TOWARDS A TCT-INSPIRED ELECTRONICS CONCEPT INVENTORY

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Biographical Note

Jonathan Scott, Ann Harlow, and Mira Peter work at the University of Waikato. Jonathan worked for Hewlett-Packard/Agilent in California, is Adjunct Professor at Macquarie University, and is the author of over one hundred patents and refereed publications. Ann's research interests encompass primary, secondary and tertiary education. She works on technology, science, and engineering education. Mira's skills lie in data analysis and expertise in language, reading acquisition, and the role of phonology in reading.

KEYWORDS

Threshold concepts, concept inventory, analogue electronics, assessment

ABSTRACT

This study reports on the initial work on the use of Threshold Concept Theory (TCT) to develop a *threshold-concept inventory* – a catalogue of the important concepts that underlie electronics and electrical engineering (EE) – and an *assessment tool* – to investigate the depth of student understanding of threshold and related concepts, independent of students' numerical ability and knowledge mimicry in the first-year course in electrical engineering. This is both challenging and important for several reasons: there is a known issue with student retention (Tsividis, 1998; 2009); the discipline is relatively hard for students because it concerns invisible phenomena; and finally it is one that demands deep understanding from the very start (Scott, Harlow, Peter, and Cowie, 2010). Although the focus of this research was on electronic circuits, findings regarding teaching and learning of threshold concepts (TCs) will inform lecturers in three other disciplines who are part of our project on threshold concepts.

INTRODUCTION

Over the past two years the research team has been involved in an intensive study of pedagogy and learning informed by Threshold Concept Theory (TCT) in several disciplines. In one of the areas – analogue electronics – the lecturer has spent three years exploring how TCs can impact his teaching and student learning (Harlow *et al.*, 2011; Scott and Harlow, 2012; Peter and Harlow, 2012). The work with this lecturer has involved exploration of various types of assessment and has culminated in the development of a concept-inventory aimed at investigating students' understanding of troublesome concepts.

THRESHOLD CONCEPTS

To students, TCs are remarkably troublesome to learn (Cousin, 2006). To practitioners, their importance lies in the transformation of the learners' ways of perceiving, thinking and practicing (i.e. acquiring the competencies of the profession (Davies, 2006)). According to Meyer (2010), TCs are transformative insofar as grasping them can change the learner's very way of thinking. Further, it has been argued that threshold concepts are either *threshold* or they are not (Meyer, 2010) – there are no degrees of *thresholdness*. Since TCs are the hardest to learn and the most cogent to identity and ways of thinking within a discipline, it would seem important, to both learners and teachers, to identify them. Once TCs are identified, lecturers can focus on them and the inordinate learning difficulty can be anticipated and addressed in a timely and appropriate manner. However, for various reasons identification of TCs often proves to be difficult (Davies, 2006).

INVENTORIES AND THRESHOLD CONCEPT THEORY

Concept inventories (CIs) are an invaluable tool for the assessment of student learning and curricular innovations. Usually, they consist of multiple-choice tests ideally designed for two learner-focused purposes (Libarkin, 2008). At their most useful, CIs can be used to diagnose areas of learners' conceptual difficulty or misconceptions prior to instruction, and to detect changes in conceptual understanding related to a particular teaching approach. In this way CIs offer an insight into the influence of a teaching-learning environment on learning.

One of the first education inventories developed by Brown and Holtzman (1966) examined factors related to study-strategies that could predict students' academic performance. The inventory contained four subscales: effective study procedures; promptness in completing work; favorable opinions about teachers; and approval of educational objectives. In 2004, Entwistle and McCune examined the historical origins and development of a series of well-known study strategy inventories in higher education. The analysis illustrated how the development of succeeding generations of inventories built on the earlier ones. The inventories Entwistle and McCune (2004) analysed were shown to have focused on motivation, study methods, and learning processes, as well as mental models, metacognition, and self-regulation, thus creating confusion of overlapping terms describing apparently similar aspects of learning and studying.

In physics, the *Force Concept Inventory* (FCI) is perhaps the most well-known example of its genre (Hestenes, Wells and Swackhamer 1992). This FCI provided the physics community with a snapshot of student learning in introductory physics. The inventory represents a set of ideas embodying Newtonian mechanics and, more centrally an accompanying, multiple-choice, non-numerical questionnaire (i.e. assessment tool) designed to gauge the depth of student understanding of those ideas. It was actually painstakingly developed over a number of years up to 1991, and has been debated and verified thereafter.

