Uncovering threshold values in first year engineering courses and implications for curriculum design

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Abstract

The concept of threshold values relates to the idea of threshold concepts, developed from a UK national project which focused on student learning in different disciplinary areas. Meyer and Land (2005) and others realised that there were certain concepts, which were held to be central to the discipline, that would open up required systems and ways of thinking and yet were troublesome for students. Not only can threshold concept theory help in focusing students’ and teachers’ attention on the tricky “stuck places” in a subject, it can also act as a powerful curriculum development tool. This project was concerned with the threshold values that students need to develop in order to become socially responsible engineers. It investigated level 4 student experiences of engineering and explored how students related their courses to learning about the values that socially responsible engineers need to develop. The outcomes of the project include recommendations about how curriculum design initiatives can enable all students in the first year of their studies to navigate through these threshold values as they progress further through their studies towards becoming an engineer.

Keywords: Threshold concepts, curriculum design, engineering, social responsibility

Background

The idea of threshold concepts developed from a UK national project which focused on student learning in different disciplinary areas. Erik Meyer, Ray Land and others realised that there were certain concepts, which were held to be central to the discipline, that would open up required systems and ways of thinking and yet were troublesome for students. Three seminal edited books have been published (Meyer et al., 2010; Land et al., 2008; Meyer and Land, 2006). Together, they traverse a wide range of disciplinary contexts and provide an international perspective on threshold concept theory. It has been suggested that not only can threshold concept theory help in focusing students’ and teachers’ attention on troublesome areas of a subject; it can also act as a powerful curriculum development tool (Cousin, 2006; Land et al., 2005; Meyer et al., 2006). There is a growing body of threshold concept research in electrical and electronic engineering and computer science and some significant recent work in chemical, civil and mechanical engineering (Flanagan, 2012). However, it is hard to find published work on threshold concepts in materials engineering, with the exception of a recent paper by Chen et al. (2010) where attempts are made to identify threshold concepts in nanotechnology in materials engineering using curriculum mapping. Current methodologies to identify threshold concepts mainly include the use of interviews of students and lecturers and evaluation of questionnaires. Recently, however, the use of concept mapping conducted at the University of Oxford during a collaborative project with the University of Birmingham proved very useful not only for the identification of threshold concepts, but also for the evaluation and study of the learning processes involved. In this project we used both questionnaires and concept mapping approaches.
Rationale

Although we are living in an exciting period of pedagogic innovation during which approaches to teaching and learning have improved dramatically, students still meet concepts that they find troublesome. An example can be found in the use of maths in materials engineering teaching. Often students complain that complicated equations are difficult to remember or understand. As a consequence, a lot of materials engineering modules, especially at level 4, are taught in a descriptive manner. A particular area is the structure-properties-applications relationship. Even though basic mathematical equations are not used, the students still cannot grasp the implication of the above relationship. Consequently, we have chosen to examine this area in the context of the threshold concept framework with the aim of helping the students understand the value of learning certain important aspects of their subject in spite of the difficulty, becoming more confident and developing their identity as professionals.

The project aimed to:

- Identify and compare possible threshold values in level 4 engineering courses in metallurgy and materials at the University of Birmingham
- Analyse and summarise how level 4 students relate the threshold values to those of being an engineer
- Evaluate the current course design in light of the identified threshold values and make recommendations for re-design of courses where appropriate to support students’ learning.

The methodology

It was initially considered that a simple questionnaire for staff and students and a face-to-face interview would be the best way to start identifying potential thresholds. An example of questions that the lecturers and students had to answer and discuss in the interviews is shown below:

A. **HE STEM staff interview questions**

- What are the key points of crystallography?
- Why do you feel that these are the most important/valuable areas of crystallography?
- What do you find are the most understandable concepts of crystallography?
- Do you think it is the same for students?
- What do you think are the troublesome areas within crystallography?
- Do you think it is the same for students?
- Why do you think students feel these areas are troublesome?
- Which of these do you think is the most troublesome?
- Which of these do you think is the most troublesome for students?
- Why do you think these are troublesome?
- Did this come from feedback and exams of the troublesome areas?
- Did these areas correlate with each other?
- When you were a student what aspects did you find troublesome in this area?

