An Electronics Threshold-Concept Inventory

Assessment in the face of the dependency of concepts

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***Abstract*—The Theory of Threshold Concepts (TCs), first articulated by Land and Meyer in 2003, provides educators in many disciplines with a tool to identify those special ideas that both define the characteristic ways of thinking of expert practitioners, and cause the greatest learning difficulties for students. Concept inventories are popular assessment tools, epitomized by the widely-accepted Force Concept Inventory of Hestenes et al., introduced circa 1992. It is a natural marriage to bring these two thrusts together to produce "Threshold-Concept Inventories". We report ongoing work to develop and verify such a TC-inspired inventory assessment tool in the field of electronics and simple circuit theory. We identify the difficulty in the development of questions targeted at assessing understanding of single threshold concepts and present results in support of a strategy to deal with this.**

Keywords-assessment; threshold concepts; concept inventory; circuit theory; electronics.

I. Threshold Concepts

The theory of Threshold Concepts (TCs) first appeared in the literature in 2003. [1] Since then a considerable base of publications has appeared including three books, and three bi-annual international symposia have been held. Reference [2] presents an excellent yet brief introduction to the theory. The idea is that concepts within a discipline can be divided into two sorts, threshold and non-threshold. The threshold concepts distinguish themselves in a number of ways. There is a considerable literature on methods to identify TCs. [3, 4] As noted in [5], the idea has struck a chord with many academics interested in research into the teaching of their discipline and its practice in diverse disciplines.

To students, the most important among the distinguishing features of TCs is that the learning of them presents inordinate difficulty in comparison to coming to grips with other ideas. [6] The ontological reasons for this have been considered. [7] Students are said to go through a "liminal passage" in moving from not understanding a given TC to properly internalizing and coming to understand it. Referred to as "passing through the portal", this passage is somehow associated with a phase change in understanding as the "light bulb comes on" and the student "gets it". This process can take time, and struggling with this passage is associated with a number of deprecated learning strategies such as mimicry.[8]

To practitioners and teachers, the most important among the distinguishing features of TCs is that they transform the learner by deeply altering their way of thinking, their very view of the world, their ontological framework. [1, 9] This profound shift in the thinking of students as they become practitioners in a discipline is variously described as representing "how people 'think' in a particular discipline, or how they perceive, apprehend, or experience particular phenomena within that discipline" [1], "allowing a learner to think more like a [computer scientist]" [5], or resulting in "a transformed internal view of subject matter" [6]. As the authors of [9] remark "the significance of these threshold concepts lies much more in their significance for ontological than epistemological change". An interesting observation of educators since Threshold Concepts became fashionable is that they appear to be more readily accepted and used in hard disciplines, and especially engineering. [9, 1]

II. Concept Inventories

The first and most famous example of a Concept Inventory is the Force Concept Inventory or FCI, chiefly attributed to the work of Hestenes, and first formally presented in [10]. The FCI comprises a set of concepts and an associated multiple-choice questionnaire (an assessment tool) designed to gauge the depth of student *understanding* of Newtonian mechanics. Several years in the making, the FCI subsequently became widely used and thoroughly explored. [11] It is credited with stimulating reform of physics education. The following decade saw a proliferation of concept inventories within engineering and related physical disciplines. [12]

The value and intended function of concept inventories, or at least the assessment tools that embody the catalog of ideas, is two-fold: In the first instance they provide the ability to measure true understanding or correct thinking on the part of students. In the second instance, following on from the first, they can, through before and after testing, gauge the effectiveness of instruction, the "reduction of ignorance". [13] This makes them pedagogically desirable and powerful.

An example of a modern engineering concept inventory is the SSCI or Signals and Systems Concept Inventory. [14, 15] This particular example is very well explored and verified. [16] Although there exists a large number of such inventories, few are as well explored as the SSCI.

III. Threshold-Concept Inventories

The idea of a concept inventory predates the appearance of threshold concept theory by more than a decade. Nevertheless, the two ideas seem made for each other. If Land and Meyer are to be believed, it is the TCs within a discipline that make all the difference, that define the thinking of effective practitioners. Other concepts may be key to practice, but presenting much less of a learning barrier they can be picked up as required, most appropriately by reading textbooks, in contrast to the troublesome TCs. [8] Therefore, assessment should focus on the threshold concepts. The first step in the development of a threshold-concept inventory must be to determine the TCs themselves.