The following two decades saw a variety of other concept inventories appear – especially within the context of engineering (Evans and Hestenes, 2001) – covering electronics (Simoni, Herniter, and Ferguson, 2004), materials (Richardson and Morgan, 2001), thermodynamics (Midkiff, Litzinger, and Evans, 2001), signals and systems (Wage and Buck, 2001), waves (Roedel, El-Ghazaly, Rhoads, and El-Sharawy, 1998). Some of these tools were more rigorously studied than others. The development of these inventories preceded the appearance of TCT (Meyer and Land, 2003). One might not be too surprised then to discover that a number of concepts addressed in these inventories, and their associated assessment tools, are neither indispensible to the discipline, nor particularly conceptually challenging to learners. In our own work we have found questions for which the so-called correct answer is theoretically and empirically wrong. Additionally, a number of questions tested only memorisation, not understanding. The premise of the current study is that TCT could provide a sound methodology by which one can arrive at a concept inventory that includes only ideas that are truly important to electrical engineering discipline.

ASSESSMENT FOR LEARNING TRIAL

An *Immediate Feedback Assessment Test* (IFAT) scratch-card test provided a trial for the development of questions for the electronics inventory and was found to have advantages for both the students and the lecturer. The IFAT test was done as a formative exercise: two students shared one scratch-card and argued their case to each other before selecting what they believed was the correct answer. Students could have multiple attempts to find the correct answer. By examining students answering trajectories the lecturer obtained information about students' understanding of the material and could identify problems that most students had difficulty with. In the second half of the tutorial session the identified problems were discussed with the lecturers help. A survey of students' opinions about the use of IFAT test revealed that:

- Students learned to articulate their knowledge;
- Students learned from each other;
- Students enjoyed the assessment and were fully engaged in solving problems;
- Students received instant feedback as they scratched the card;
- Students' incorrect ideas could be dealt with in a timely fashion; and
- If a scratch card was to be used in a formal exam, students will have practiced this type of test and know what to expect.

The use of IFAT test provided certain advantages for the lecturer as well:

- It was easier to mark than a long-answer test, but more difficult to mark than a simple multi-choice test;
- It was a good diagnostic tool, but care needed to be taken in the design of the questions;
- Feedback from students helped to make the questions more reliable;
- Misconceptions could be dealt with as they arose;
- Targeted tutorials could be planned to help students having difficulties; and
- Teaching became more informed about where students get stuck and how to help them move forward.

In sum, the IFAT test was found to be an engaging assessment tool when trying to ascertain whether or not students had the basic knowledge needed for the first-year analogue electronics course. It also confirmed that Thévenin's equivalent circuit (i.e. one-port circuit can be simplified to a circuit with one voltage source and a resistor) was one of the most important threshold concepts taught in the first-year analogue electronics course. Namely, it emerged that students had remarkable problems in grasping Thévenin's theorem and it was where many students got stuck. Many years of teaching experience have alerted the lecturer to the fact that unless students grasp Thévenin's theorem they cannot move on in electronics engineering. Important, the use of IFAT test provided a clear insight into the precursor questions crucial for understanding and learning of Thevenin's theorem.

PERSONAL PRACTICE

Our recent findings revealed that some assessment questions evaluated only students' recall of facts, not deep understanding; others had ambiguous answers (Scott and Harlow, 2011). These and related findings on identification of threshold concepts involved in early electronics (Scott and Harlow, 2012) informed the design of a matching series of questions. Their effectiveness in assessing the depth of students' understanding will be the focus of our future work.

The creation of an *Electronics Threshold-Concept Inventory* (ETCI) has proven challenging for various reasons. Because the electronics concepts deal with invisible phenomena, students tend to have not *misconceptions*, such as *Aristotelian thinking* in the case of Newtonian mechanics, but *no* preconceptions. This makes it difficult to identify universal, misleading wrong answers for the incorrect choices in the multiple choice (MC) questions. Electronics involves deep understanding from the very start (Scott *et al.,* 2010; Foley 2010), resting crucially on ideas such as conservation of charge and the impact of conductors and insulators on current pathways, without which students cannot understand the questions, let alone identify their correct answers. Consequently, care must be taken to discount answers to such questions as reflecting upon the intended knowledge.

