Engineering Thresholds: an Approach to Curriculum Renewal

Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts

The University of Western Australia

Project Team: Caroline Baillie (Project Lead), Cara MacNish, Angus Tavner, James Trevelyan, Gordon Royle, Dianne Hesterman, Jeremy Leggoe, Andrew Guzzomi, Carolyn Oldham, Matt Hardin, Jasmine Henry, Nathan Scott, James Doherty

Author, Project Manager, Researcher: Sally Male

<ecm.uwa.edu.au/engineeringthresholds>
Support for the production of this publication has been provided by the Australian Government Office for Learning and Teaching. The views expressed in this publication do not necessarily reflect the views of the Australian Government Office for Learning and Teaching. Further acknowledgements are made below.

With the exception of the Commonwealth Coat of Arms, and where otherwise noted, all material presented in this document is provided under a Creative Commons Attribution 3.0 Australia licence (http://creativecommons.org/licenses/by/3.0/au/).

The details of the relevant licence conditions are available on the Creative Commons website (accessible using the links provided) as is the full legal code for the CC BY 3.0 AU licence (http://creativecommons.org/licenses/by/3.0/au/legalcode).

Requests and inquiries concerning these rights should be addressed to:
Office for Learning and Teaching
Department of Industry, Innovation, Science, Research and Tertiary Education
GPO Box 9880,
Location code N255EL10
Sydney NSW 2001
<learningandteaching@deewr.gov.au>

2012

ISBN 978-1-922218-33-9  PRINT
ISBN 978-1-922218-34-6  PDF
Acknowledgements

This guide was written as part of the research project ‘Engineering thresholds: an approach to curriculum renewal’. The project evaluator, John Bowden, provided valuable formative evaluation during the project. The reference group members are gratefully acknowledged for their advice: Erik (Jan) Meyer (Consultant), Denise Chalmers, Roger Hadgraft, Robin King, Euan Lindsay, Sally Sandover, Charlotte Tay.

The students, tutors, and academics who participated in this research are gratefully acknowledged for generously sharing their insights and their time. Participants include many who participated anonymously and the following (in alphabetical order): Paul Abbott, Kazem Abhary, Reem Al-Mahmood, Tim Aubrey, Mahfuz Aziz, John Bamberg, George Banky, Iouri Belski, Susan Bertei, Aaron Blicblau, Robert Bucat, Gavin Buskes, David Callaghan, Antonio Cantoni, Hui Tong Chua, Gregory Crebbin, Brenton Dansie, James Deeks, Alice Devillers, Llana Dzanzanovic, Kate Edgeloe, Cameron Esslemont, Ciara Farris, Chris Fraser, Clive Ferguson, Tyrone Fernando, Andrew Fitch, Darryl Fitzgerald, Kate Fitzgerald, Chris Ford, Andy Fourie, Gillian Gan, M. Garrett, Rosalie Goldsmith, Jane Goodyer, Greg Griffin, Andrew Guzzomi, Ali Habibi, Roger Hadgraft, William P. Hall, D.J. Hargreaves, Dianne Hesterman, Des Hill, Julienne Holt, Ian Hooper, Yuxia Hu, David Huang, Rob Jarman, Dhammika Jayalath, Randika Anjaliie Jayasinghe, David Jenner, Chris Jones, Matthew Joordens, Jurij Karlovsek, Alan Kerr, Blake Klyen, Yarra Korczynskyj, Erin Langworthy, Jeremy Leggoe, Nicholas Ling, Brett Linke, Wei Liu, Bill McBride, Chris McDonald, Pat McMillan, Cara MacNish, Llewellyn Mann, Alex Mazzolini, Mauro Mello Jr, Wendy Miller, Euan Nichol, Carolyn Oldham, Jaden Osseiran, Gia Parish, Lyndal Parker, Christopher Parkin, Roshun Paurobally, Robert Prast, Aaron Pytte, Kathleen Quinlan, Felicity Reynolds, Robert Ross, Christopher Rowles, Geoffrey G. Roy, Tom Rufford, Stephen Russell, Sally Sandover, Shivvaan Sathasivam, Johannes Scholz, Tim Sercombe, Brice Shen, Paul Slatter, Liz Smith, Laurence Spencer, Ibrahim Sultan, Geoff Sutherland, Peter Sutton, Siong Tang, Angus Tavner, Roger Thompson, Mark Tingay, Roberto Togneri, Anh Tran, James Trevelyan, Ray Volker, Anya Waite, Phillip White, Stephen Whitely, Keith Willey, Adam Wittek, Lin Ye, Marjan Zadnik. Three troublesome features and a suggestion for identified threshold concepts were noted during several valuable conversations with Donald Richards.

Members of the University of Western Australia (UWA) Engineering Science Working Party, Foundation Team, and Kay Horn, are gratefully acknowledged for their contributions to identifying and negotiating threshold concepts in meetings, workshops, and discussions.

David Parkinson and Julian O’Shea interviewed first-year students. David Parkinson is acknowledged for his valuable analysis of interview and extensive survey data.

Support for this research has been provided by the Australian Government Office for Learning and Teaching. The regional workshops were further supported by the Australian Council of Engineering Deans.

The following people are gratefully acknowledged for providing venues and support for regional workshops held at their universities: Elizabeth Smith and Martin Shanahan at University of South Australia; Roger Hadgraft at the University of Melbourne; Tim Aubrey and Rosa Tay at University of Technology Sydney; Graham Schaffer, Lisa Deacon, Peter Sutton, Lou Wheeler, and Kamilla Wells of the University of Queensland; and Friso De Boer and Asma Khan of Charles Darwin University.

Gerard Rowe and Elizabeth Godfrey are thanked for initiating and organising the New Zealand workshop at the University of Auckland.

Jens Kabo and Tom Adawi, of Chalmers University in Sweden, are thanked for discussing methodology with the project team and co-facilitating a workshop at UWA. Jonathan Scott
from the University of Waikato in New Zealand is gratefully acknowledged for generously spending a day at UWA sharing his experiences.

The project received a UWA Research Collaboration Award for invaluable collaboration with researchers in England: Kathleen Quinlan, Chris Trevitt and Johnny Fill of the University of Oxford, and Artemis Stamboulis and Zahira Jaffer of the University of Birmingham.

The author is deeply grateful to Rebecca Benson for editing the guide. It was a pleasure working with Rebecca.
List of Acronyms Used

CDIO:  Conceive-Design-Implement-Operate (an approach to engineering curriculum development)
UWA:  The University of Western Australia
Preamble

This guide is an outcome of the project ‘Engineering thresholds: an approach to curriculum renewal’ <ecm.uwa.edu.au/engineeringthresholds>. During the project, engineering educators at UWA developed an entirely new engineering curriculum (Trevelyan, Baillie, MacNish, & Fernando, 2010). This guide describes how a threshold concept framework was used in the development of the integrated engineering foundation curriculum. ‘Integrated’ refers to integration of all engineering disciplines. ‘Foundation’ refers to the first year of a Bachelor of Engineering, or first and second year of an engineering science major. ‘Curriculum’ refers to the complete learning experience, including especially the syllabus, pedagogy, and assessments and also other aspects such as learning spaces, faculty culture, and student clubs. The methodology could be used by university educators as one element of the development of a new curriculum, or it could be adapted to renew a curriculum, or develop or renew a unit or a topic within a curriculum.
Table of Contents

Acknowledgements ..................................................................................................................... 3
List of Acronyms Used ............................................................................................................... 5
Preamble ..................................................................................................................................... 6
Examples and Figures .................................................................................................................. 9
   Examples .................................................................................................................................. 9
   Figures .................................................................................................................................... 9
1. Introduction .......................................................................................................................... 10
   Scope .................................................................................................................................... 11
   How a curriculum development approach using a threshold concepts framework differs from other approaches ........................................................................................ 11
   Background .......................................................................................................................... 12
   Combining a threshold concepts approach with other approaches to curriculum development ................................................................. 12
2. Methodology for Identifying and Investigating Threshold Concepts .................................. 13
   Theoretical framework ......................................................................................................... 13
   Approach to identifying and investigating threshold concepts and how this was shaped by the theory ......................................................................................... 15
   Researchers ........................................................................................................................ 18
   Diverging phase .................................................................................................................. 19
   Integrating phase ................................................................................................................ 23
   Presentation of threshold concepts ..................................................................................... 34
4. Identified Threshold Concepts ........................................................................................... 36
5. Curriculum Development ................................................................................................... 37
   Syllabus ............................................................................................................................... 37
   Pedagogy ............................................................................................................................ 39
   Assessment .......................................................................................................................... 40
   Teachers ............................................................................................................................... 41
6. Reflections and Future Research ......................................................................................... 43
   Working with the curriculum development team ............................................................. 43
   Building a research team ................................................................................................. 44
   Sustaining the curriculum development ....................................................................... 44
   Curriculum development for ever? .................................................................................. 45
7. Resources ............................................................................................................................... 46
   Literature ............................................................................................................................. 46
Examples and Figures

Examples

Example 1: Academic interview plan ................................................................. 19
Example 2: Student focus group plan ............................................................... 21
Example 3: Student tutor/demonstrator focus group plan ................................ 22
Example 4: Student workshop notes ............................................................... 25
Example 5: Student workshop individual handout 1 ....................................... 26
Example 6: Student workshop group handout 1 ............................................. 27
Example 7: Student workshop group handout 2 ............................................. 27
Example 8: Student–staff workshop notes .................................................... 28
Example 9: Handout for workshop introducing threshold concepts ............ 29
Example 10: Regional workshop plan ........................................................... 30
Example 11: Regional workshop group exercise ............................................. 31
Example 12: Regional workshop evaluation questionnaire .......................... 32
Example 13: Instructions for participants in negotiation workshop to refine inventory .... 33
Example 14: Item in the threshold concept inventory ..................................... 36
Example 15: Example of extract from a unit reader—identifying threshold concepts .... 38

Figures

Figure 1: Concept map of most integrative engineering foundation threshold concepts .... 50
1. Introduction

With continuous technical development there is a risk that engineering educators will jam increasing content into engineering curricula. Excessive content has been linked to encouraging students to take a ‘surface’ rather than a ‘deep’ approach to learning (Ramsden, 2003, p.47). Therefore, it is valuable to improve curricula such that students and teachers spend less time and effort on peripheral or easy concepts and more on the concepts that are most critical to students’ progress and yet are difficult for many students.

Godfrey and King (2011, pp.64–66) noted ‘killer’ or ‘barrier subjects’ in engineering curricula—units that many students find difficult or fail. High attrition rates have been prevalent in engineering programs in Australia. King (2008, p.39) estimated ‘male Australian engineering students have about 52% likelihood of successful graduation from a bachelor level engineering program, and females about 60%’. Therefore, curriculum enhancement to help students through troublesome concepts in ‘killer subjects’ is due.

Meyer, Land and others recognised that many disciplines have concepts that act as gateways or thresholds for students. These ‘threshold concepts’ open up new ways of thinking and understanding that are critical to students’ progress (Meyer & Land, 2003). The threshold concept theoretical framework in higher education can be used to help educators focus their teaching and their students’ learning on the concepts that are most transformative once mastered (Cousin, 2006). The framework can also be used by engineering educators to improve students’ learning of transformative concepts, by considering the critical and troublesome features of these concepts. Additionally, the framework can be used to improve assessments to collect evidence of students’ transformation.

This guide introduces engineering educators to using a threshold concept framework as one aspect of curriculum development. After reading the guide and cited literature, engineering educators will be able to identify and investigate threshold concepts and then refine curriculum features to improve students’ development of understanding of identified threshold concepts.