Courses in antipodean universities typically teach a syllabus that combines what is properly called circuit theory along with electronics, rather than separating the two. In the first year it is usually called something like “Introductory Electronics”. University entry criteria typically require the equivalent of the highest level of high-school physics, meaning that students should understand current flow and voltage potential, though many arrive having never constructed a circuit, nor are they able to quantitatively solve circuits with Kirchoff’s laws, let alone truly understand them. [17] A first course will typically review dc circuit theory and then introduce diodes, including construction and measurement of circuits in the laboratory. Later on, students encounter opamps, transistors (possibly acting as switches at first then as linear amplifiers), and learn to deal with complex impedances. Calculus and complex numbers are typically taught in mathematics courses in parallel with the study of electronics and circuit theory.

Between 2009 and 2011 we carried out a detailed project to identify the TCs within the curriculum. [18] A major achievement from that project has been the “leveling” of the syllabus to ensure that no course covered too many or too few TCs. It is not in the scope of this article to enumerate or justify the TCs themselves, and the reader is referred to [18].

Over the last year, we have sought an assessment tool, based on threshold concept theory, for students studying introductory electronics. We assert with some confidence that there are only 5 threshold concepts in the syllabus. The eventual aim, is to test understanding of these five ideas. Following the wisdom of Hestenes and those who came after, the test is expected to be multiple-choice, and substantially non-numeric, so strongly graphic. One of the concepts will be used for examples in this manuscript, namely the idea of modeling, epitomized by Thévenin’s Theorem.

IV. An Electronics Threshold-Concept Inventory

The idea of an Electronics Concept Inventory is not new. In [19], the authors 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, the authors of [19] were well aware of the difficulty inherent in trying to limit the focus of a question to a single concept. This is virtually impossible. The example of a half-wave rectifier and RC filter that appears in [19] may emphasize 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?

The circuit shown, like all circuits with two terminals, has a Thévenin equivalent. You build the circuit and want to measure the Thévenin equivalent resistance directly to see if your calculated value is correct. Which of the measurement setups shown in the photographs depicts an arrangement that will give a measured value to compare with calculation?

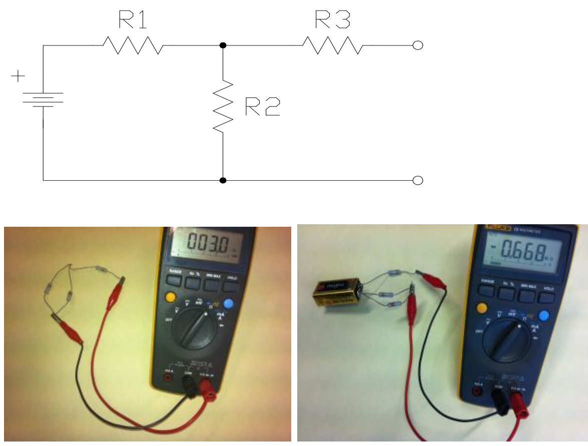

Figure 1. Example question shown with two of the possible answers.

In principle, our Electronics Threshold-Concept Inventory or ETCI would need perhaps as little as 5 questions, if we had high confidence that a given question tested the desired concept. We have found this confidence elusive in practice. Consider the question presented in figure 1. The question intends 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 the photographs or who cannot use a DMM will have great difficulty answering the question, even given an excellent understanding of equivalent circuits and how to obtain them. The authors of [19] included questions “carefully chosen to reflect the background knowledge that is necessary to correctly answer the electronics questions”, but did not expand on this comment.

Logically, if a question tests a concept **Z**, but inherently requires understanding of lower-level concepts **X** and **Y**, then failure to correctly answer questions testing **X** or **Y** implies that no conclusion can be drawn about understanding of **Z** from the answer to its question.

The photograph shows a meter making a measurement on a circuit whose schematic diagram appears adjacent. Is the meter is measuring (a) the voltage across R2, (b) the current across R2, (c) the voltage across R3, (d) the voltage across R4, or (e) the current through R2?

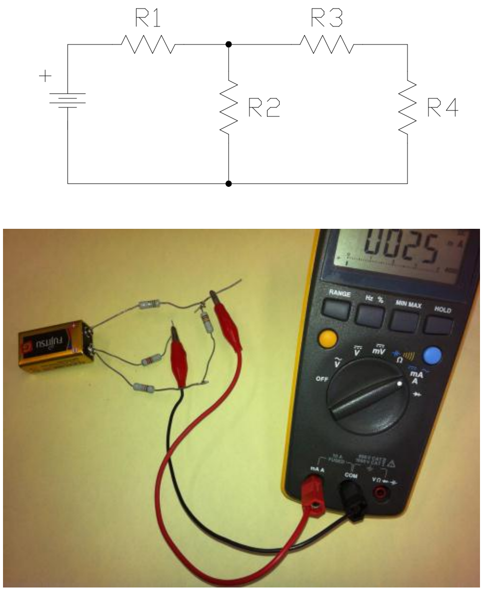

Figure 2. Example precursor question.

