Research in Science Education: Threshold Concepts

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ABSTRACT

This article introduces the idea of threshold concepts as a means to better understand student learning and, hence, to develop an enhanced curriculum to facilitate that learning. The debate surrounding threshold concepts is relatively recent and has mainly been focused within other disciplines such as economics, maths and history. Following on from their contributions to a conference in the UK on threshold concepts in geography, earth and environmental sciences, the authors are seeking to open the debate more widely to the geoscience community and thereby begin to develop an understanding of what this new approach to learning means for our subject area.

INTRODUCTION

> "What students really want is trouble-free knowledge" (Land, 2004).

It is well recognised by teachers of geoscience that students tend to find some geological concepts more difficult to grasp than others. It is also apparent that our curricula are becoming increasingly 'stuffed' as advances in geoscience reveal new and ever-changing concepts that are 'vital' to our understanding of the Earth. So how do we decide what our students 'need to know' in order to become geoscientists, and to what extent is this dictated by the fact that teachers often spend a lot of time and effort trying to help their students acquire concepts that they simply 'do not get'?

A student experiencing difficulty in grasping a particular concept can lead to an apparent 'blockage' in their learning, which is only cleared when the student finally gains the necessary understanding to proceed. With some concepts this can be a fairly straightforward process, requiring only an alternative explanation or carefully worked example to smooth the way for continued learning. With other concepts, however, the clearing of this mental blockage has a much more significant and fundamental impact, with the resulting understanding or 'insight' opening up a whole new way of thinking and practising in a discipline. These concepts have been termed threshold concepts (Meyer and Land, 2003) and they represent:

> "a transformed way of understanding … something without which the learner finds it difficult to progress within the curriculum".

WHAT ARE THRESHOLD CONCEPTS?

The easiest way to envisage a threshold concept is as a 'gateway' or 'portal' that leads the learner to a previously undiscovered, and perhaps inaccessible, way of thinking. While the exact nature of threshold concepts is still under review, some key characteristics have been identified (Meyer and Land, 2003):

1. They are **transformative** - acquiring threshold concepts will change the way in which students perceive and practice aspects of their discipline.

2. They are **irreversible** - once learned, threshold concepts are unlikely to become 'un-learned' or forgotten.

3. They are **integrative** - threshold concepts will allow connections (e.g. between isolated concepts or pieces of knowledge) to be made in ways that were previously unknown to, or hidden from, the student. For example, understanding the rate and scale of geological processes may enable a student to connect aspects of structural geology and metamorphic petrology which they had not previously linked, in order to form a more complete understanding of crustal processes.

4. They are **bounded** - threshold concepts can help to define the boundaries of a subject area or discipline. For example, historians and scientists recognize that their disciplines are distinct from one another, and within science, disciplines are also viewed as fundamentally distinct. The concept of "density" is important for most science domains, while the concept of subduction (which requires an understanding of density) is unique to the geologic sciences (although whether or not subduction is a threshold concept as such is open to debate for the geoscience community).

5. They may also be **troublesome** - threshold concepts may require students to deal with knowledge that is conceptually difficult, or that appears to be counter-intuitive or 'alien' in some way. In this respect, threshold concepts may be deeply entwined with entrenched or difficult-to-change misconceptions. Meyer and Land (2003; 2005) expand upon the importance of Perkins' (1999) notion of troublesome knowledge to threshold concepts.