B. **HE STEM student interview questions**

- In your opinion, what are the main aspects of crystallography/phase diagrams?
- Why do you feel that these are the most important/valuable areas?
- What do you find are the easiest concepts (areas) of crystallography/phase diagrams to understand?
- What do you think are the troublesome areas within crystallography/phase diagrams?
- Why do you feel these areas are troublesome?
- Which of these do you think is the most troublesome and why?
- What do you think is the value of understanding and overcoming these troublesome areas?
- What impact do you think it will have on your career if you don’t overcome the troublesome areas?
What do you think the value of understanding crystallography and phase diagrams will be in your life as a professional materials engineer?

We eventually came to the conclusion that we were able to identify troublesome areas but not necessarily any threshold concepts from these questionnaires. The questionnaires were extremely helpful in uncovering the thoughts of staff and students, understanding their relationship, what they think about the subject and what they feel about the subject. The process of learning, however, could not be unveiled from the answers. We therefore decided to use the idea of concept mapping to connect and relate the answers within the context of the subject. This was helpful in order to reach an understanding of how the module under study was developed, what areas were emphasised in teaching and what areas were the troublesome ones and why.

Both lecturers were interviewed and 50 students were interviewed in focus groups of five. The interviews were transcribed and, together with the answers to the questionnaires, the responses were used to develop concept maps. The concept maps, prepared in Cmap Tools, take phrases or words from the coded transcripts and explore the relationships between them by linking them with arrows and linking phrases. This type of analysis is highly subjective but has been used by other authors to help to organise and structure knowledge with small units of interacting concept and propositional frameworks (Novak and Canas, 2006).

Lessons learned

Crystallography concept map 1. Figure 1 explores the connection and relationship between words that all together form the meaning of crystallography. The colours do not have a particular meaning but they have been used to facilitate or group related areas. It was considered that points that link large areas or are more populated might be troublesome areas, as more concept units are necessary to the learning of the specific area. We can see that 3D visualisation, for example, connects the three larger areas in the map. Also, concepts such as crystal, Bragg's Law, XRD and planes (crystallographic) are central and understanding of them could be important to understanding crystallography.

![Crystallography concept map 1](image1)

Lessons learned

Crystallography concept map 2. Figure 2 shows a concept map of atomic structure that follows on from the "atomic arrangement" in Figure 1. Similarly, in this map it was thought to be important to analyse the concept of atomic structure that also seems to be central to crystallography. Here concepts such as types of bonds and the periodic table are also central.

![Crystallography concept map 2](image2)
Phase diagrams concept map 1. From the student interviews, an area that was identified as troublesome was “understanding phase diagrams”. In this map, shown in Figure 3, we tried to analyse the learning process from information that the students themselves gave. It was impressive to see that a lot of the problems were caused by a lack of basic maths knowledge, lack of familiarity with new terminology and visualisation ability (including memory).

Phase diagrams concept map 2. In this map, shown in Figure 4, it is clear that concepts such as thermodynamics, Gibbs phase rule and microstructure are important in order to read and understand a phase diagram.
However, it was evident that phase diagrams, although having been identified as a troublesome area by the students, are the tools with which students can potentially predict and identify phases in materials. A concept such as a phase diagram cannot be a threshold concept. On the contrary, there are areas (such as specific terminology behind the tool) that students need to have understood prior to the use of phase diagrams, for example, what a eutectic alloy is or what phase separation is. In order to identify these areas a more detailed questionnaire should have been designed, although it should be obvious to the lecturer that they must identify the knowledge required prior to using phase diagrams as a tool by exploring the capability of their students and then adapting the level of background knowledge that needs to be taught. Using a method like concept mapping, it is possible to build up the level of knowledge and identify the points that need to be understood before trying to learn a troublesome area or concept. It is therefore understood that this “prerequisite knowledge” should satisfy the main characteristics of a threshold concept (as identified by Meyer and Land) and involve a learning process that could be represented by the schematic diagram in Figure 5.
Evaluation

The method of using questionnaires and interviewing students and lecturers had been widely used and it was thought that this would be a good way to start exploring the area. This project was a part of a larger study in engineering threshold concepts and therefore, we thought that feedback from the existing consortium would be a good way to evaluate its results. The consortium looked at both methodologies used in this project and it was clear almost from the beginning that using questionnaires was a rather limited process, but in combination with concept mapping we were able to both identify a number of concepts and understand the process of learning them.

