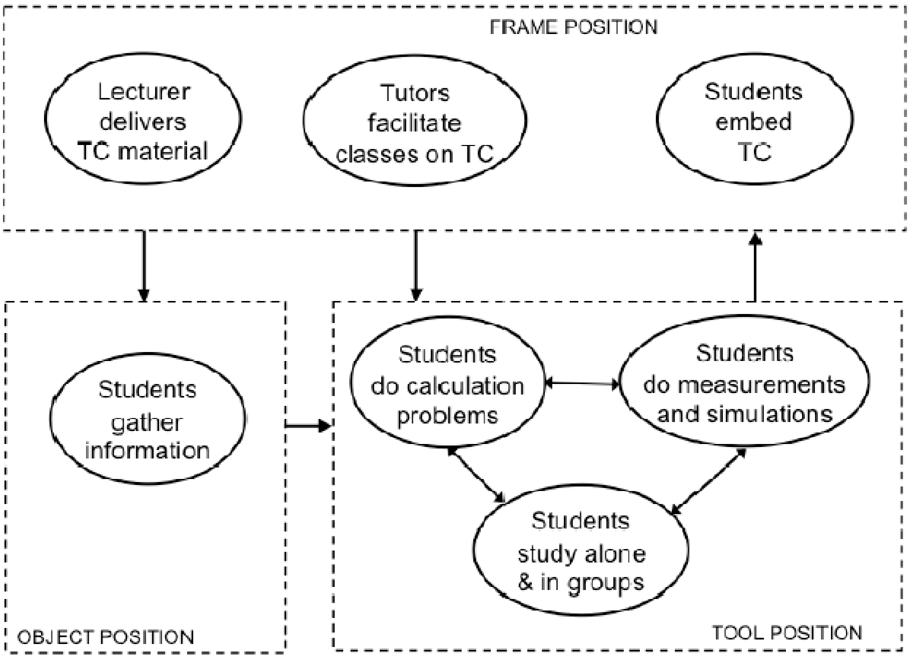
> One of the things I found is by the end of the analogue session, my lab partner was showing me something and I was saying I know exactly what you are saying and I can understand it but I've got nowhere to hook it, because anything that I might have had as a foundation of understanding was totally displaced – I didn't trust it. So I could say 'I understand the dynamics….' but I don't know where to put it. (Focus group student)

Meyer & Flanagan (2010) suggest that this troublesome part of the journey is because students must spend time training their minds to suspend belief, they must almost 'forget' certain knowledge in order to cope with the new threshold concept, and to integrate it into their minds. The suspension of belief is not the only concern of the learner at this stage, however, as it is unlikely that the student will accept such a transformation easily, and will require a great deal of practice over time, with many operative concepts, authentic applications, problems and discussions amongst peers in particular, so that *thinking with* the 'tool' becomes almost automatic. The learner can then become familiar with, and is able to select between, several concepts to apply the appropriate 'tool' to achieve an outcome. It is perhaps a matter of how long it takes to pass through this liminal space, and how (graded assessments may help learners to 'see' their own progress), and at which stage, to assess learners' knowledge as they pass through it – perhaps an assessment at the end of one semester's work in analogue electronics is too early to observe the transformative potential of threshold concepts in analogue electronics?

4.2 Developing teaching to encourage students to enter the liminal space

David Perkins (2010a) argues that threshold concept learning is not a 'steady march forward' and that there are many stages where students can get stuck. He suggests that there are two places in particular where this can occur – moving from *thinking about* (object) to *thinking with* (tool), and from thinking with (tool) to *thinking from a sense of* (frame). These places are included in Figure 1 which shows the how the expected pattern of concept development is supported by the various teaching and learning opportunities offered within the analogue electronics course.

Figure 2. Proposed model of process and progress in learning threshold concepts in electronics



Students gathering information are learning about new ideas and focusing their attention on the 'object', or thinking *about* the new information. Then their attention is divided between the new ideas and how they might be used – the students start to think *with* the new information, 'wielding the tool' so to speak. Once they have 'got it', their attention is freed and they start to think *from a sense of* the new 'framework', and do what they do almost intuitively. According to Perkins (2010a) a possible reason that the two places are troublesome for students may be that at tertiary levels of teaching most emphasis is on the object position. However, arguably this was not the case in ENEL 111, where there were numerous opportunities for students to work *with* the knowledge as a *tool* in both the tutorials and the labs. We now look at these teaching opportunities in the light of Perkins' ideas

The lecturer, coming from the 'frame' position, did not find the things that students found 'difficult to get' to be particularly obvious (although he did recall having trouble with particular concepts when he was a student).

Barriers to progression in electronics engineering thinking and learning may arise from a number of sources: students may have insufficient prior knowledge in physics or maths to be able to make a connection with the new learning; they might have missed a crucial lecture, tutorial or lab session; they may not be able to relate the abstract circuit diagram to components or to the 'real life' situations; and they may have failed to 'grasp' a threshold concept.

In analogue electronics, the lecture is where first year students learn about key concepts such as Ohms Law, or threshold concepts such as Thévenin's theorem and Dynamic Resistance. The students' attention is focused on *thinking about* the concepts – they are gathering the information, learning about formulae, and in effect 'filling their toolbox with basic tools'. Then the lecturer talks about examples of these concepts in real world situations, draws associations between them, and begins to model the use of these concepts with basic problems.