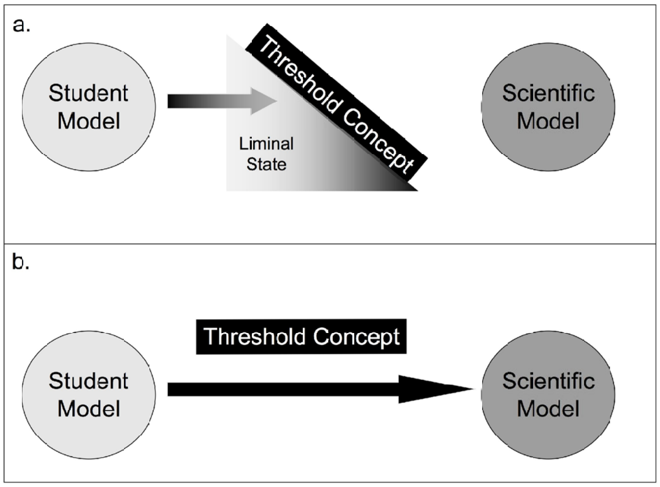

Figure 1. Simplified schematic of the relationship between threshold concepts and learning. a. The threshold concept can be a barrier to student learning, inhibiting the student's ability to move from preexisting models towards scientific models of natural phenomena. As threshold concepts are encountered, learning is inhibited, and students may become stuck in liminal states, gaining limited understanding of the threshold concept but with incomplete transformation of models from student into scientific. This liminality may involve oscillation between original models and emerging understanding of the threshold concept. b. After the threshold concept is fully understood, the barrier lifts and the student is able to achieve complete understanding of the scientific model, with learning progressing completely from the preexisting to scientific models (Meyer and Land, 2003; 2005).

HOW DO STUDENTS GAIN UNDERSTANDING OF THRESHOLD CONCEPTS?

The first stage in acquiring a threshold concept involves the student entering what Meyer and Land (2003) refer to as '**liminal space**' (from the Latin limen meaning 'threshold'; Figure 1). Cousin (2006) likens this state to that experienced by adolescents who are not quite children but not yet adults, and which may cause them to 'oscillate' between states of childhood and adulthood (Meyer and Land, 2005). During this period the student may encounter difficulties in understanding, or find that what they once thought was certain is now challenged in some way. While in this state of 'liminality', the student will attempt to grasp new concepts and understandings that will ultimately transform how they think and practice, or how they perceive, apprehend, or experience particular phenomena within their discipline (Land, 2005). Hence, students occupying a transitional and unstable liminal space may find themselves oscillating between old and emergent understandings. If the student does not acquire the understanding necessary to 'cross the threshold' they risk becoming 'stuck' in a state of liminality, gaining only a partial or limited understanding of the concept. Such 'sticking points' in students' learning, apparently relating to areas of conceptual difficulty, have previously been recognised in physics education, but are poorly understood (e.g. McDermott, 2001).

As a student acquires a threshold concept the transformation in their understanding may be rapid, it may oscillate between old and new understandings as described previously, or it may occur over a protracted period of time (e.g. Meyer and Land, 2003). This transformation can be an exhilarating experience, opening up the student to new and powerful ways of seeing and thinking, but it may also prove unsettling or invoke a sense of loss (Palmer, 2001). The journey that the student takes in crossing a threshold has both cognitive and affective elements, bringing about a shift in feelings, attitudes and emotions as well as in perception and understanding. In addition, threshold concepts may lead to an extension in language and vocabulary (as your vocabulary is extending simply by reading this article!) along with a shift in the student's own subjectivity, or perhaps even their identity (i.e. they will begin to perceive themselves as geoscientists rather than simply college students). The transformation that can occur when a threshold concept is finally acquired is made explicit in the following statement from Kennedy (1988: p142) in relation to statistics:

> "They [students] view statistics as a branch of mathematics because it uses mathematical formulas, so they look at statistics through a mathematical lens. What they are missing is the statistical lens through which to view the world, allowing this world to make sense. The concept of sampling distribution is this statistical lens. My own experience discovering this lens was a revelation, akin to the experience I had when I put on my first pair of eyeglasses - suddenly everything was sharp and clear".

Analysis of advice from computer science students about how best to overcome the challenges of acquiring threshold concepts indicates that students are cognizant of their role in learning. To these students, the responsibility for learning rests clearly with the individual, although this understanding may not be shared by all novice students (Boustedt et al., 2007). Providing students with an understanding of their role in learning, particularly in the case of threshold concepts, is perhaps as important as initiation of learning itself.