V. Effectiveness of Precursor Questions

Returning to the example question (QTC1) presented in figure 1, we constructed a test including suitable precursor questions by means of which we hope to verify that the question truly tests understanding of Thévenin. Figure 2 presents part of one of the precursor questions corresponding to question QTC1 in figure 1. Our logical assertion would be that a student who correctly answers QTC1 understands the TC, and also the ideas embodied in the precursor questions. If our logic holds and the scheme works, there should be no students who answer QTC1 correctly but fail to get the precursor(s) also correct, except by chance.

We are carrying out an extended study on students enrolled in "Introduction to Electronics", a one-semester first-year course that is mandatory for all students enrolled in Engineering, optional for all Science students, and a prerequisite for a number of later Physics courses. Ethical approval requires individual student consent, and most of 139 initial enrollments agreed to participate. This manuscript reports outcomes from progress assessments administered during the semester.

A cohort of 119 consenting students sat the test incorporating this question. All questions had 5 possible answers. Of these students, 74 answered the TC question correctly, but of those 74 only 54 also correctly answered the precursor questions perfectly. Probability theory predicts that, of the 119 students, one-fifth of those who do not know the answer to QTC1 ought to be able to guess correctly anyway, and some simple algebra implies that 11 of the 20 anomalous results alone can be accounted for by that chance. Whence the others? Either this contradicts our assertion or the number is elevated through extraneous factors such as carelessness, ambiguity or language. [20]

We subsequently interviewed the students who correctly answered a question but not all of its precursors. Every case proved to be chance or an extraneous factor. One student had tackled questions out of order and ran out of time. Another "fluffed" a precursor question through carelessness. The test was assessed using Instant Feedback Assessment Technique (IF-AT) "scratchy cards" [21,22], and one student started out blithely forgetting that he could not change his answers. However, most anomalous results were accounted for by chance---that is the student guessed---and it was clear in the interviews that the student did not understand the threshold concept with any rigor. The number of correct guesses was elevated because students were able to eliminate some of the possible answers through reasoning not connected with the concept central to the question. For example, one distracting answer to QTC1 pictured a resistor that only had one wire connected, and some students reasoned that this resistor had no impact on the meter reading but probably contributed to the value they had been asked to find, and so discounted that answer, improving their chance of guessing the correct answer.

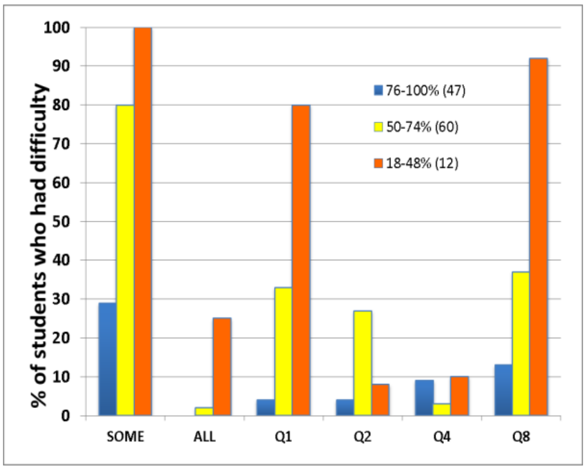

Figure 3. Performance of students on precursor questions as a function of their overall grade. Some precursor questions seem to correlate very strongly with overall weakness.

The set of students who correctly answered both a TC-based question and its precursors could be expected to understand the TC. Of course there is a chance that a student will guess both the precursors and the TC question, but this is a much lower chance than that of guessing a single question. As has been discovered by previous scholars constructing concept inventory assessment tools, the quality of the distracting answers is of paramount importance. We expect it to take some more time to get this right.

VI. Correlation With Overall Grade

It is interesting to note that students who did not do well on the test overall tended to be the same students that had trouble with precursor questions. Figure 3 plots the percentage of students in three performance bands who had difficulty with each, any or all of the precursor questions. The lowest performance band was clearly hampered through not being prepared with ideas tested, in this case by questions 1 and 8. More data will be available after final exams but this will occur between the submission of this manuscript and the conference presentation.

VII. Conclusion

All our work to date reinforces our belief that an ETCI will provide a most compact assessment of ability. It is not really surprising to say that a student who understands the difficult ideas will be able to understand the easy ones. However, it is very useful knowledge when you have a mechanism for identifying the hard concepts and a tool that can test understanding of given concepts. Threshold Concept Theory and Concept Inventory assessment instruments provide these.

Given that we seek to assess only 5 ideas, a test of 20 to 30 questions might allow for two or three questions on each idea and plenty of opportunity to check the underlying ideas with precursor questions. There would be then 10 to 15 logical conditions, each requiring a TC-question and its precursors to have been correctly answered, and which would form a score on the subject area as a whole.

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