One of the criticisms of the several decades of effort in CI use in science learning and development is that standard practice in CI development results in production of isolated CIs, often with specific relevance to a single course or sub-discipline. It is argued that these CIs have no specific meaning relative to one another, inhibiting meaningful comparison across content. This results in understanding of student learning across very small time spans, from a few weeks during instruction to the more common semester long, pre-post evaluation. Rarely, students are given delayed CIs several months to a year post-instruction, providing some measure of short-term longitudinal effects. It is claimed that investigation of conceptual change across a program is currently outside of the reach of any existing CI (Mestre, 2008).

With these developments and issues in mind, we have managed to construct some parts of a complete ETCI in less than one year. We have showed that students' threshold concept (TC) understandings measured by our questions were a good predictor of their total year grades. Those students who could articulate their knowledge well achieved the highest grades.

DEVELOPING AN ELECTRONICS THRESHOLD-CONCEPT INVENTORY

Considerable work has gone into identifying the TCs that are associated with the introductory electronics curriculum taught at our university. We assert, with some confidence now, that there are only five threshold concepts in the syllabus (Scott and Harlow, 2011). The eventual aim, therefore, is to test students' understanding of these five ideas. Following the wisdom of Hestenes, Wells and Swackhamer (1992) and those who came after, the test is expected to be multiple-choice, substantially non-numeric, and strongly graphic.

The idea of an Electronics Concept Inventory (ECI) is not new. Simoni, Herniter and Ferguson (2004) developed questions through a four-step heuristic applied to evolve existing electronic problem questions into ECI questions. The steps are identified as: focus on a single concept, substitute graphical for numerical elements, produce distracting answers in the light of known student misconceptions, and finally eliminate use of terms with which students might not be familiar to ensure question clarity. Quite apart from the debate about what concepts ought to be included in their ECI, Simoni, Herniter and Ferguson (2004) were well aware of the difficulty inherent in trying to limit the focus of a question of a half-wave rectifier and RC filter that may emphasise the understanding of the impact of the filter, and particularly its time constant in relation to line frequency, but it depends upon many other understandings. In the case of TCs, one of whose defining characteristics is a tendency to integrate diverse concepts (picture an especially widely-connected idea on a concept map). This desire to capture in isolation seems especially fraught. How might one test the understanding of a single (threshold) concept, or more importantly identify that a failure to correctly answer a given question involving that concept was not caused by a failure to understand one of any underlying (or many connected) concepts, upon which the question depends?

In principle, our Electronics Threshold-Concept Inventory or ETCI would need perhaps as little as five questions, if we had high confidence that a given question tested the desired concept. We have found this confidence elusive in practice. Consider a question intending to test understanding of the Thévenin equivalent circuit through a request to measure the calculated equivalent resistance, whatever that might be. The problem is that a student who cannot associate the nodes in the circuit diagram with the correct conductors in the assembly depicted in photographs or who cannot use a multimeter will have great difficulty answering the question, even given an excellent understanding of equivalent circuits and how to obtain them. Simoni, Herniter and Ferguson (2004) included questions carefully chosen to reflect the background knowledge that is necessary to correctly answer the electronic questions, but did not expand on this comment.

CONCLUSION

Threshold Concept Theory and Concept Inventories seem to be two educational disciplinary pushes that are made for each other.

The use of Threshold Concept Theory has expedited our construction of this concept inventory. If we believe that the threshold concepts within a discipline are the ideas that are important to shaping practitioners and troublesome to students then a concept inventory should need only to assess understanding of these threshold concepts in order to usefully assess student ability and worth.

Creation of concept inventories in electronics is made complex, as is the teaching of the discipline, by the lack of phenomena that can be observed directly. Rather than having wrong ideas, weak students tend to have no idea about how to tackle questions. The authors hope to expand and verify the ETCI in the coming year.

There are two ways in which we propose that this development will inform the communities of practice in which we work. In order to investigate conceptual change across the programme (Mestre, 2008) we plan to give students delayed CIs several months to a year post-instruction, to provide some measure of short-term longitudinal effects. This will allow teachers of year two and three courses to benefit from the results. We also observe that our postulated TCs can be discerned in other disciplines, often far removed from engineering. This raises the possibility that TCs may be so integrative because they run across disciplines. Our research team is discussing the benefits and constraints of such an inventory within their own disciplines.

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