The approach to using a threshold concept framework as one aspect of curriculum development has the following steps:

- Identify potential threshold concepts in the curriculum and investigate how they are perceived as transformative and troublesome.
- Negotiate these identified potential threshold concepts.
- Develop features of the curriculum to help students overcome identified threshold concepts. At this point consider program structure, pedagogy, assessment, and any other curriculum features that might be relevant.

The threshold concept approach described in this guide includes a method to identify the concepts that are most transformative and troublesome for students and therefore should be a focus of teaching and learning. By identifying threshold concepts, engineering educators can ensure that programs are not overcrowded—with equal attention paid to too many concepts and insufficient opportunity to develop understanding of critical concepts.

The approach also includes a method to investigate the transformative and troublesome aspects of identified threshold concepts. Findings can inform improved teaching, to help students experience transformation and overcome difficult concepts. Pedagogy can be designed to ensure that students have opportunities to develop an understanding of and capability to apply identified threshold concepts. Findings can also inform development of assessments, as these can be designed to encourage and collect evidence of transformation, rather than ability to mimic understanding. It should be noted that threshold concept theory...
alone does not provide an entire curriculum development process, or prescribe how concepts should be taught.

The following parts of Chapter 1. Introduction position the approach to help readers decide whether it fits their needs. Chapter 2. Methodology describes relevant theories, introduces UWA’s approach to identifying and investigating threshold concepts, and describes how the theory shaped the approach. Chapter 3. Method introduces protocols and tools for identifying and investigating threshold concepts. Chapter 4. outlines identified integrated engineering foundation threshold concepts, with reference to the separate inventory. Chapter 5. Curriculum Development introduces ways to consider shaping the curriculum after identifying and investigating threshold concepts.

Scope

In this guide, ‘curriculum development’ refers to designing or improving any or all features of a curriculum. A curriculum includes all aspects of the experience of students in a program. The guide discusses course content and structure (syllabus), pedagogy or approach to teaching, and assessment. Other aspects of curriculum include faculty culture, industry engagement, learning support, internships, teacher and student demographics, learning spaces, student social and sporting opportunities, the campus, student accommodation or demands of commuting, and learning resources. It has been found that students can develop ‘accidental competencies’ (Walther, Kellam, Sochacka, & Radcliffe, 2011, p.706) that were not necessarily intended learning outcomes, through their experiences of curricula.

The approach described in this guide, using a threshold concept framework, could be used as an aspect of curriculum design or curriculum improvement for a complete course, a unit, or a single topic. As described below, the approach described in this guide is one aspect of curriculum development. It is not the complete curriculum design.

How a curriculum development approach using a threshold concepts framework differs from other approaches

Using an engineering thresholds approach, engineering educators can focus teaching, learning, and assessment on concepts most critical to students’ progress and most likely to require extra effort to achieve understanding. This is preferable to steadily working through a syllabus, with too little attention on thresholds and too much time on concepts that students can readily learn independently.

By approaching curriculum development using a threshold concepts framework, engineering educators can identify concepts that are critical to students’ progress and yet are often overlooked by engineering educators. Some identified threshold concepts are not normally listed in a syllabus because they are tacit, or because they are integrating concepts that are not apparent from within disciplinary silos (Male, Guzzomi, & Baillie, 2012).

Three examples of threshold concepts that might not normally be explicitly taught in an engineering program are modelling, vectors, and the principle of conservation (Hesterman, Male, & Baillie, 2011). With regard to modelling, engineering educators can forget to teach the relationships between representations and physical systems, and the positioning of each model among the arrays of models that are helpful in different contexts. Similarly, they can fail to recognise the need to teach underlying perceptively simple concepts such as vectors. Engineering educators teaching separately from within their own engineering disciplines might not notice or teach underlying engineering concepts, such as the power and significance of principles of conservation. These are examples of frequently overlooked transformative and troublesome concepts that are often left for students to learn incidentally or not at all.
Background

The curriculum development approach described in this guide has been developed at UWA. In 2012, UWA introduced new programs across the university. Thirteen engineering programs were replaced with one engineering science major to be taken as part of a three-year bachelor program, and six two-year masters of professional engineering programs (Trevelyan et al., 2010). The design was informed by stakeholder consultation and literature on research and best practice in engineering education and higher education. The curriculum design provides a strong, broad foundation followed by depth. The engineering foundation integrates traditional engineering disciplines and generic attributes to broaden learning outcomes, improve learning, and better align education with engineering practice (Male, Bush, & Chapman, 2010). One aspect of the curriculum design was the threshold concept framework.

At UWA, the complete curriculum development for the integrated engineering foundation, forming the first two years of the new three-year engineering science major, was undertaken in six stages, described in a book chapter (Male & Baillie, forthcoming). Before threshold concepts were considered, two earlier stages of curriculum development were undertaken. First, a team of academics identified three big ideas for their program of study. Free body diagrams, equilibrium of forces and moments, and stress and strain are examples. Potential clusters of learning outcomes were taken back to the schools and effectively negotiated among all academics in the engineering faculty. Second, learning outcomes (Moon, n.d.) and capabilities (Bowden, 2004) that underpinned the selected three big ideas were identified. Bowden’s (2004, pp. 42–44) capability theory describes levels of capability: ‘scoping’ (basic entry level), ‘enabling’ (with basic abilities), ‘training’ (with specific abilities relating to context, and ‘relating’ (with ability to adapt for various contexts). The learning outcomes were reduced following discussion, and finally agreed on by all schools. This guide focuses on how a threshold concept approach contributed to the curriculum development after learning outcomes had been agreed.

Combining a threshold concepts approach with other approaches to curriculum development

The above outline of the initial development of the engineering foundation units at UWA demonstrates how a threshold concepts framework can be combined with other curriculum development approaches. Threshold concept theory complements rather than precludes other theories. The theoretical framework for the curriculum development at UWA combined the following: threshold concept theory to identify and investigate concepts that demand special attention, capability theory to understand that students must develop capability to apply understanding in future unseen contexts, and variation theory to inform pedagogical approaches to helping students develop understanding of identified threshold concepts (Bowden, 2004; Bowden & Marton, 1998). These theories are introduced below.

Engineering educators could take the approach described in this guide to identify and investigate threshold concepts and use the findings to inform aspects of any curriculum. For example, a threshold concepts framework could inform improvement of a Conceive-Design-Implement-Operate (CDIO) curriculum (Crawley, 2001), or another curriculum using problem or project-based learning.
2. Methodology for Identifying and Investigating Threshold Concepts

Theoretical framework

The theoretical framework for this approach includes threshold concept theory, capability theory, and variation theory. All three are introduced here. Threshold concept theory is the main theory providing the framework for the research involved in this approach to curriculum development. Capability theory was used in the second stage of the curriculum development introduced above in the Background section of Chapter 1. This theory also informed an adaptation of threshold concept theory in this project. Variation theory is used in Chapter 5. Curriculum Development, after identification and investigation of threshold concepts.

Threshold concept theory

Developers and users of threshold concept theory recognise that many disciplines have threshold concepts that are transformative for students—opening up new ways of thinking and understanding—and are required by students for future learning and progress into the profession (Meyer & Land, 2003). The theory states that all threshold concepts are transformative ontologically and epistemologically. This means that threshold concepts are transformative in a fundamental and personal sense. Students change who they feel they are and their understanding of valid knowledge when they develop understanding of a threshold concept (Meyer & Land, 2005).

When an engineering student has developed understanding of a threshold concept, the student is able to undertake future learning in engineering, or undertake engineering practice for which the student was not previously capable. Threshold concepts therefore act as gateways to progress in an educational program and into a profession.

Examples of threshold concepts in engineering can be found in the Integrated Engineering Foundation Threshold Concept Inventory document on the project website. The inventory includes threshold concepts required to learn to become an engineer, think and understand like an engineer, and shape the world as an engineer. An example in the first cluster is ‘self-directed learning’. In the second cluster, ‘modelling and abstraction’ is an overarching threshold concept, with ‘system identification’ within this overarching threshold concept, and specific manifestations such as ‘free body diagrams’ at an even more specific level. In the third cluster, shaping the world as an engineer, ‘sustainability’ is a threshold concept. These clusters are illustrated in Figure 1, Appendix A.

Troublesome knowledge

Due to their transformative features, threshold concepts are almost always ‘troublesome’ for students (Meyer & Land, 2003, p.5). The concepts can be troublesome in any way. The UWA engineering threshold concepts research was based on the assumption that threshold concepts can be troublesome due to the nature of the concept, the curriculum—especially how the concept is taught—or the background of the student. This understanding has implications for curriculum development designed to help students overcome threshold concepts. It could be possible to address a troublesome feature of a threshold concept by teaching it differently, or at a later stage in a program. Some of the types of troublesome knowledge as described in the literature are outlined below. Engineering examples are described in our book chapter (Male & Baillie, forthcoming).

Perkins (1999; 2006, pp.37–41) identified five types of troublesome knowledge as follows. ‘Ritual knowledge’ is used habitually without understanding. ‘Inert knowledge’ is abstract knowledge without context or application, such as many mathematical concepts in engineering programs. This is an example of a type of troublesome knowledge that can be
addressed by engineering educators, for example by integrating engineering examples into mathematics (Wandel, 2010). ‘Conceptually difficult knowledge’ is often counter-intuitive. ‘Tacit knowledge’ is knowledge that educators frequently neglect to teach because educators are not aware they use the knowledge, or find it difficult to identify. ‘Foreign’ or ‘alien knowledge’ requires a different way of thinking from that familiar to students. Open-ended problems can require alien knowledge for students with science backgrounds. Baillie and Johnson (2008, pp.137–138) identified ‘fear of uncertainty’ as an additional cause of trouble. Finally, Meyer and Land (2003, pp.8–9) identified a further potentially troublesome feature of knowledge: ‘troublesome language’, which is unfamiliar language or language used differently from common usage.

Liminal space

Meyer and Land (2005, pp.375–377) describe the state experienced by a student when a threshold concept has come into view but remains troublesome as the ‘liminal space’. Students in the liminal space frequently ‘mimic’ understanding, which has implications for design of assessments. Some students traverse the liminal space for a specific threshold concept relatively easily. Many students travel back and forth in the liminal space, perhaps glimpsing the concept but not yet understanding or accepting it, perhaps struggling to discard a previous identity or misconceptions, or perhaps uncomfortable with the concept. Some students will never pass through the liminal space. The time, effort, and experience required for students to traverse the liminal space all have implications for the structure of a syllabus.

Meyer and Land (2005) describe the ‘pre-liminal space’ as the mental state of a student before a threshold concept comes into view. The pre-liminal space for any student can be shaped by many factors, especially the student’s educational background. Within the threshold concept theoretical framework there is, therefore, an expectation of variation between students’ experiences of threshold concepts. Students will experience different concepts as threshold.

Critical features

Within the threshold concept theoretical framework are other critical features of threshold concepts. Meyer and Land (2003, pp.6–7) describe threshold concepts as frequently ‘irreversible’ (meaning that the transformation is not reversed), ‘bounded’ (meaning limited to a disciplinary scope), ‘integrative’ (connecting otherwise unconnected concepts), and ‘discursive’ (enhancing use of language). Some researchers have interpreted some or all of these features as criteria for identifying threshold concepts. However, in a reference group meeting, Jan Meyer, consultant to this project, confirmed that these features of threshold concepts are critical rather than compulsory (personal communication, 27 October 2010). Some of these are features that are dimensions, along which there is variance between students with different levels of development of understanding of the concept. For example, a student with stronger understanding of a threshold concept is likely to find that the concept connects other previously unconnected concepts and enhances language significantly. Therefore, the critical features of threshold concepts could help researchers to investigate dimensions of transformation. However, they are not necessarily valuable as criteria for identification of threshold concepts.

