Engineering Thresholds: an Approach to Curriculum Renewal

Final Report 2012

The University of Western Australia

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<ecm.uwa.edu.au/engineeringthresholds>
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List of Acronyms Used

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AAEE</td>
<td>Australasian Association for Engineering Education</td>
</tr>
<tr>
<td>ACED</td>
<td>Australian Council of Engineering Deans</td>
</tr>
<tr>
<td>ALTC</td>
<td>Australian Learning &amp; Teaching Council Ltd.</td>
</tr>
<tr>
<td>HERDSA</td>
<td>Higher Education Research and Development Society of Australasia</td>
</tr>
<tr>
<td>OLT</td>
<td>Australian Government Office for Learning and Teaching</td>
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<td>UWA</td>
<td>The University of Western Australia</td>
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Executive Summary

In threshold concept theory, Jan Meyer, Ray Land and others realised that many disciplines contained certain concepts, known as ‘threshold concepts’, that were considered central, opened up required ways of thinking and understanding for many students, and yet were troublesome for many students (Meyer & Land, 2003). It has been discovered that identifying threshold concepts can help in designing curricula in which students and teachers focus their attention. This is a powerful curriculum development approach where there is a tendency to overcrowd a curriculum (Cousin, 2006, 2010; Land, Meyer, & Baillie, 2010; Land, Meyer, & Smith, 2008; Meyer, Land, & Baillie, 2010).

During this project, engineering educators at The University of Western Australia (UWA) developed an entirely new engineering curriculum (Trevelyan, Baillie, MacNish, & Fernando, 2010). A threshold concept framework was used in the development of this 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 other aspects such as learning spaces, faculty culture, and student clubs.

The project achieved the outcomes listed below:

1. Engineering Science major foundation at UWA based on sound pedagogical principles, which can act as a model for other institutions and disciplines.
2. Inventory of threshold concepts and ways of thinking within core engineering introductory courses.
3. A guide for engineering lecturers and curriculum developers on curriculum renewal using threshold concepts.
4. A dedicated website, ‘Engineering Thresholds’, including a web discussion forum, where the inventory and guide are easily accessible <ecm.uwa.edu.au/engineeringthresholds>.
5. Three regional ‘knowledge-creation’ workshops to identify thresholds in Perth, Adelaide, and Melbourne and three to disseminate the findings and gain feedback in Brisbane, Sydney, and Darwin.

The inventory includes not only threshold concepts, but also threshold capabilities, with items listed under the headings ‘threshold concepts for learning to become an engineer’, ‘threshold concepts for thinking and understanding like an engineer’, and ‘threshold concepts for shaping the world as an engineer’. Each item in the inventory includes how the concept or capability can be ‘transformative’ and ‘troublesome’ for many students and offers suggestions for helping students overcome the thresholds.

The guide provides a description of the methodology for identifying and investigating threshold concepts by engaging students and academics in identifying potential threshold concepts and negotiating these identified potential threshold concepts. The guide also describes how a curriculum might be informed by the inventory developed using this methodology.
The threshold concept approach has the advantage of identifying thresholds that can otherwise easily be overlooked in a curriculum design, including concepts that integrate the engineering disciplines, and tacit concepts such as relating mathematical representations to systems.

The approach is designed to help students and teachers focus on the concepts that are most critical to students’ progress and yet require extra attention due to their troublesome features. By identifying the transformative and troublesome features, it was possible to design experiences to give students opportunities to overcome the troublesome features and also to design assessments to collect evidence of students’ transformation.

This approach to curriculum renewal by identifying threshold concepts could be used by university educators as one aspect of the development of a new curriculum; it could also be adapted to renew a curriculum, or to develop or renew a unit or a topic within a curriculum.
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Chapter 1. Project Outcomes and Impact

In this project, the engineering foundation curriculum at UWA was developed using a threshold concept theoretical framework. The theory, motivation, and contribution to knowledge are introduced before the approach and outcomes.