Discussion, summary

This project has helped to develop a methodology, based on knowledge concept maps, of identifying engineering threshold concepts as a part of a larger consortium that explored different areas of engineering education. It is understood that the threshold concepts identified in this project will lead to an improvement of current module design by incorporating elements that can reinforce background knowledge, leading to a better understanding of troublesome areas that are not themselves threshold concepts (such as phase diagrams).

Further development

Some of the ideas that came out of this project were well received not only by some of the members of staff at the University of Birmingham, but also by the Director of Education who is very keen to further explore engineering threshold concepts. We are planning to submit a proposal to the university for internal funding to continue the work and expand our research to other disciplines, with the aim of applying threshold concept theory in the schools across the College of Engineering.

Dissemination outputs


Discovering the thresholds in materials education

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Abstract: Threshold concepts were developed from a UK national project which focused on student learning in different disciplinary areas. Meyer and Land (2005) realised that certain concepts central to the discipline would open up required systems and “ways of thinking” but yet were troublesome for students. Meyer and Land (2006) suggest that the learners may be left in a state of liminality (Latin ‘limen’ - a threshold). Liminality is a suspended state in which “understanding” falsely approximates to a kind of mimicry. Identifying the threshold concepts can help with curriculum design by focusing students’ attention on the most troublesome and yet transformatory areas. Understanding why these concepts are threshold can assist with designing teaching methods and assessment approaches.

This paper develops the work of threshold concepts in 1st year engineering, combining the results of research programmes in three institutions UB (materials engineering), UO and the UWA (materials is a common module in their engineering degree programme). The UB and UO are funded by The Royal Academy of Engineering (National HE STEM Programme) and the UWA by the Australian Learning and Teaching Council to develop the methodology for exploring thresholds, identifying thresholds and bringing these into curriculum design where possible. The three universities shared and compared the initial results of their studies following an approach recommended by Erik Meyer, one of the founders of Threshold Concept Theory, whose experience with the disciplines of economics and computer science suggested that after preliminary investigations of concepts a crucial stage is the debate and discussion of such concepts at disciplinary community level.

In this paper, we will present the emerging methodologies developed by the team, demonstrating the way that they collected data using interviews, focus groups and workshops and how they analysed data using concept mapping tools. We will also focus on the materials concepts discovered during the research within each institution, noting areas of overlap and considering differences and the potential reasons for these. We will particularly invite debate, discussion and feedback by members of the materials education research community at this conference.

Oral presentation at the 4th Biennial Threshold Concepts conference, Dublin, Ireland, 28-29 June 2012.

A developing methodology to locate curricula thresholds in first year engineering

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Abstract: This paper describes the development of a methodology to identify and investigate first year engineering threshold concepts. The project emerged from an Australian ALTC (Australian Learning and Teaching) project and developed nationally and then internationally into a global study incorporating UK HE STEM projects at Birmingham and Oxford Universities. It was inspired by and incorporated lessons from the important precedent of economics and computer science communities. The methodology involves three major phases: 1) identification of potential threshold, 2) negotiation across unit, disciplinary, institutional, and eventually international boundaries and 3) data processing and analysis.

UWA initially developed phases one and two – approaches to identify threshold concepts and to negotiate these. In the Diverging Phase, students, tutors, and academics identify and discuss potential threshold concepts based on their teaching and learning experiences in one unit or
engineering discipline. In the Integrating Phase, students and academics interact, facilitating discussion of concepts between people with diverse perspectives.

At Oxford, a concept clustering and mapping technique was developed to draw out the connections between and the hierarchies within the concepts. At Birmingham, knowledge based concept maps were then developed. We are currently exploring the factors influencing different data interpretations and analysis.

This paper shows how the diverse approaches to data collection and analysis were shared and developed so that the whole was greater than the sum of the parts, drawing on the expertise of participants’ backgrounds in education, engineering and engineering education.

Papers in preparation


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**Further reading**


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