Capability theory

In capability theory, Bowden (2004, pp.42–44) expounds the idea that university students should prepare for situations they have not seen before. To do this, students must develop capability to take advantage of the understanding they have, develop an approach to respond to a new situation, and have capability to implement the approach they have developed. Therefore a student must develop not only understanding of concepts, but capabilities for unseen futures.
Variation theory

In variation theory, Bowden and Marton (1998) describe how students can learn by experiencing structured variation. This theory is useful for developing teaching and learning experiences to help students develop capabilities. The theory is central to the Pedagogy section in Chapter 5. Curriculum Development of this guide.

Threshold capability theory

In this project, several engineering academics identified potential threshold concepts that other academics felt were not strictly concepts but were capabilities. Baillie, Bowden and Meyer (2012) have combined threshold concept theory with capability theory and variation theory in a new theory named ‘threshold capability theory’. In the UWA curriculum development, threshold concepts and threshold capabilities were identified. The goal was to develop a strong curriculum and by allowing both threshold concepts and threshold capabilities to be identified, opportunities for improving engineering education were taken, without being restricted by tight definitions. In future at UWA, it is likely that threshold capability theory will be adopted.

Approach to identifying and investigating threshold concepts and how this was shaped by the theory

We now consider how to identify and investigate threshold concepts. The approach uses features of a phenomenographic framework (Booth, 2004). Phenomenography is a methodology that can be used by researchers to investigate variation in understanding or development across a pool of students. In phenomenography, responses from a group of students are pooled to identify the range of understanding among students. Because students experience different concepts as threshold, the UWA approach to curriculum development is designed to identify concepts experienced as threshold by many students (Male, Guzzomi et al., 2012).

Participants

Whether a concept is a threshold concept depends on whether it is transformative for students and consequently threshold concepts are also almost always troublesome for students. These features of concepts arise from students’ experiences of learning the concepts. Therefore, the approach to identifying and investigating threshold concepts involves collecting data about how students experience concepts—specifically evidence of students experiencing concepts as transformative and troublesome. Students and their teachers have experiences that build awareness of concepts that students can find transformative and can explain why students experience concepts as troublesome or transformative. Students have recent experiences of learning in engineering, and have received questions and comments from students, observed students tackling problems, and marked students’ work. Academics have received students’ questions, heard their responses to questions, seen ‘blank expressions’, and marked students’ work. All of these experiences can contribute to an understanding of concepts that one or more students have found transformative and troublesome. At UWA, data about which concepts students find transformative and troublesome were collected from engineering students, student tutors, and academics who had taught engineering or related disciplines.

Diverging and integrating phases

A two-phase methodology was developed to identify and investigate threshold concepts in a program (Male & Baillie, 2011a, 2011b). In the diverging phase, potential threshold concepts were identified through interviews, focus groups, and open survey questions with
participants from individual units or disciplines. In the integrating phase, identified potential threshold concepts were negotiated, in workshops, by participants from diverse backgrounds: students and teachers, teachers from multiple engineering and related disciplines, and teachers from multiple universities. The two phases were implemented over a similar period of time, although the diverging phase began first.

Other researchers have identified threshold concepts in a discipline or unit using student surveys, laboratory observation, and teacher and student interviews (Male & Baillie, 2011a). Interviews and focus groups are valuable when the range of possible responses is unclear and depth of response, such as explanation for initial responses, is important to the research. Surveys are valuable in situations when generalisable results are sought from responses from a large number of participants. In the diverging phase, interviews, focus groups, and open survey questions were used to allow participants to raise unexpected ideas. An advantage of the methodology is that previously unrecognised concepts such as tacit concepts can be identified. In the interviews, it was possible to ask probing questions to discover why participants perceived suggested concepts as transformative and troublesome. Rather than obtaining generalisable results, in the diverging phase concepts were identified that at least one participant perceived as threshold to one or more students.

In the integrating phase, identified potential threshold concepts were negotiated in workshops among diverse groups of participants. Threshold concepts negotiated and agreed among participants were then considered to be threshold for many engineering students, and hence important for curriculum development. Workshops were suitable for negotiation—as in interviews, participants were able to raise unexpected ideas. Nominated facilitators in each group asked probing questions and thereby again encouraged depth of response. In workshops, unlike focus groups, up to 40 participants were engaged simultaneously.

Data collection and analysis

The combination of the diverging and integrating phases balanced the ability to collect unexpected data indicating potential threshold concepts and depth of explanation about how concepts had been experienced as transformative or troublesome, with the ability to collect data from many participants from diverse backgrounds. Data were collected as handwritten notes, as detailed in Chapter 3. Methods below, and transcribed recordings of interviews, focus groups, and workshop discussions. Data were analysed for evidence of transformative features of potential threshold concepts, troublesome features, and suggestions about how to help students overcome the thresholds.

As noted earlier, threshold capabilities were included among the threshold concepts. The most common evidence of transformation was evidence of future learning, or a feature of engineering practice that requires understanding of, or capability in, the potential threshold.

An inventory of threshold concepts was developed iteratively. Each item in the inventory included identification of the concept, how the concept was perceived as transformative, how it was perceived as troublesome, and any suggestions for helping students overcome the concept (Male, 2012).

Within the threshold concept theoretical framework, threshold concepts are understood to exist at various levels of specificity. In the diverging phase, the inventory tended to grow as individual participants suggested additional potential threshold concepts. Students suggested very specific concepts, such as the direction of friction. In interviews with academics, especially senior professors, the inventory was sometimes reduced as these participants recognised underlying concepts that caused specific examples to be troublesome. For example, professors explained the direction of friction as a consequence of system identification, rather than a concept in its own right.
In the integrating phase, many potential threshold concepts were clustered into smaller numbers of underlying or overarching threshold concepts. For example, several conservation principles such as conservation of mass, energy, charge, and momentum were recognised as manifestations of an overarching principle of conservation. Alternatively, potential threshold concepts such as the meaning of a $k$ axis when representing circular motion as a vector, or the difference between rate of change of speed and acceleration in circular motion, were later recognised as depending on an underlying threshold concept, vectors.

Throughout the approach, participants were introduced to the theory, the purpose of the project and findings to date. Introducing the theory was designed to privilege the participants’ analysis of their experiences, awareness and insight, over researchers’ analysis of their reports of experiences. The practice also helped to gain trust and cooperation from participants, and build understanding about the threshold concepts among academics who might later be teaching the developed curriculum. Introducing the findings to date was designed to efficiently develop the threshold concepts inventory without wasting participants’ and researchers’ time raising ideas already collected.

Chapter 2. Methodology describes the theory and how this shaped the method used in the study. The method is described in two conference papers (Male & Baillie, 2011a, 2011b). As described above in Chapter 2. Methodology, two phases were undertaken: the diverging phase and the integrating phase. The diverging phase included interviews and focus groups, each with academics or students from one discipline only. The integrating phase included workshops with participants from various disciplines and backgrounds. Events in the integrating phase were a student workshop, a follow-up student–staff workshop, regional workshops attended by engineering teachers, and a final workshop to refine the inventory of threshold concepts. Therefore, participants in this project included students, people who were teaching engineering and related disciplines at UWA, and people teaching engineering and related disciplines at other universities. Human research ethics approval was obtained for the project.

Researchers

The author undertook all the interviews and focus groups in this project, except the interviews with first-year students. She undertook most of the analysis with assistance from Caroline Baillie, the project lead. The project lead and author have qualifications in engineering and engineering education research. The workshops were led by the project lead or the author and were co-facilitated by members of the project team, who all had engineering backgrounds and extensive teaching experience. The interviews with first-year students were conducted by David Parkinson, a final year engineering student, and Julian O’Shea, a PhD student with an engineering degree, trained in conducting interviews by the project lead and the author.

Researchers identifying and investigating threshold concepts using this approach will be well-placed if they have familiarity with engineering, so that they can understand participants’ responses and ask appropriate probing questions, combined with skills for interviewing and analysing qualitative data. It is not necessary for one person to have all of these skills. Research on threshold concepts has commonly been undertaken as a collaboration between education researchers and disciplinary researchers (Cousin, 2009).

Researchers at the Universities of Oxford and Birmingham in England collaborated with UWA, adapting the methodology presented in this guide (Quinlan et al., forthcoming; Quinlan et al., 2012). The team in Birmingham included an academic in materials, and a materials student. This team used concept maps as a tool for identifying threshold concepts. They mapped all of the concepts on the topic of ‘Mohr’s Circle’, based on the introduction to Mohr’s Circle in a text book. They then mapped concepts in parts of a materials engineering program, by interviewing academics. The team went on to identify threshold concepts on the maps as those on which many other concepts depended, effectively using the transformative and integrative features of threshold concepts as selection criteria. Findings were triangulated with findings from focus groups with students and the interviews with academics. The project lead guided the team from Birmingham, complementing their technical strengths.

The team in Oxford included a researcher in the field of higher education, a researcher in higher education with a physics degree, and a physics PhD student. They adapted the UWA approach. To avoid influencing responses, the Oxford researchers chose not to share previously identified potential threshold concepts.
The Oxford team analysed transcripts using a coding system, whereas at UWA transcripts were analysed in their complete form so as to keep the complete understanding of the participants. At Oxford, the probing questions in the interviews and the identified threshold concepts focused more heavily on learning processes and less on technical concepts than at Birmingham or UWA, as might be expected based on the researchers’ backgrounds.

Diverging phase

The purpose of the diverging phase is to identify potential threshold concepts by interviewing individual teachers and students in one discipline at a time.

Interviews with academics

At UWA, interviews were held with academics with current or recent experience teaching fields relevant to the curriculum development. This included units at higher levels, in which students apply learning undertaken in the part of the curriculum being developed. Academics were invited by telephone and email to participate, and were provided with the information sheet and a sample consent form. Below is a sample plan for a typical semi-structured interview with an academic.

Example 1: Academic interview plan

<table>
<thead>
<tr>
<th>Interview on threshold concepts in statics in John Smith’s experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date: 11/05/2011</td>
</tr>
<tr>
<td>Time: 10 to 11am</td>
</tr>
<tr>
<td>Participants: John Smith</td>
</tr>
<tr>
<td>Interviewer: Sally Male</td>
</tr>
<tr>
<td>Location: meeting room in engineering</td>
</tr>
<tr>
<td>At the interviewee’s request, the interview was/was not recorded.</td>
</tr>
<tr>
<td>The interviewee did/did not wish to be acknowledged by name.</td>
</tr>
</tbody>
</table>

Flexible Plan for semi-structured interview:

1. Interviewer asks participant to read the information sheet if the participant has not already done so. Interviewer asks participant to sign the consent form if, having read the information sheet, he or she agrees to participate. Interviewer starts the recorder if permission is granted on the consent form.
2. Interviewer explains threshold concepts without jargon. Interviewer presents lists or concept maps of those identified to date and relevant threshold concepts in the literature.
3. What is your role in current and future units?
4. Briefly, what is the unit concept [for a unit John Smith is mainly involved in]?
5. Can you think of any possible thresholds in this or similar previous units?
6. [For each,] why is this threshold significant: what is the new way of thinking and for what is it used?
7. [For concepts identified,] can you describe the particular transformative way of thinking that students have trouble with? (Possible probe: what makes you think this? [questions from students, assignments scripts, exam scripts, labs performance])
8. Can you identify causes of the thresholds identified? (Possible probes: Types of troublesomeness, program structure, teaching method, learning opportunities, students’ backgrounds?)
9. Are the threshold concepts taught earlier in the course or do they rely on concepts taught in other units?
10. Are there ways you have found useful to help students understand each identified concept?
At UWA, academics were interviewed individually except in one case in which two academics taught units that were closely related. The interview with two participants was beneficial for both participants because they learnt much about how each other teaches. However, the more junior of the two participants sometimes referred questions to the more senior participant. This participant might have said more in an individual interview setting. Most interviews took approximately one hour and the majority of participants agreed to be recorded.