THRESHOLD CONCEPTS IN ACADEMIC DISCIPLINES

Meyer and Land (2003) suggest that threshold concepts may be more readily identified in some subjects (e.g. physics) than others (e.g. history). This point is echoed by researchers from the Centre for Applied Research in Educational Technologies (CARET) at Cambridge University who have identified apparent disciplinary differences in terms of how threshold concepts are identified and conceptualised (www.caret.cam.ac.uk/tel.html). For example, they propose that physical scientists are focused on the individual learner and transformations in thinking that occur for the individual, while bioscientists focus on cross-disciplinary ideas. In addition, CARET suggest that the varied use of metaphors, analogies and descriptions to describe the role and scope of threshold concepts points to the existence of both *epistemological* and *pedagogical* difference across academic disciplines (i.e. it relates to both the nature of the knowledge that exists within a

Subject	Suggested Threshold Concept(s)	Reference
Economics	Opportunity cost; Elasticity	Reimann & Jackson (2006)
Pure Mathematics	Complex numbers; Limits	Meyer & Land (2003)
Electrical Engineering	Frequency response	Carstensen et al. (2006)
Statistics	Sampling distribution	Kennedy (1988)
Computer Science	Object oriented programming; Pointers	Boustedt et al. (2007)
Health Care	Care; Pain	Clouder (2005)
Law	Precedence	Land (2005)
Biology	Process, e.g. energy transfer	Taylor (2006)

Table 1. Examples of suggested threshold concepts in academic disciplines

subject and the methods used to acquire that knowledge). Given the currently limited research that has been undertaken into threshold concepts in individual disciplines, however, the extent to which this is actually the case is unclear. Nonetheless, several examples of studies that attempt to identify the threshold concepts that exist within a particular discipline provide a framework for thinking about threshold concepts across disciplines (see in particular Meyer & Land, 2006, and http://www.caret.cam.ac.uk/tel/outcomes.html) (Table 1).

THRESHOLD CONCEPTS AND MISCONCEPTIONS

The study of conceptions and conceptual change in science is a rich and long-standing field of research (Driver, 1985; Driver, 1994; Chi, 2005) Significant effort has gone into understanding areas of conceptual difficulty, illuminating and describing alternative conceptions held by students, investigating the impact of diverse instructional approaches, and considering the relationship between conceptions and other student or learning factors (such as attitude). The majority of this work has had its home in the elementary and secondary (K-12) environment, and only recently has the community of higher education researchers embraced this approach to thinking about student learning. In many disciplines, researchers are still trying to understand the nature of college student conceptions, with little consideration of the larger questions that conceptions research both suggests and has the potential to answer.

The relationship between student misconceptions and threshold concepts was first recognized by Meyer and Land (2003). In particular, they embraced the notion of troublesome knowledge as being a key characteristic of most threshold concepts. That is, threshold concepts are often fundamental concepts for which students may express a tacit understanding, yet students have difficulty applying to real life, have little evidence for, or have little understanding of the origin of the ideas (Perkins, 1999). In this sense, the investigation of threshold concepts in sciences may be greatly informed by the wealth of conceptions research across disciplines. In the geological sciences, our emerging understanding of student conceptions and conceptual change would benefit from reconsidering why we teach what we teach. Once they have been identified, threshold concepts might provide us with a key to those core areas where misconceptions researchers might want to concentrate.

IMPLICATIONS OF THRESHOLD CONCEPTS FOR GEOSCIENCE TEACHING, LEARNING AND CURRICULUM DESIGN

The threshold concepts that exist within the geosciences are currently undefined, and are likely to be the subject of much future discussion and debate. Nevertheless, it seems reasonable to assume that, once these concepts have been identified, they will offer a powerful means by which students can gain access both to higher order learning (Taylor, 2006) and to the ways of thinking and practising which characterise the geological sciences. On this basis it might be argued that assessment should focus upon identifying whether students have in fact acquired these concepts, since they will reflect a students' ability to think in the way expected of an expert in that discipline (Davies & Brant, 2006). If it is merely assumed that students understand a threshold concept it may result in some students, i.e. those that have failed to cross the threshold, adopting a surface approach to learning simply to get through the remainder of the program (Boustedt et al., 2007).

The role of the teacher is crucial in helping students to cross conceptual thresholds. A deeper understanding of the way in which students experience threshold concepts, i.e. if and how they manage to become 'unstuck', will provide insight for teachers on how students develop their understanding in order to cross the threshold (Boustedt et al., 2007). This need for a deeper understanding is echoed by Cousin (2006) who further suggests that exploration of the threshold concepts which need to be mastered - ideally with students - should form part of the curriculum design process. By recognising the threshold concepts that exist within their discipline, teachers can then help students to see how different concepts and pieces of knowledge are connected, and thus transcend individual course or program boundaries (Boustedt et al., 2007). Throughout this process it is important for teachers to engage sympathetically with students and make themselves aware of their misunderstandings and uncertainties for, as Cousin (2006: p5) states, "mastery of a threshold concept often involves messy journeys back, forth and across conceptual terrain".

