Transformative Learning in First Year Engineering: How do we know it has happened?

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Abstract

Using the notion of threshold concepts we sought to understand the transformation students undergo in the first year of university engineering or material science as they transition from secondary school problem solving to thinking like an engineer. We interviewed 14 tutors and 8 students at Oxford to identify the key threshold students must pass through during their first year, focusing on how this threshold is transformative and how one can tell whether this transformation has happened. Tutors emphasised a set of related discipline-specific thinking processes that evolve over the course of the year, including connecting maths and the physical world, modelling problems, estimating and approximating and balancing convergent and divergent thinking. Students that "got it" (i.e. had transformed or passed over the threshold) were perceived as a) tackling problems differently; b) being more independent; c) having increased confidence; d) embracing a broader view of the subject and; e) communicating differently.

Introduction

Educational research that treats teaching and learning generically (i.e. removed from the context of particular disciplines) is often insufficient to engage scholars whose primary interest is in their discipline. In this project, we worked with engineering teachers in what Shulman (1989, p. 10) calls a 'pedagogy of substance', one which is 'rooted in the subject matter itself as well as in a connection with the lives and culture [*of the students and teachers*]'. Shulman's work on subject-specific aspects of teaching (Shulman, 1986, 1989, 1993, 2005; Shulman and Quinlan, 1996) has helped spawn the *scholarship of teaching* movement, first in US higher education, but increasingly internationally (e.g. Huber and Morreale, 2002).

In the UK, Meyer and colleagues introduced and developed the idea of *threshold concepts* (Meyer and Land, 2003a; Land, Cousin, Meyer and Davies, 2005; Land and Meyer, 2010; Land et al., 2010), which has been fundamental in creating a body of subject-specific educational research in a variety of disciplines. Thresholds are said to open up required ways of thinking in a discipline. Students may experience a threshold as troublesome (Perkins, 2006), transformative (fundamentally changing how a student views the field and/or themselves), integrative (connecting previously un-integrated ideas), irreversible (once a student "gets it", they won't unlearn it), bounded (referring to a subset of a discipline), involving a passage or journey characterised by liminality (in which students may feel confused, lost or stuck) and leading to the use of a new discourse (Meyer and Land, 2003a, 2003b, 2005, 2006).

We used threshold concept theory because it has effectively engaged academics in discussions about teaching in their disciplines. The project was designed to contribute both to discussions about enhancing engineering education and to advance the understanding of threshold concepts. This paper specifically explores the transformative nature of thresholds and the evidence that supports such transformation in engineering education.

Methods

We interviewed 14 Oxford academics (7 engineering; 7 materials science) who tutor first year university students in either the materials science or engineering science undergraduate degree programme. We invited those who tutor first year students if they had won an award for teaching or were recommended by another interviewee. Eight (two engineering; six materials) students were also interviewed, individually or in pairs. Most student interviews took place early in the second year of their studies. Before the interview, participants were asked to:

> *Give some thought in advance to what "threshold concepts" you might like to discuss during the interview. "Threshold concepts" is a term used by educationalists to describe particular ideas within disciplines that open up new ways of thinking and that allow students to progress in that discipline. Threshold concepts are transformative for students insofar as they change the way that students perceive the field. Often thresholds are particularly troublesome or tricky for students. In fact, some academics find it easier to start by thinking about where students get "stuck".*

Each interviewee discussed a threshold that students typically experience during the first year. We analysed the interviews, coding segments of text that roughly corresponded to different features of threshold concepts, enabling comparison across transcripts on particular sub-questions. We looked specifically at responses to questions about what makes the threshold transformative for students and how students think or act differently before and after they understand it. We identified emergent themes through successive re-reading and data representations using a concept map (Novak, 1990). Concept maps array a set of ideas hierarchically and provide linking words to show the relationships between different nodes on a map.

Findings

We found that students must learn to connect mathematics and the physical world, which involves three tightly connected thinking processes: a) modelling a problem; b) approximation and estimation; c) convergent and divergent problem solving. (Quinlan, 2012)

Participants identified six main ways students who "got it" would be different. Students who have made the transformation:

a) *tackle problems differently.* They tend to look at principles before looking at worked examples, and start by asking what the system is or what they are trying to do. This approach is different than the typical "pattern-matching" approach used in secondary school in which they look for a similar problem and mimic it.
b) *are more independent.* They are "able to set up the equations themselves", "handle problems they haven't seen before" and "come up with answers that are different from the model answers given".
c) *have increased confidence.* They are more likely to approach a tutor saying "I think the answer for the problem is wrong". They can "see the way ahead" which is a "massive confidence boost."
d) *have a broader view of the subject.* Students are less likely to treat the subject as "little bits" and can see connections, are able to "do more complicated mathematical quantities" that are "applicable across a wide range of the course."
e) *communicate differently.* Students use notation, pictures and language differently, such as "talking about a 'rate of change' rather than just a 'dy by dx'.", demonstrating that "they've got the concept, rather than just the mathematical notation."

Discussion

This paper sought to explore one specific feature of threshold concepts – their transformative nature. We did this in part by asking Oxford tutors, who have an integrative view of the entire undergraduate programme, to identify a single threshold in the first year. While tutors gave many examples of specific concepts, they identified the common transformative and integrative element in these specific concepts as a change in thinking and problem solving approach. We specifically probed interviewees to describe how students are different (transformed). This results can be thought of as "evidence of transformation". This evidence – or description of the end goal - can be used to clarify intended learning outcomes that include attention not only to content, but to thinking processes, thus linking the notion of threshold to the theory of cognitive apprenticeship (Collins et al, 1991). Our findings, then, also could help clarify assessment tasks and criteria, an application that is relatively unexplored in the threshold concepts literature.

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