The collaborators in Oxford modified the methodology slightly. They did not present previously identified threshold concepts during the interviews, because they did not wish to influence responses. However, at UWA academics were found to have no hesitation declaring that a previously identified concept was not a threshold concept, because it arose from an underlying threshold concept. For example, one electrical engineering academic suggested ‘Thevenin’s Equivalent Circuit’ and aspects of linearity as potential threshold concepts. A professor subsequently interviewed declared that these were simply specific manifestations of the threshold concept, ‘modelling and abstraction’. Similarly, a civil engineering academic suggested Mohr’s Circle was as a potential threshold concept and a professor subsequently interviewed declared this to be a tool. In his view, trouble with Mohr’s Circle stemmed from an underlying threshold concept, stress (Quinlan et al., 2012). Rather than hindering open-minded identification of potential threshold concepts, the iterative approach adopted in the interviews encouraged negotiation of identified potential threshold concepts and possibly inspired identification of further potential concepts underlying the previously identified concepts.

The interview location must be convenient to the participant. However, meeting rooms are preferable to academics’ offices. Interviews in academics’ offices were frequently interrupted by telephone calls and people at the door. This reduced the effective length of the interview and interrupted the flow. In addition, the recording either had multiple breaks or unwanted sections to remove before transcription.

Handwritten notes were taken during the interviews. Following each interview, the notes and transcribed recordings were analysed for evidence of transformative and troublesome concepts, and the threshold concept inventory revised. The revised section of the inventory was emailed to the participant for confirmation.

**Student focus groups**

Students were interviewed in small focus groups, as this was expected to be less threatening than individual interviews. Each student focus group was attended by students from one engineering discipline only. Participants were either undergraduate students, or senior undergraduate students and postgraduate students who were tutoring or demonstrating in relevant existing units.

Students were recruited by email through relevant unit coordinators and student societies. Three to seven students and one to three relevant unit coordinators attended each focus group. The academics asked some of the probing questions and provided background. The presence of a unit coordinator helped to demonstrate to the students that the focus group was a real opportunity to contribute directly to teaching. The duration of focus groups was 45 to 105 minutes. Lunch was provided if the time was appropriate.
Examples 2 and 3 below are the plan used for a student focus group and a focus group with student tutors. The interviewer’s role was to:

- give every participant an opportunity to contribute
- ensure that participants knew that their responses were valued
- avoid any irrelevant and inappropriate discussion topics, such as the quality of individual teachers
- keep the conversation on task
- ask probing questions to clarify comments and delve deeper to collect evidence of threshold concepts.

Example 2: Student focus group plan

| Focus group on threshold concepts in chemical engineering as experienced by students |
|---------------------------------|---------------------------------|
| Date: 25/10/2010 (last teaching week of the year) | Time: 1 to 1.45pm |
| Participants: chemical engineering students and a chemical engineering academic | Interviewer: Sally Male |
| Location: meeting room in engineering | Flexible Plan for semi-structured focus group: |
| 1. Interviewer asks participants to read the information sheet if the participant has not already done so. Interviewer asks participant to sign the consent form if, having read the information sheet, they agree to participate. Interviewer starts the recorder if permission is granted on the consent form. | 2. Interviewer explains threshold concepts without jargon. |
| 3. Interviewer shows students list of Thresholds Identified to Date October 11, 2010. | 4. Can you think of any other possible thresholds in your course? |
| 5. Please briefly outline the concept. | Focussing on any one concept: |
| 6. Please describe the transformation in thinking that it provides. | 7. Please describe how you found it troublesome. |
| 8. How did you think or act differently before you understood it? | 9. How has the threshold been significant for other parts of the course since you came to understand that concept? |
| 10. Can you identify barriers to understanding the threshold? | 11. Are there ways you have found useful to help students understand each identified concept? |
| 12. Does the threshold link concepts together? Which ones? How? | Questions 12 to 15 below are possible prompts based on critical features of threshold concepts. These were used with varying success, and are not recommended as core questions. These questions encouraged discussion about the theory, which the students found interesting, but the conversation must be contained to identifying and negotiating threshold concepts as far as possible. |
| 14. How did you develop understanding or the new way of thinking or practising? | 13. Has the threshold given you an expanded use of language? |
| 15. After you understood the threshold, did you need to revisit it? | 14. How did you develop understanding or the new way of thinking or practising? |
| Repeat 4 to 11 and possibly 12 to 15 for other concepts depending on time. | 15. After you understood the threshold, did you need to revisit it? |

Repeat 4 to 11 and possibly 12 to 15 for other concepts depending on time.
Example 3: Student tutor/demonstrator focus group plan

Interview with students who were electrical engineering tutors and demonstrators, on threshold concepts experienced by students studying electrical fundamentals

Date: 22/11/2011 (after tutors had marked examination scripts)
Time: 12noon to 1.30pm
Participants: unit coordinator and three undergraduate and postgraduate students who were tutors/demonstrators of first-year electrical engineering. Two academics developing the new curriculum also attended and asked some questions for clarification.
Interviewer: Sally Male
Location: meeting room in engineering

Flexible Plan for semi-structured interview:

1. Interviewer asks participants to read the information sheet if the participant has not already done so. Interviewer asks participant to sign the consent form if, having read the information sheet, they agree to participate. Interviewer starts the recorder if permission is granted on the consent form.
2. Interviewer explains threshold concepts without jargon.
3. Interviewer asks about participants’ teaching experience in electrical fundamentals and current position e.g. undergraduate student or postgraduate student?
4. Interviewer presents concept maps of previously identified potential threshold concepts, with those most relevant to electrical fundamentals highlighted.
5. Do you think these are threshold concepts and why? Are they transformative/troublesome and on what basis do you think this?
6. Can you think of any other possible thresholds in the first year electrical engineering unit?
   Focussing on any one concept:
7. Please briefly outline the concept.
8. Why is the concept significant - i.e. what is it used for? For which other parts of the course or work is the threshold concept significant?
9. Please describe the transformation in understanding that it provides.
10. How do students think or act differently before and after they understand it?
11. Please describe what can make it troublesome. Can you identify barriers to understanding the threshold?
12. Are there ways you have found useful to help students understand each identified concept?

Steps 5 to 12 are repeated for other concepts depending on time.

The most effective student tutor focus group was held immediately after the participants had assisted in marking examinations. At this time the participants were able to refer to their observations about students’ attempts at problems in classes, assignment responses, students’ questions, responses to examination questions, and the student tutors’ own recent experience as students and school students (Male & Baillie, 2011a, 2011b; Male, MacNish, & Baillie, 2012).

Five students taking the first new foundation engineering unit to be offered, ‘Introduction to Professional Engineering: Global Challenges in Engineering’, were interviewed in pairs or as individuals by a final year student and a postgraduate student. Interviews were one-hour long and lunch was provided. Interviews were held in the final two weeks of semester. Participants were not introduced to the theory.
The interview questions pertained directly to students’ experiences of troublesome and transformative concepts in the unit:

1. What was the most difficult aspect of the [unit] and why?
2. Has anything in this [unit] changed your perception and why?

Probing questions requesting explanation and evidence followed each of the above questions. The discussions were transcribed and notes were taken. The final year student analysed responses along with survey responses described below, for evidence of transformative and troublesome concepts. A difficulty was recruiting participants at such a busy time of semester for the students.

Student surveys

Students taking the first foundation engineering unit were also surveyed for unit feedback. Of the 435 students enrolled, 80 per cent participated in the first survey and 82 per cent in the second. Open responses were analysed by the same final year student, along with the first-year students’ interview responses. The first survey, a one minute paper, was the most useful for identifying threshold concepts (Angelo & Cross, 1993). The survey questions were:

1. Give an example of something new you have learned in this course.
2. If there is anything you find muddy/confusing and which you would like more help with/clarification on, please describe it here, explaining why it is confusing.
3. Any other comments.

Several of the threshold concepts identified by the final year student through analysis of the above are presented in the Integrated Engineering Foundation Threshold Concept Inventory and are acknowledged as having been identified by David Parkinson.

Integrating phase

The integrating and diverging phases continued over most of the two years of the project. Throughout, the inventory of threshold concepts was developed iteratively based on analysis of data collected. While the diverging phase involved collecting data from participants in one discipline at a time, the integrating phase involved collecting data from participants from multiple disciplines and/or multiple universities. As noted above, in the diverging phase potential threshold concepts were identified, and in the integrating phase potential threshold concepts were negotiated, and overarching, underlying, or other potential threshold concepts were identified. The integrating phase consisted of workshops with various groups of diverse participants.

Features of a successful workshop

Sixteen workshops were held in this project and related collaborations. Below are some pointers identified from the workshop experiences.

Facilitators

Workshops involve plenary and group discussions. In this project, every workshop was held by at least two, and preferably more, well-prepared facilitators. The team of facilitators for any workshop encompassed members who could take the following roles: workshop lead, a lead for the introduction on threshold concept theory, and disciplinary experts to facilitate conversations about potential threshold concepts. Most facilitators had extensive experience teaching in engineering. All facilitators were deeply familiar with threshold concept theory and the project, and all facilitators clearly understood their roles.
With sufficient workshop facilitators everything usually happened as planned, such as data collection and planned conversations. Without sufficient workshop facilitators, it would be more difficult to keep the pace, address all questions, ensure that all groups stay on track, ensure that all data collection takes place, and deal with any unforeseen issues.

In addition to the workshop facilitator roles noted above, a group facilitator was nominated at each table—either one of the workshop facilitators, or a participant facilitator. This was critical to ensuring that everyone contributed in group discussions, probing questions were asked, discussions remained focused on threshold concepts in engineering, rather than spending too long on the theory, and responses were recorded on handouts. Where possible, group facilitators were prepared before the workshop. For the regional workshop held in Perth, it was possible to prepare all facilitators beforehand, and participants recorded appreciation of the facilitators in their evaluations of the workshop. Not all workshop facilitators can be occupied as group facilitators. The workshop lead moved between groups to maintain awareness of ebb and flow and any common issues in conversations around the room and adjust the schedule in response.

The presence of well-prepared disciplinary facilitators as group facilitators where possible, was designed to enhance the discussions in groups they facilitated. This was achieved through their probing questions, respect among participants, and by establishing discussions in which members felt privileged to belong and held a desire to impress. Additionally, disciplinary facilitators were able to record accurate notes on technical concepts because they understood the conversations and terms.

**Data collection**

Group facilitators took notes or nominated another group member to do so. In many of the workshops, handouts were completed by participants. Recording groups’ comments on butchers’ paper or a whiteboard, when reporting in plenary after discussions, can be important for the participants. This occurred at all workshops, except one regional dissemination workshop and a participant at that workshop recommended it in the evaluations.

Audio recordings are a relatively reliable way to collect participants’ responses for analysis. It is difficult to record everything in notes while a conversation is under way. Audio recordings of group discussions in workshop settings often had poor signal-to-noise ratios, because not all participants in a group were close to the recorder and because conversation at surrounding tables was often animated. There is a trade-off between placing groups sufficiently close together for the plenary discussions and far apart for group discussions. It is important to remind group facilitators to turn off recording devices between discussions. Otherwise files can easily be over 100MB and unwieldy to listen to and upload for transcription.

Initially, analysis of participant responses in this project was undertaken by listening to sections of the audio recordings. It quickly became apparent that it is much faster to pay for transcription services and analyse the resulting transcriptions. Due to the sometimes poor quality of recordings, strong accents, and technical terms, it was essential to correct transcriptions. Facilitators helped with this process. Even with the audio recordings and transcriptions, notes written during interviews and workshops were critical.