CONCLUSIONS AND FUTURE DIRECTIONS

The notion of threshold concepts and their potential to characterise ways of thinking and practising within a discipline is emerging as a powerful and innovative means of gaining insight into students' conceptual understandings. Originating from work undertaken through the Enhancing Teaching and Learning Environments in Undergraduate Courses project at the University of Edinburgh, UK (http://www.tla.ed.ac.uk/etl/), the threshold concept approach has spread rapidly to become incorporated into a wide range of disciplines and universities worldwide. The preceding discussion attempts to outline the nature of threshold concepts and their potential for transforming the way in which students acquire geological knowledge and faculty view the learning process. However, as previously stated, threshold concepts within the geosciences are currently undefined, and classification of some core concepts as threshold concepts is an important first step for the geoscience community to take. Given that they represent such fundamental and potentially powerful aspects of the geoscience discipline, it seems clear that efforts to identify threshold concepts should include both expert (i.e. academic staff) and novice (i.e. student) geoscientists.

The question of how we go about identifying threshold concepts is an interesting one, and one which we expect to trigger some lively future debates. As stated by Meyer and Land (2005: p384):

> "to move forward in our understanding of the acquisition of threshold concepts, from both teachers' and students' perspectives, we need to devise methods of observation and enquiry that allow us to explore variation in students' experiences of threshold concepts in rather special ways".

Methods that have been employed so far have focused mainly on interviews and questionnaires (e.g. Boustedt et al., 2007), but more innovative techniques involving the use of critical reflection through on-line discussion forums (Clouder, 2005) and videoed laboratory sessions (e.g. Carstensen et al., 2006) are being utilized as well. Davies (2006) also points out the potential for biographical interviews and reflective diaries for describing the 'critical incidents' in a students' learning that might reveal threshold concepts.

Despite the limited nature of existing investigations into discipline-specific threshold concepts, some interesting questions have nevertheless started to emerge which could help to focus how we identify threshold concepts in the geosciences:

- Why are some students able to understand threshold concepts and pass through liminal space with apparent ease, while others find this process inherently troublesome?
- What is the role played by learning environments (e.g. fieldwork, labwork) in helping students to acquire threshold concepts?
- What triggers the transformation in thinking that moves students though a threshold?
- How does acquiring threshold concepts impact students' affective, as well as cognitive, learning?
- Are threshold concepts purely mental constructs, or can they also be physical skills?
- Do we only become aware of crossing a conceptual threshold retrospectively, e.g. through critical reflection?
- Do we pass through thresholds only once, or are we constantly re-visiting them?
- Are threshold concepts universal or personal, changing or unchanging?

Ultimately, the utility of the threshold concepts theory for advancing learning in the geosciences will rest on our and students' ability to recognize them, and on our ability to aid students as they cross conceptual thresholds.

NOTE. The notion of threshold concepts will be new to the majority of US geoscience educators, but it has already started to generate some interest in the UK. In June 2006 the annual meeting of the Geography, Earth and Environmental Sciences Subject Centre (GEES) ran with the theme of "Threshold Concepts and Troublesome Knowledge", and included a series of discussions between educators in geography, geology and environmental science about the nature of threshold concepts within their disciplines – the outcomes of which can be found at http://www.gees.ac.uk/pubs/planet/index.htm#P17. Although the meeting provided a forum for some lively and interesting debate, it is interesting to note the length of the resulting list of 'proposed' threshold concepts (http://www.gees.ac.uk/pubs/planet/p17/tcideas.pdf) – the curriculum was still 'stuffed' so to speak! So the focus of future meetings of this type needs to be less about listing, and more about identifying what is necessary to enhance students' conceptual understanding in the geosciences. The next opportunity to undertake these types of discussions will be the 2nd International Threshold Concepts Symposium to be held in Kingston, Ontario in June 2008, where the authors will be convening a session dedicated to exploring the nature of threshold concepts in the geosciences. Contact Helen King (H.King@plymouth.ac.uk) for further details.

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