During follow up tutorials, students start to apply the learning and to use the formulae with theoretical problems - there are two sources for ENEL 111 tutorial questions, they are either taken from textbooks or designed by the lecturer from his experience or recent research reading. The lecturer explained:

> I ask a question around the circuit, usually simplified and idealised to focus on the relevant aspect and ignore complications. The question is aimed at making the students apply the concept in the lecture to the new circuit and obtain a numerical result or a "this will happen" response. (Lecturer)

Students are expected to be thinking about how the concepts can be 'put to work' and to move into *thinking with* the new concept as they practise problems using the new knowledge, sharing their concerns about the application with their peers and being carefully guided by the lecturers and demonstrators.

Students continue to practise *thinking with* the new concept in the lab sessions which provide not only authentic situations for the concepts to be put to work, but also give students a chance to figure out which part of their new learning is needed and to start to recognise the concept within a new context. Students work in pairs, and if they encounter problems the lecturer will give a mini-tutorial on the board for a group of students who may be stuck at the same point – in effect he returns to 'object' position as a repetition of what he has already explained in the lecture, but with a focus on the most difficult part for the students in the room at the time.

4.3 Suggestions for further facilitation of students' learning

The study attempted to find ways to support students to 'pass through the liminal space' of these troublesome concepts and based on the findings outlined above, we offer suggestions for further facilitation of students' learning within the three teaching modes.

During the lecture, the lecturer can be repetitively explicit about the importance of the threshold concept and what it actually is (a model, an example of linearity versus non-linearity, etc). Filming the threshold concept lectures and posting them on Moodle may improve student's understandings as they revisit the lecture in their own time. Students may be asked to articulate their first ideas about the threshold concept, for example, in writing a quick sentence to their neighbour, or in a message after the lecture on Moodle, and students may be given opportunities to articulate their knowledge and to *think about* the threshold concept as well as their own learning and academic development by summarising the relevant page of the textbook in their own words (Foley, 2010).

According to Cartensen and Cartensen (2010), offering varied examples in tutorials helps students identify possible solutions to the problems they have to solve, in order to carry out tasks later in the lab sessions. Foley (2010) suggests beginning tutorials with a closed problem then forcing students to make a choice, giving them problems that have many solutions. Students enjoyed the materials posted on Moodle and this platform could be further exploited in a similar way - Gangadhara (2010) found that an adaptive eLearning tutorial system lowered student failure rate in a Year 1 and 2 mechanical engineering course.

Deciding whether the lab sessions should be focused on developing, confirming, or extending students' ideas could lead to clarification of how to support students as they work in the labs. Adding learning objectives to the lab sheet may reduce anxiety of students who are confused about how to approach a problem that appears to have no relevance to them, may provide a springboard for them to get started – "By the end of this lab you will have…" or "The problems you will be working on today involve an understanding of Thévenin. If you cannot articulate to your partner what Thévenin is, please come up to the whiteboard at the beginning of the lab for a revision of Thévenin's equivalent circuit, so that you can get started…" Using a demonstrator-led mini-tutorial for those who are unsure nearer the start of a lab session, may alleviate the need for a later tutorial after students have been down the wrong track, and free up the lecturer to talk with those who have begun to master the threshold concept and to use this knowledge to help the slower students.

5. Conclusion

The affordances of the various teaching opportunities and the barriers that students perceived have been examined in the light of recent international research in the area of threshold concepts and transformational learning, to see if there are ways that students could be helped to move forward in their thinking, without compromising the need for maintaining the element of intellectual uncertainty (Royle, 2003) that is crucial for tertiary teaching. It is possible that the difficulties that students had in coming to grips with the course content will dissuade them from continuing in electronics, and other quantitative findings from this study will now be used to help lecturers to understand why students opt out of electronics early in their tertiary education. The focus group findings reported in this paper have focused more on the possibilities for changes in pedagogy that may support learners.

A threshold concept lens was useful for the lecturer to engage with the complexities of his first year paper in analogue electronics, and to review and revise his teaching approach, but students still found the course challenging and there were some discrepancies between the students' and the lecturer's beliefs about what was necessary for effective learning to occur.

It appeared that articulation of knowledge and reflection on learning in analogue electronics was the most difficult thing for students to do. This was something that they had not been encouraged to include in their work apart from when discussing problems in the labs and tutorials – which tended to be of a procedural nature, rather than being exploratory or of a co-constructivist nature.

Students did find the threshold concepts to be of a troublesome nature and it is not known whether this could be alleviated somewhat by further changes in pedagogy. The study has highlighted the places where teaching could be developed to help learners enter into and pass through the liminal space with more confidence, and raises issues around timing of assessments as a measure of conceptual development or the crossing of thresholds. At this stage we do not know how long it takes students to fully grasp a threshold concept so that they can make sense of the world from a perspective of knowledge of the fully integrated and transformative concept. There is a need for further research to determine how, and in particular, at which stage to assess student progress in electronics education - at what point do students 'get' the threshold concepts introduced in Year 1, and what happens when different methods of teaching and learning are implemented?

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