**Venues**

All workshops were held in large rooms with level floors and café style tables and chairs. One of the pleasures of the regional workshops was experiencing different learning spaces in host universities. Computer monitors in tables can be obstacles to group discussions. A flat table is preferable. A visualiser on which everyone could see each group’s annotation on concept maps during the plenary discussions was handy, although not essential.
Planning for participant numbers

In this project all workshops were free to participants. Lunch was provided. Sometimes up to a third of registered participants did not attend. The project’s reference group members reported this problem in their projects involving workshops. Participants who registered but did not attend caused problems, not only for catering.

Registrations including the disciplines of participants were taken for all regional workshops. Before the workshop, groups were designed for diversity among the represented universities and links between represented disciplines. This was generally successful. However, occasionally a group had only two attending participants. On one occasion such a group was not combined with other groups and one participant explained in the evaluation questionnaire that this limited discussions. At workshops for participants from only one university, participants formed their own disciplinary groups.

Foundation team

The foundation teaching team consisted of ten academics from across the engineering faculty who held weekly meetings over ten months. This team identified short preliminary lists of potential threshold concepts in the planned curriculum. Most members had previously attended a workshop on threshold concepts facilitated by Jan Meyer.

Student workshop and student–staff workshop

Two interdisciplinary workshops were attended by students, the first with students only and the follow-up workshop with students and staff (Male, 2011; Male, MacNish et al., 2012).

Participant recruitment

Undergraduate students from across the engineering disciplines participated in the student workshop and a student–staff workshop. Students were recruited through the engineering student bodies. Thirteen students participated in the student workshop and seven of the same students with eight academics participated in the student–staff workshop a month later. Academics came from across the faculty and were recruited by an email invitation to all academics. Both workshops were 90 minutes long and included light lunch. Examples 4–7 below present the student workshop notes and the three handouts used.

Example 4: Student workshop notes

<table>
<thead>
<tr>
<th>Engineering Threshold Concepts: Student Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuesday September 14 2010, 12.00noon–1.30pm</td>
</tr>
<tr>
<td>Facilitator: two facilitators</td>
</tr>
<tr>
<td>Participants: 13 students</td>
</tr>
</tbody>
</table>

Procedure

The workshop was held in a level teaching room in the mechanical/civil engineering building. Lunch was provided.

1. Students were welcomed. Students read information sheets (which accompanied the workshop invitation) and signed the consent form.
2. Students started in a circle. The lead facilitator outlined the project and students introduced themselves by name, year and course. Students moved into groups by discipline.
3. Students identified threshold concepts individually using individual handout 1 (Example 5). Students identified one potential threshold concept per sticky note, and then worked in groups to group and identify similar concepts. Students described these and completed group handout 1 (Example 6).
4. Groups reported to the whole room—audio recorded.
5. Groups selected one or two thresholds to discuss in more detail, completing group handout 2 (Example 7).
6. Students reported to the whole room—audio recorded.

Example 5: Student workshop individual handout 1

Engineering Threshold Concepts: Students Workshop—Individual handout 1

The Faculty of Engineering, Computing and Mathematics at The University of Western Australia is using threshold concept theory to improve engineering education. Engineering threshold concepts are critical to progression in engineering, but difficult for many students. They open up new ways of thinking. They provide a transformed way of understanding, or interpreting, or viewing something without which the student cannot progress in engineering. However, the transformation to understanding is troublesome for many students and can be sudden but is protracted for many students (Meyer & Land, 2003). Students often mimic solutions before they understand a threshold concept (Cousin, 2006).

We wish to identify engineering threshold concepts, and to understand the transformation that occurs as a student comes to understand each of these, the barriers to understanding thresholds and how these can be overcome.

1. Your engineering discipline:

2. Combined degree? YES / NO
   
   a. If YES, with which? ARTS / COMMERCE / _____________

3. Some examples of thresholds you have experienced or noticed other students in your course experience:

4. Identify one example and provide a brief explanation of how it is transformative or opens up new ways of thinking.

5. Explain what you think makes the threshold concept difficult.

6. Explain how you developed your understanding of the threshold concept or helped another student to understand it.

7. Explain any suggestion you have for helping students to understand the threshold e.g. a particular learning experience, teaching method, or change to the course structure.

References

Notes: Blank lines have been removed for the guide.
Example 6: Student workshop group handout 1

Engineering Threshold Concepts: Student Workshop

Group handout 1: Identifying Threshold Concepts

Please sort the threshold concepts on the post-it notes into groups of the same or similar concepts. List the groups with examples below.

Please complete one of these sheets for each group of similar threshold concepts.

1. Engineering discipline(s) of people in your group:

2. Name of threshold concept:

3. Examples of similar concepts:

4. Concept is relevant engineering students in the disciplines: (circle all appropriate)
   mech / civil / environmental / electrical / chemical / mining / computing

5. Concept is learnt in the units:

Example 7: Student workshop group handout 2

Engineering Threshold Concepts: Student Workshop (and also used in the student–staff workshop)

Group handout 2: Threshold Concepts: transformation, barriers, improvements

The Faculty of Engineering, Computing and Mathematics at The University of Western Australia is using threshold concept theory to improve engineering education. Engineering threshold concepts are critical to progression in engineering, but difficult for many students. They open up new ways of thinking. They provide a transformed way of understanding, or interpreting, or viewing something without which the student cannot progress in engineering. However, the transformation to understanding is troublesome for many students and can be sudden but is protracted for many students (Meyer & Land, 2003). Students often mimic solutions before they understand a threshold concept (Cousin, 2006).

We wish to understand the transformation that occurs as a student comes to understand each threshold concept, the barriers to understanding thresholds, and how these can be overcome.

Consider one engineering threshold concept per sheet.

1. What is the engineering threshold concept?

2. How is the threshold concept transformative? (e.g. What is the change in thinking or perceiving that occurs as a student gains understanding of the threshold concept? Perhaps you can identify levels of understanding that a student undergoes while gaining understanding of the threshold concept.)

3. What makes the threshold concept difficult? (e.g. misconceptions, features of the concept and features of opportunities for developing understanding of the concept within the engineering course)
4. How could we reduce/remove barriers to help students understand the threshold concept?

References

Notes: Blank lines have been removed for the guide. This handout was used in the student workshop and the student–staff workshop.

After the student workshop, all potential threshold concepts were emailed to the student participants for confirmation and participants were invited to the student–staff workshop. Example 8 presents notes from the student–staff workshop. Findings are presented in two conference papers (Male, 2011; Male, MacNish et al., 2012).

Example 8: Student–staff workshop notes

**Engineering Thresholds: an approach to curriculum renewal**

**Student–Staff Workshop**

Tuesday October 12, 2010, 12.00noon – 1.30pm
Facilitator: Sally Male
Participants: 7 students, 8 academics (Table 1)

<table>
<thead>
<tr>
<th>School</th>
<th>Students</th>
<th>Academics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil and Resource Engineering</td>
<td>1 civil, 2 mining</td>
<td></td>
</tr>
<tr>
<td>Computer Science and Software Engineering</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Environmental Systems Engineering</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mathematics and Statistics</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mechanical and Chemical Engineering</td>
<td>3 mechanical</td>
<td>3</td>
</tr>
</tbody>
</table>

**Procedure**

The workshop was held in a single-level teaching room in the mechanical/civil engineering building. Lunch was provided.

1. All started in a circle. All welcomed. Participants introduced themselves by name and school or course and nominated any particular role in the development of new courses. The facilitator outlined threshold concepts and the purpose of the event and noted the previous student workshop at which students identified threshold concepts. The facilitator listed threshold concepts identified by students and academics to date (in the student workshop, the staff workshop previously facilitated by Caroline Baillie and Jan Meyer, and in interviews on solid mechanics), noting the similarity between those identified by staff and students.

2. As prepared by email (Friday October 8, 2010), students were invited to speak briefly about a threshold concept that they had identified in the previous workshop, focussing on features that were troublesome or barriers to overcoming the thresholds, how they or another managed to understand it, and any suggestions for helping students’ understanding of the concept. Academics also asked questions. The discussion on thresholds was recorded with consent.
3. Participants worked in small groups of one to three students with one to three academics, to discuss a particular threshold concept already raised. Each group completed a handout on the threshold concept (Example 7).

4. Participants returned to the circle and reported on group discussions (recorded with consent). Cara MacNish, Deputy Dean Academic, briefly summarised key suggestions.

5. Participants completed and returned evaluations before leaving.

Workshops at the University of Oxford and the University of Birmingham

A workshop was held early in this project at the Universities of Oxford and Birmingham in England, and Lund University in Sweden. Later, dissemination workshops for the collaborations were also held at the Universities of Oxford and Birmingham. The early workshops could be of interest to readers because they assumed no previous knowledge of threshold concepts and could be a valuable starting point for some readers to introduce the threshold concepts approach at their universities. Participants included postgraduate students and academics. Threshold concept theory was introduced and participants completed the handout shown in Example 9.

Example 9: Handout for workshop introducing threshold concepts

Engineering Thresholds: an approach to curriculum renewal
Focusing engineering education on concepts that are critical to progression yet troublesome for many students

Threshold concepts are transformative and critical to students’ progress, yet troublesome for many students (Meyer & Land, 2003). By identifying and investigating engineering thresholds we can improve learning and teaching in engineering. People who have taught or studied engineering are critical to this approach as they often have valuable insights into threshold concepts within their area of experience.

Please complete the items below, identifying only one threshold concept per sheet.

1. Your institution:

2. Engineering discipline and specific area in which you have taught/studied and for which you will now consider the thresholds:

3. Please identify a threshold (troublesome, tricky and yet potentially transformational) that exists in your classes/subject areas. (Please be more specific than naming a topic.)

4. Why do you think this is a threshold? (Please describe evidence such as student feedback, assessment issues etc.)

Regional workshops

In this project, regional ‘knowledge-creation’ workshops were held in Perth, Adelaide and Melbourne in 2011. An additional regional knowledge-creation workshop was held in Auckland, New Zealand. These workshops were part of the integrating phase. Regional dissemination workshops were held in Brisbane, Sydney, and Darwin in 2012. The knowledge-creation workshops were part of the integrating phase in the approach to identification and investigation of threshold concepts. Readers might find that the procedure for the regional knowledge-creation workshops is valuable in other projects, as a step in which teachers from across departments meet together to negotiate potential threshold concepts, or when participants from multiple collaborating sites meet.

At the workshops, participants were introduced to the theory, the project, and some identified threshold concepts. Participants identified threshold concepts and then negotiated threshold concepts either already identified, or identified during the workshops. Participants also discussed ways to help students overcome threshold concepts. The workshops were four hours long, including lunch (Examples 10–12). Following the workshops, summaries of identified threshold concepts were posted to participants, either on the web discussion forum or directly by email for further comment.

Participant recruitment

Academics and postgraduate students who taught engineering and related disciplines (physics, mathematics, computing, and chemistry) and postgraduate students who taught engineering, attended the workshops. Participant numbers ranged from 12 to more than 40 at one workshop. Participants were recruited by email invitation through the deans or associate deans (teaching and learning) at each host university and the universities in each region. The workshops were also promoted in electronic newsletters of the Australasian Association for Engineering Education Conferences and the Higher Education Research and Development Society of Australasia.

Example 10: Regional workshop plan

<table>
<thead>
<tr>
<th>Engineering Thresholds Knowledge-Creation Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 July 2011, University of Melbourne</td>
</tr>
<tr>
<td>Facilitators: Sally Male, Cara MacNish, Jeremy Leggoe</td>
</tr>
</tbody>
</table>

**Workshop Agenda**

**10.00–10.10am Participants Arrive and Settle (10 minutes)**

Participants arrive, tick registration sheet, are given nametags and booklets and invited to help themselves to tea/coffee, and directed to tables.

**10.10–10.45am Introduction (35 minutes)**

- Lead facilitator introduces facilitators and purpose of the workshop: for participants, the project, and theoretical development.
- Overview of threshold concepts: compulsory features, liminal space, common features, types of troublesome concepts, can be capabilities rather than concepts.
- Overview of method.
- Consent forms *(Not earlier, and not in the booklet, because explanation is required. Must be collected immediately to avoid clutter.)*

**10.45am–12.00noon Threshold Identification and Negotiation (1 hour, 15 minutes)**

- Lead facilitator announce what participants are about to do and why.
- **Exercise 1 in booklet: Identification of Thresholds — audio recorded** *(1 hour to 11.45am)*
- *(Participants can negotiate thresholds identified at UWA or identify/negotiate new ones)*
• Lead facilitator announce what participants just did and why.
• **Feedback from groups to room** *(15 minutes to 12.00noon – 3 minutes per table. Notes taken by a disciplinary facilitator on butchers’ paper.)*

**12.00noon–12.30pm Lunch Break**
*(Facilitators ensure audio recorders are off, post butchers’ paper summaries around the room for discussion during lunch, photograph completed handouts in order for participants and researchers to keep a copy.)*

**12.35–1.35pm Engineering Thresholds: An Approach to Curriculum Renewal (1 hour)**
• Lead facilitator: How to help students overcome thresholds: curriculum structure, teaching, assessment, capability theory, variation theory *(15 minutes to 12.50pm).*
• Lead facilitator announce what participants are about to do and why.
• **Exercise 2 in booklet: Helping Students Overcome Thresholds – audio recorded** *(45 minutes to 1.35pm)*
• Lead facilitator announces what participants just did and why.

**1.35–1.50pm Group Feedback to Room (15 minutes – 3 minutes per table)**
Lead facilitator invites people to share overarching summaries, achievements and tools and ideas they will take away.

**1.50–2.00pm Close**
• Evaluation forms
• Photograph completed handouts
• Note web discussion forum
• Thank everyone for coming: participants, Roger Hadgraft and University of Melbourne

---

**Example 11: Regional workshop group exercise**

Group Exercise 1. Identification and Negotiation of Threshold Concepts

*(Identify and negotiate new potential threshold concepts and/or negotiate potential threshold concepts previously identified.)*

1. Your institutions:
2. Engineering disciplines and specific areas in which you have taught/studied:
3. Please identify a threshold (troublesome, tricky and yet potentially transformational) that exists in your classes/subject areas. *(Please be more specific than naming a topic.)*
4. Why do you think this is a threshold? *(Please describe evidence such as student feedback, assessment issues etc.)*
5. Please identify a second threshold (troublesome, tricky and yet potentially transformational) that exists in your classes/subject areas. *(Please be more specific than naming a topic.)*
6. Why do you think this is a threshold? *(Please describe evidence such as student feedback, assessment issues etc.)*
7. Please identify a third threshold (troublesome, tricky and yet potentially transformational) that exists in your classes/subject areas. *(Please be more specific than naming a topic.)*
8. Why do you think this is a threshold? (*Please describe evidence such as student feedback, assessment issues etc.*)

Group Exercise 2. Helping Students Overcome Threshold Concepts

1. Your institutions:

2. Engineering disciplines and specific areas in which you have taught/studied:

3. Potential foundation engineering threshold you are discussing:

4. Do you have suggestions for helping students to overcome this threshold or type of threshold?

5. Another potential foundation engineering threshold you are discussing:

6. Do you have suggestions for helping students to overcome this threshold or type of threshold?

7. Another potential foundation engineering threshold you are discussing:

8. Do you have suggestions for helping students to overcome this threshold or type of threshold?

*Note: the two exercises were printed in a booklet for participants.*

**Evaluation**

All regional workshops and the final negotiation workshop, noted below, were evaluated by John Bowden, the project evaluator. The evaluator attended one knowledge-creation workshop and one dissemination workshop. He also designed the evaluation questionnaires (Example 12) and collated responses. Completed questionnaires were collected by a nominated person from the host university and posted to the evaluator. Reports were used to inform improvements to the workshops and to inform this guide. For example, participants at the Perth regional workshop reported too many handouts on the tables. Therefore, at later workshops, booklets rather than individual handouts were used.

**Example 12: Regional workshop evaluation questionnaire**

Engineering Thresholds Knowledge-Building Workshop

The University South Australia: 6 April 2011

**Evaluation and feedback:**

*The goal of the workshop series is to develop ‘an inventory of negotiated engineering thresholds’ through the following questions: What do engineering educators identify as possible thresholds? What makes (them) think these are thresholds? What are the troublesome features of the thresholds? How are the thresholds transformative for students? How can engineering educators help students to overcome the thresholds?*

(1) Please reflect on your way of seeing threshold concepts before the workshop, and write about any changes in your thinking as a result of the experience today.

(2) Please comment on any aspects of today’s activities that you found particularly difficult.

(3) Please write a few words about any aspects that you found easier to manage.*
Workshop to further negotiate threshold concepts

A final workshop was held at UWA. Participants were academics and postgraduate students who taught or had taught engineering and related disciplines. Academics were from engineering, physics, mathematics, computing, and chemistry. The purpose was to further negotiate the potential threshold concepts. A concern was that many identified potential threshold concepts were troublesome, but not necessarily transformative. Effectively, the participants filtered the previously identified potential threshold concepts by further negotiating whether students often experienced the concepts as having the compulsory transformative feature of threshold concepts, and the common feature of being integrative, which is closely linked to the transformative feature.

Participants formed groups around each of the four planned engineering foundation units: ‘Global Engineering Challenges’, ‘Materials’, ‘Motion’, and ‘Energy’. Each group was presented with a list of generic engineering threshold concepts, which would be developed in all foundation engineering units, and a list of threshold concepts that would be the main focus of one of the engineering foundation units.

Most participants were already familiar with threshold concept theory. As before, notes were recorded by hand and discussions were audio-recorded. Participants followed instructions (Example 13). Very little time was spent introducing the theory. The instructions included definitions for ‘transformative’ and ‘integrative’ features as negotiated by the project team and three visiting international engineering education researchers, two of whom had extensive experience using threshold concepts. Each group was facilitated by a well-prepared project team member.

Example 13: Instructions for participants in negotiation workshop to refine inventory

<table>
<thead>
<tr>
<th>Workshop to refine threshold concept inventories</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 December 2011</td>
</tr>
</tbody>
</table>

**Instructions to participants:**

Please review the provided list of threshold concepts. These have been identified as troublesome and transformative. Please debate whether you agree that they are transformative and integrative using the definitions below.

**Transformative Feature of Engineering Threshold Concepts**
Understanding a transformative concept involves a conceptual shift in our ways of thinking and understanding. A transformative engineering concept is so powerful and useful that there are classes of engineering problems that cannot be addressed without it.

**Integrative Feature of Engineering Threshold Concepts**
Integrative engineering concepts help to connect concepts in engineering that students might not
It would not have been wise to introduce definitions, such as those in Example 13, in earlier workshops attended by participants who mostly had no experience with threshold concepts. The concept of ‘transformation’ is complex. While a brief definition might be appealing as a way to increase reliability in participants’ responses, there is inevitable variation between participants’ understanding of definitions such as these, and hence the reliability is not as high as researchers and participants might imagine. Furthermore, by suggesting that strict definitions apply, the facilitators risked giving an impression to participants that there was one true list of threshold concepts. As previously discussed, this is not the case. A concept that is threshold to one student in a program might not be threshold to another student with a different background enrolled in the same program. Similarly, a concept that is experienced as a threshold by a student in one program might not be experienced as a threshold if the student had been taught the concept differently, or in a differently structured syllabus. Therefore, definitions such as those in the instructions above must be introduced with caution.

Presentation of threshold concepts

As discussed in the methodology, data were collected as handwritten notes, completed handouts and transcriptions of recorded discussions. These were analysed for evidence of transformative and troublesome concepts or capabilities, and an inventory of threshold concepts was developed iteratively, initially growing and then being reduced.

The identified threshold concept inventory should not be confused with key or core concept inventories (Concept Inventory Hub, 2011). Each item in the inventory is identified in a manner designed for readers with engineering backgrounds. Items also include any details about the concept under the following headings:

- **Transformative because...**
- **Troublesome features**
- **Suggestions** (for how engineering educators might help students understand the threshold concept)

Selected quotations from participants are included to retain participants’ meanings.

The inventory has a nested structure. The structure indicates how the threshold concepts are interrelated and have various levels of specificity. Understanding one threshold concept can depend on understanding another underlying threshold concept. For example, the items, ‘value of learning’ and ‘there are many different ways to learn and sources of information’, are listed under ‘self-driven learning’, because both items are required for self-driven learning. Additionally, one overarching threshold concept can manifest in various ways. For example, ‘system identification and definition’ includes ‘free body diagrams’, ‘shear force diagrams’, ‘bending moment diagrams’, ‘control volumes’, and ‘equivalent circuits’, as illustrated in Figure 1, Appendix A.

The inventory is in three sections: ‘Learning to become an engineer’, ‘Thinking and understanding like an engineer’, and ‘Shaping the world as an engineer’. The first section includes items that form a backdrop to the motivation and capability needed to develop the understanding and capability identified in the second section. Items in the third section are required to connect and mobilise the items in the first and second sections, in order to make a positive difference to the world as an engineer, through engineering practice including design and problem-solving.

This threshold concept inventory could be used directly by engineering educators to help them to focus teaching, learning, and assessment on concepts in an integrated engineering foundation. At a more specific level, engineering educators might spot items relevant to a
single unit or topic within a foundation program. Alternatively, the inventory could be adapted or used as an initial framework or springboard for research to identify threshold concepts and develop curriculum enhancements better suited to a different university context, or at higher levels of engineering programs.

The inventory is approximately 40 pages long. Threshold concept maps were drawn to complement the inventory (Appendix A). It is easier to see an overview of identified threshold concepts and some of their relationships in a concept map than in the inventory. Concept maps were created using CmapTools <cmap.ihmc.us>.

At a workshop on threshold concept methodology held at the Australasian Association for Engineering Education Conference 2011 by members of the UWA engineering threshold concepts project team, researchers discussed their methodologies. A participant noted that threshold concept maps are appealing as a tool but it is too difficult to clearly represent all of the relationships between concepts. This was also the experience at UWA. It is difficult to present all of the dependencies between concepts in a manageable map.

Towards the end of the project, when the maps were fairly comprehensive, they were used to present identified threshold concepts to participants for discussion in a focus group and the regional dissemination workshops. To completely understand the concept maps, people can look up details about concepts in the inventory.

Others have used concept maps in different ways in engineering threshold concept research. UWA’s collaborators in Oxford and Birmingham used concept maps to assist with their analysis and to present findings. These researchers also created concept maps to analyse academics’ descriptions of development of understanding in students.
4. Identified Threshold Concepts

In this project, threshold concepts relevant to an integrated foundation engineering threshold program were identified. The inventory is presented separately (Male, 2012). As noted above, threshold concepts in the inventory are presented in conceptual clusters. This includes threshold concepts or capabilities for: ‘Learning to become an engineer’, ‘Thinking and understanding like an engineer’, and ‘Shaping the world as an engineer’. The most integrative threshold concepts are presented in a concept map in Appendix A. Here ‘integrative’ is used to mean connecting all disciplines of engineering.

Threshold capability theory is likely to prove more useful than threshold concept theory. Many of the threshold concepts identified, even if they were identified as concepts, open up capability rather than simple understanding of a concept. For example ‘sustainability’ is a threshold concept identified in this project. Perkins (2006, p.41) refers to some concepts as ‘double trouble’, because they are transformative due to the ‘activity systems’ they open, as well as their categorical value. ‘Threshold capability’ is a more suitable term than ‘threshold concept’ for these items. Below is an excerpt relating to sustainability, located in the Integrated Engineering Foundation Threshold Concept Inventory.

Example 14: Item in the threshold concept inventory

<table>
<thead>
<tr>
<th>Sustainability: the viability for an activity to be continued for ever, or the long-term viability of an activity such that needs of future generations are not compromised</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transformative because required for:</strong></td>
</tr>
<tr>
<td>• building sustainability into designs and solutions</td>
</tr>
<tr>
<td><strong>Troublesome features:</strong></td>
</tr>
<tr>
<td>• vague</td>
</tr>
<tr>
<td>• ‘sustainability’ can have multiple meanings</td>
</tr>
<tr>
<td>• complicated</td>
</tr>
<tr>
<td>• influenced by and requires understanding of culture</td>
</tr>
<tr>
<td>• students understand the idea but have difficulty using it</td>
</tr>
<tr>
<td>• requires students to think about topics that engineering students might rather avoid e.g. spirituality, love, social context</td>
</tr>
<tr>
<td>• revisiting the concept of sustainability when students think they already know about it from school</td>
</tr>
<tr>
<td>• thinking more critically and broadly than students have learnt to think of sustainability at school</td>
</tr>
<tr>
<td>• integrating the concept of sustainability with engineering</td>
</tr>
<tr>
<td>• relevance of sustainability to engineering</td>
</tr>
<tr>
<td>• considering social, environmental and other aspects of the context</td>
</tr>
<tr>
<td>• waste</td>
</tr>
<tr>
<td><strong>Suggestions:</strong></td>
</tr>
<tr>
<td>• Ask student to consider planetary boundaries in solutions to problems.</td>
</tr>
<tr>
<td>• Using the systems, accounting, and modeling approach (Richards, 2002), every system interacts with its surroundings, and thus this approach emphasises how a system and its environment are related.</td>
</tr>
</tbody>
</table>
5. Curriculum Development

Having identified engineering threshold concepts and how they are transformative, it is possible to consider aspects of curriculum that can be improved to help students experience the transformation associated with developing understanding of a threshold concept, or developing a threshold capability. Curriculum developments that can be considered include:

- designing lesson and course plans to focus teaching and learning on threshold concepts
- drawing teachers’ and students’ attention to threshold concepts
- designing learning experiences to help students experience transformation
- assessing the transformative aspects of learning, rather than students’ ability to emulate understanding.

The Integrated Engineering Foundation Threshold Concept Inventory lists findings from this project, and it is intended that the inventory will be read with this guide. The inventory includes many suggestions for developing curricula to help students overcome thresholds. Academics suggested strategies they have found effective. Students suggested strategies based on their experiences of barriers to learning.

Awareness of learning theory, past engineering curriculum developments, and literature on engineering education, can help to inform responses to the research findings. For example, some of the sources of troublesome knowledge identified in this project have been previously identified as issues relevant to female engineering students and previous recommendations for gender-inclusive curriculum development address the same or similar issues (Male, 2011).

Syllabus

The structure of a program and of units within a program can be designed to ensure that students have sufficient opportunity to pass through the liminal space for each threshold concept. Threshold concepts should be well-separated, with no more than one per week in any unit. Especially tricky threshold concepts should be revisited and further developed throughout a course. Concepts that are not troublesome can be learnt by students outside lesson time. Threshold concepts not usually taught, perhaps because they are tacit, can be included in the curriculum.

Engineering curriculum designers should consider how the effect of the order in which threshold concepts are first introduced to students affects the pre-liminal space. Within the threshold concept theoretical framework, the pre-liminal space—which is influenced by a student’s capabilities before a threshold concept first comes into view—can influence a student’s passage through the liminal space. Students suggested that, when teaching programming, educators should take into account different levels of computing experience.

Students made several practical suggestions during the research (Male, 2011; Male, MacNish et al., 2012). They suggested that threshold concepts in computer programming should not be confounded with threshold concepts in engineering, for example, through assignments in which students are expected to apply new engineering concepts with new programming concepts. This is a request not to cluster threshold concepts unnecessarily. Additionally, students suggested that they would like to be aware of engineering applications when concepts are introduced in mathematics. This is also supported by threshold concept theory, as the suggestion would reduce the inert nature of the concepts.
Threshold concepts can be identified as such so that teachers and students know to give them extra attention. Example 15 is a summary of the main threshold concepts in the UWA engineering foundation unit ‘Motion’. This summary is in the readers for students in the unit and is also used in the training sessions for teachers in the unit.

Example 15: Example of extract from a unit reader—identifying threshold concepts

Excerpt from reader for the unit ‘Motion’
Kindly provided by Andrew Guzzomi and Dianne Hesterman

Threshold Concepts: (www.ecm.uwa.edu.au/engineeringthresholds)

Threshold concepts are concepts that are recognised as being troublesome; you will find them, as we did, challenging and difficult to understand. You will need to be persistent in your pursuit of this understanding. However, you will gain great satisfaction when ‘it clicks’ and you arrive on ‘the-other-side’ of the hurdle. Threshold concepts are transformative. Understanding a threshold concept involves a conceptual shift in your way of thinking about the world and how it works. They are also integrative. You will see how different areas of knowledge and experience fit together. In engineering, a threshold concept can be so powerful that complete classes of problems cannot be attempted without first passing through the threshold.

Concepts that may be threshold in this unit include*:

- Modelling and abstraction
  - System identification and definition—converting a physical system into a mathematical model. This includes the idea of free body diagrams and control volumes. System identification and definition fall under the more general threshold concepts of abstraction and modelling.
  - Thevenin’s equivalent for electrical systems—using a simplified model to represent a complex electrical circuit. We can extend this idea beyond electrical circuits.
  - Temporal and spatial frames of reference—choosing an appropriate time scale and form of equation to capture the necessary information about a system’s behaviour. Temporal and spatial frames of reference also form part of the modelling tool kit.
  - Vectors and vector calculus—using a multidimensional mathematical construct to represent a number of system properties in a single variable. For example, velocity \( \mathbf{v} \) is a vector that combines magnitude and direction.
  - Dimensional reasoning—using the idea that equations are dimensionally homogeneous to derive relationships in complex systems. This technique can yield great insight into the system when the underlying equations are too complex to solve.

- The conservation laws—nothing is lost. Which properties are conserved and why? We can use this understanding to solve a wide variety of engineering problems.

The above threshold concepts will be acquired within a threshold framework that includes:

- Self-driven learning—understanding the value of learning and realising that there are different ways to learn and from different sources (textbooks, online resources etc.).
- Teamwork—teams can achieve more than the sum of the individuals working alone (by leveraging the diverse knowledge and capabilities of members, inspiring each other, developing together and sharing tasks).
- Communication—two-way, effective communication in many forms is critical to engineering practice. Engineers spend much of their time working with others and coordinating the work of people over whom they might have no direct authority.

*You may identify others. Please let us know!
Curriculum features should be designed to encourage students to engage with concepts frequently over an extended period to allow sufficient time to pass through the liminal space, rather than trying to learn concepts quickly before a final assessment. Formative assessments during semester and active learning are potentially beneficial curriculum features.

**Pedagogy**

Threshold concept theory alone does not prescribe a pedagogy. The main purpose of the threshold concept approach to curriculum development is to focus teaching and learning on the most transformative and troublesome concepts, because these are the concepts that are critical to students’ progress and where students are likely to meet barriers.

Having identified concepts to which teachers and students should pay special attention, numerous pedagogies might be appropriate. As noted in Chapter 1. Introduction, active and hands-on learning, problem-based learning and the CDIO curriculum could be used with the threshold concept approach to curriculum development.

Findings about how each identified threshold concept is transformative and can be troublesome can inform how to teach the concept. Perkins (1999) describes approaches for each type of troublesome knowledge. When threshold concepts and their troublesome aspects are identified, many experienced engineering educators are likely to be able to develop suitable initiatives to give students learning experiences that help them overcome thresholds.

Many suggestions regarding pedagogy, provided by academics and students, are identified in the **Integrated Engineering Foundation Threshold Concept Inventory**. For example, students suggested refraining from mathematical representations until after explaining or demonstrating engineering concepts. This is supported by the theory, because it is likely to reduce the inert nature of the engineering concepts.

Engineering academics at a workshop explained their success in teaching the concept that engineering is more than technical, by using electrical plugs for the end of power cables. Students connected plugs and tested them using meters to find that they performed as they hoped. However, when they checked the standards they found that their plugs did not meet the standards because they were not safe. This is supported by threshold concept theory. The concept that engineering is more than technical is inconsistent with students’ ‘common knowledge’ about engineering. An inconsistency between the students’ previous understanding and their experience forces them to either respond defensively or reflectively such that a new understanding can form (Schwartzman, 2010).

As discussed in Chapter 1. Introduction, variation theory complements threshold concept theory by describing a way that students can learn. In variation theory, Bowden and Marton (1998) describe how students can learn by experiencing variation in critical aspects of a concept. This has been adapted to threshold concepts (Akerlind, McKenzie, & Lupton, 2010; Booth, 2004). Variation can take one of three types.

First, students can develop understanding of a threshold concept through opportunities to experience structured variation in critical features of the concept. The variation might be around the features that make the concept transformative, troublesome, integrative, or discursive. The variation must be structured. For example, for students to understand the concept of the colour blue (if they had no prior understanding), they could experience a series of blue objects of different shapes, a series of objects of the same shape and size but different colours, and a series of objects the same shape and size, but different shades of blue. In each case they would need to experience the variation by comparing and contrasting within the series.
Without this structure, the critical aspect of a concept can be confused by students. For example, a UWA student learning about calculating the voltage across a resistor in series with a second resistor (i.e. in a voltage divider) saw two examples with the voltage calculated across the smallest resistor in each case. The student then assumed that to calculate the voltage across a resistor in a voltage divider, the value of the smallest resistor forms the numerator. Carefully structured variation in the examples can overcome confusion such as this.

Second, students can learn through experiencing variation in ways to approach a problem. For example, students reducing a complex circuit to a simpler equivalent circuit, or explaining how an output will change when an input is changed, might approach the problem in any one of several acceptable ways. Students can be asked to consider the problem individually, in groups and then explain solutions to the class, with students then invited to compare and contrast the solutions. In this way, students experience variation in approaches and validation of approaches they might have been considering. The threshold concept, ‘system identification’, lends itself well to this learning activity. One of the troublesome aspects of system identification is understanding that there are multiple systems that could be identified and engineers must identify the system most convenient for solving the problem at hand, rather than any one correct system.

Third, students can learn from variation in the manifestation of a concept or a capability in various contexts. This will help students develop capability for unknown circumstances, as described in the threshold capability framework for higher education. For example, the threshold capability of system identification could be applied to draw a free body diagram and also to identify a control volume. Alternatively, the threshold capability of ‘modelling’, and examples of modelling that are also threshold concepts, could be developed through experiencing limitations and power of:

- micro and macro models of materials and structures
- time-domain and frequency-domain models for circuits
- the principle of conservation applied to mass, charge, and energy (Richards, 2002)
- relationships between electromagnetic theory and circuit analysis techniques (Black, 2012; Cantoni & Budrikis, 2008).

Through interaction such as debating, explaining, and sketching, students can experience variation in features of a concept, manifestation of the concept in a variety of contexts, and possible approaches to understanding or applying the concept among students. Students must experience the variation. This can be encouraged through an activity in which they compare and contrast examples with variation. Students can discuss possible answers to questions in small groups, present group responses to the class, and then compare and contrast responses. Physically experiencing the variation through a practical experience is also helpful, although not essential. In the new engineering foundation units at UWA, lectures have been replaced with interactive tutorials, both theoretical and practical. These classes are held in a level room with only approximately 20 to 30 students per class.

Assessment

Students can often pass units and courses without understanding critical concepts. While in the liminal space, students frequently mimic understanding by following solutions to solve problems. In capability theory, Bowden and Marton (1998) proposed that students should develop knowledge capability in order to draw on past experiences in unknown futures. A student in the liminal space, with capability only to mimic understanding, does not have sufficiently sophisticated understanding to address unknown problems. Assessments must be designed to encourage and collect evidence of transformation in students. Therefore, assessments should be designed to collect evidence of the thinking or understanding that is opened up for students when they have overcome the threshold.

Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts
Assessments in which students can pass by substituting values into equations using memorised steps are not sufficient. One way to enhance assessments is to add a requirement for students to explain or justify a solution. For example, to collect evidence that students understand a critical feature of modelling, students could be asked to identify and justify assumptions made. To collect evidence that students understand a critical feature of system identification, students could be asked to identify more than one system, then select one and explain how they consider it to be most convenient. To collect evidence that students understand the relationship between physical systems and graphical representations, students can be asked, for example, to compare oscilloscope outputs and indicate which represents a higher frequency, or whether frequency increased or decreased.

Students can also be asked to solve problems with no values. For example, Jonathan Scott (University of Waikato, New Zealand) demonstrated at the workshop at the Australasian Association for Engineering Education Conference that to collect evidence of holistic circuit analysis, students could be asked to estimate the change in brightness of a light bulb as increased or decreased when a resistor is added elsewhere in a circuit. Students could be asked to estimate whether voltage or current would increase or decrease when a component is added or removed or doubled in value. At a workshop in Sydney, held as part of this project, participants demonstrated another circuit used to test for holistic circuit analysis. Students were asked to identify the voltage across and current in an open circuit connected to a closed circuit.

Academics at one of the regional workshops held as part of this project raised the concern that open questions, such as requests for explanations or justifications, can be too time-consuming to mark in units with large numbers of students. Participants at different universities and within different departments of the same university reported various levels of support for marking. Some unit coordinators are responsible for all of the marking in their units. Others have resources to pay tutors and demonstrators to assist with marking. An efficient and reliable system was described by tutors in one of the focus groups at UWA. The tutors and unit coordinator marked the examination scripts in a single room. Each tutor marked one question on all papers. The unit coordinator and tutors decided on rules for how various types of unexpected mistakes were marked as they arose.

**Teachers**

At UWA, teachers of integrated foundation engineering units were trained over two days. They were presented with the threshold concepts in the units they taught, so that they understood the importance of focusing on these concepts, and of addressing troublesome features of the concepts. The teachers were trained in facilitating active learning and using variation theory to help, rather than accidentally confuse students.

The threshold concepts labelled as those required to learn to become an engineer include:

- self-driven learning
- confidence in ability to become an engineer
- the variety of ways to learn
- engineering as more than technical
- teamwork (including several more specific threshold concepts)
- communication (which also includes several more specific threshold concepts).

Concepts and capabilities such as these are developed by students as they develop the other threshold concepts, such as those required to think and understand like an engineer, including modelling and abstraction, and system identification. Teachers must be aware that their role includes guiding students to develop not only the capability to think and understand like an engineer, but also the capabilities required to learn to become an
engineer. Poor teaching practices could incidentally undermine students’ development of threshold capabilities that support learning to become an engineer. Practices to be avoided include humiliating students in front of their peers, describing the engineering profession in a non-inclusive manner, or suggesting that visualisation skills are innate rather than improved with practice.
6. Reflections and Future Research

Working with the curriculum development team

A threshold concept approach has been found to be a successful way for higher education researchers to engage disciplinary researchers in curriculum development (Cousin, 2010). Cousin observed that a threshold concept approach to curriculum development is more appealing to disciplinary teachers than other curriculum development approaches. This is because the approach focuses more on the discipline, which is familiar to disciplinary academics. This was our experience at UWA. However, features of the UWA approach were designed to address predictable initial issues. Three challenges are identified below.

The first challenge was resistance to using research as part of curriculum development. Initially some members of the curriculum development team were sceptical about undertaking research to inform curriculum development instead of taking a well-tested approach. Academics in the engineering faculty requested evidence of the credibility regarding the approach to curriculum development. In particular, they requested evidence that universities similar to UWA had successfully used this approach. Fortunately, Flanagan’s (2011) bibliography, hosted by University College London, provided evidence of research in engineering fields. However, the methods used to identify and investigate threshold concepts had been diverse and the curriculum development at UWA was the first to identify threshold concepts across an integrated engineering foundation.

The second challenge arose from fear that identified learning outcomes might be removed from the curriculum as a result of the threshold concept approach. As outlined in the Background section in Chapter 1. Introduction, many academics had worked on the initial curriculum development team to identify three big ideas and clusters of learning outcomes. One academic expressed concern that the research to identify and investigate threshold concepts would ‘trump’ the earlier curriculum development. However, learning outcomes were not removed in response to the research on threshold concepts. The threshold concept research complemented the earlier stages of curriculum development. The purpose of the threshold concept research was to identify the concepts that teachers and students must focus on, especially in class, to help students meet the required learning outcomes.

The third challenge was that threshold concept theory was initially unfamiliar to faculty members. Academics at more than one of the regional workshops declared that threshold concept theory was a threshold concept for them. As noted above, threshold concept theory was introduced to participants at the beginning of interviews, focus groups, and workshops. As participants in the research, many academics in the engineering faculty developed understanding of and capability with threshold concept theory.

It is now over two years since the first workshop on threshold concepts in the engineering faculty at UWA. At a meeting to discuss sharing of units between engineering disciplines in the third year of the engineering science major, academics outside the project team used threshold concept theory to help make and justify decisions.

Despite the challenges, for several academics the philosophy behind threshold concept theory was not foreign. In the interviews with academics, there were occasions when a participant described an approach that mapped directly to threshold concept theory. For example, one academic described how at the start of semester he identified for students the concepts that they must have understood from their previous units to be ready to embark on his unit. He set a test worth no marks and suggested resources and offered assistance to help students with concepts they could not apply correctly in the test. Similarly, he identified the most difficult and crucial concepts in his unit that students must ensure they came to understand during semester. On occasions when academics’ practices had similarities to a threshold concept approach, the interviewer noted that it was as if the academic was already using threshold concept theory without being aware of it. In these
cases the theory legitimised their approaches, and during the threshold concept study researchers also recorded the insights of experienced teachers who participated, and presented these insights for future teachers.

The threshold concept approach has engaged students and teachers in curriculum development. Additionally, the approach has initiated conversations between teachers and between teachers and students. Workshops and focus groups with students proved a successful way to engage students in discussion about the curriculum, gaining students’ unique and valuable perspectives (Male, MacNish et al., 2012). By engaging participants from across disciplines, threshold concepts that integrate the disciplines were identified (Male, Guzzomi et al., 2012).

Incidental curriculum improvements have arisen from the discussions. For example, two academics teaching Mohr’s Circle in different years of the program discovered they were unwittingly using different coordinate systems. The third-year teacher had students indicating they had not seen the representation he drew, although students had apparently been taught to use Mohr’s Circle in second year. This is an example of how the threshold concept approach to curriculum development initiated discussions in which academics identified simple curriculum changes that could help students to learn.

Building a research team

As Cousin (2010) noted, the threshold concept approach proved accessible to engineering academics because it focused on their teaching experience. As illustrated above, some academics were already thinking about their teaching in a manner similar to threshold concepts thinking, although without threshold concept terminology.

At UWA, in this project, a final year engineering student identified threshold concepts in one of the foundation engineering units. A PhD student is investigating threshold concepts in engineering for social justice. Two academics who taught engineering at higher levels adapted the threshold concept approach to investigate threshold concepts in their units. One created a final year student project investigating threshold concepts in fluids and the other academic undertook research on threshold concepts in control systems.

Nationally and internationally, this project received extensive interest. Engineering academics from New Zealand, England, South Africa, Sweden, Denmark, and Singapore expressed interest in and engaged with the project at various levels. Workshops were held in Sweden, England, and New Zealand. Engineering academics at the Universities of Oxford and Birmingham adapted the approach and compared methodologies and findings (Quinlan et al., 2012).

Sustaining the curriculum development

Sustaining a carefully developed curriculum change can be difficult (De Graaf & Kolmos, 2007). Short-term evidence of success can be limited by initial teething problems and scepticism about change. Next, teachers who are new to units and have not been involved in the curriculum development might revert to old practices.

Schwartzman (2010) found that students respond to inconsistency between their understanding of the world and a new experience in either a reflective or a defensive way. In both cases the experience is accompanied by anxiety. Consequently, students enrolled in a unit designed to focus on threshold concepts are likely to be uncomfortable. Student ratings of the unit might be low due to discomfort as they experience transformation. Data collected for program evaluation must be interpreted carefully.
Evaluation can be useful as a way to collect evidence for continuing with a new curriculum (Cousin, 2009). Akerlind et al. (2010), who developed learning activities that used variation theory to help students overcome threshold concepts in three disciplines, found that evaluation was difficult. In second semester 2012, the UWA engineering faculty is now investigating students’ development of identified threshold concepts in two of the engineering foundation units, using an adapted phenomenographic approach. A researcher, who was not involved in the curriculum development, is observing classes and interviewing students. Responses will be pooled and analysed to identify levels of understanding and investigate students’ perceptions of how various learning activities either helped them to develop understanding or confused them. Additionally, in first semester 2012, students in all units completed questionnaires to investigate the extent to which the students were encouraged to adopt deep approaches to learning in the units.

Further research would be helpful for curriculum evaluation, such as investigating indicators of levels of development of the identified threshold concepts, and developing an instrument to measure these.

Curriculum development for ever?

Curriculum development is never finished. Required learning outcomes, students’ backgrounds, teachers’ backgrounds, resources, and regulations change. With all these factors, the concepts experienced as ‘threshold’ by many students in a program will change. Additionally, by helping students to overcome a threshold, it is possible that educators might create a new threshold. Therefore, a ‘curriculum for ever’ cannot be developed. Instead, the cycle of curriculum development must continue.
7. Resources

Literature

An Integrated Engineering Foundation Threshold Concept Inventory was prepared as an outcome of the project. This is available on UWA’s engineering thresholds website <ecm.uwa.edu.au/engineeringthresholds>. The website also lists all publications from the project ‘Engineering thresholds: an approach to curriculum renewal’ and other publications on threshold concepts by members of the project team.

A comprehensive threshold concepts bibliography is maintained by Michael Flanagan at University College London (Flanagan, 2011). This is an excellent resource for finding introductory and generic literature on threshold concepts. It is also an excellent resource for identifying literature on threshold concepts in a specific field.

For papers on threshold concept theory, how others have identified and investigated threshold concepts, and how people have used these to improve curricula, the three edited books containing papers from the first three Biennial Threshold Concepts Symposia are most valuable (Land, Meyer, & Baillie, 2010; Land, Meyer, & Smith, 2008; Meyer & Land, 2006). A fourth symposium was held in June 2012, in Dublin.

Web discussion forum

The project website <ecm.uwa.edu.au/engineeringthresholds> includes a web discussion forum. Everyone can join the forum and the discussions. Users must first create a username and password and wait for membership to be approved. Position title and organisation are requested, in order to filter spammers. Updates on publications and events also are posted on the forum.

Collaborators

The project website <ecm.uwa.edu.au/engineeringthresholds> includes a list of contact details for people with a research interest in engineering threshold concepts. Researchers are listed by engineering field.
References


Appendix A. Most Integrative Engineering Foundation Threshold Concepts

Figure 1 presents the most integrative engineering foundation threshold concepts in a concept map.

Legend

Grey: threshold concepts for learning to become an engineer

Pale blue: threshold concepts for thinking and understanding like an engineer

Yellow: threshold concepts for shaping the world as an engineer

Figure 1: Concept map of most integrative engineering foundation threshold concepts