Background and how the project uses and advances existing knowledge

Threshold concept theory

Threshold concept theory originated from a multi-disciplinary project in the United Kingdom on learning. Jan Meyer, Ray Land and others developed threshold concept theory when they realised that in many disciplines there were certain concepts, known as ‘threshold concepts’, that were considered central, opened up required ways of thinking and understanding for many students, and yet were troublesome for many students (Meyer & Land, 2003). Since then, much research has been focused on identifying these thresholds (Cousin, 2006, 2010; Land et al., 2010; Land et al., 2008; Meyer et al., 2010). It has been discovered that identifying threshold concepts can help in designing curricula in which students and teachers focus their attention. This is a powerful curriculum development approach where there is a tendency to overcrowd a curriculum (Cousin, 2006, 2010; Land et al., 2010; Land et al., 2008; Meyer et al., 2010).

Rationale

Attrition rates in engineering programs in Australia have long been high. In the report of the project, ‘Addressing the Supply and Quality of Engineering Graduates for the New Century’, supported by the Carrick Institute for Learning and Teaching, King (2008, p.39) estimated that ‘male Australian engineering students have about 52 per cent likelihood of successful graduation from a bachelor level engineering program, and females about 60 per cent’. In the report of the project ‘Curriculum Specification and Support for Engineering Education: Understanding Attrition, Academic Support, Revised Competencies, Pathways and Access’, supported by the Australian Learning & Teaching Council (ALTC), Godfrey and King (2011, pp.64–66) noted that engineering curricula in Australia have ‘killer’ or ‘barrier subjects’ that many students find difficult or fail. Engineering educators should design and develop curricula to help students overcome these thresholds—with the first step being to identify and investigate the thresholds.

A unique opportunity arose at The University of Western Australia (UWA) to build on global developments in threshold concept driven curriculum and to adopt the resulting framework as a basis of the new engineering foundation program, which all UWA engineering students must take. From 2012, all new UWA undergraduate students are enrolled in one of only five bachelor degrees. Those students intending to study engineering take a three-year Engineering Science major, most often in a Bachelor of Science or a Bachelor of Design, followed by a two-year masters in an engineering discipline. All professionally accredited programs will be postgraduate, requiring a critical foundation of knowledge built within the bachelor degree.

The Engineering Science major of the bachelor degree includes an engineering foundation in the first two years, followed by discipline streams in the third year. The project lead on this engineering foundation program was also the chair of the Foundation Working Party, with the remit to design the foundation curriculum with appropriate learning outcomes, associated pedagogical approach, and ways of assessing student capabilities. Designing the program using threshold concept theory as the basis, allowed the project team to focus on how the foundation program could open up ways of knowing and doing, thinking and practising that are essential for upper levels of the bachelor degree and the engineering masters programs. Instead of a long list of curriculum content, the team was able, for the
first time (globally), to create a holistically designed foundation learning experience for engineers, based on how students learn and focusing on how to facilitate their passage through troublesome blocks.

Contributions to knowledge

The project contributed to advances in knowledge in several areas. These included advances in identification of integrated threshold concepts in engineering, advances in methodologies for identifying and investigating threshold concepts, and advances in combining threshold concept theory with ‘capability theory’ and ‘variation theory’ to inform pedagogy. These three areas are outlined below.

Advances in identification of integrated engineering foundation threshold concepts

Threshold concepts have been identified previously within individual units or disciplines of engineering (Baillie & Johnson, 2008; Ben-Naim & Prusty, 2010; M. T. Flanagan, Philip, & Meyer, 2010; Harlow, Scott, Peter, & Cowie, 2011; Kabo & Baillie, 2009; Park & Light, 2010; Smaill, Rowe, Godfrey, & Paton, 2011; Thomas et al., 2010). A current project, ‘An Adaptive E-Learning Community of Practice for Mechanics Courses in Engineering’ supported by the ALTC, used a threshold concept framework to focus adaptive tutorials in mechanics on the concepts most critical to progress and troublesome for students (Ben-Naim & Prusty, 2010). However, prior to this project no-one had identified and investigated threshold concepts across an integrated engineering foundation.

The outcome of this particular advance in knowledge was the identification by project researchers of the first ever Integrated Engineering Foundation Threshold Concept Inventory <ecm.uwa.edu.au/engineeringthresholds>. Findings include the identified troublesome and transformative features of the concepts, and suggestions for helping students overcome the thresholds. The threshold concepts are grouped in the inventory under the headings:

- **Learning to become an engineer**
- **Thinking and understanding like an engineer**
- **Shaping the world as an engineer**.

The findings presented in the inventory are consistent with the philosophy behind two previous projects supported by the ALTC (Cameron, 2009; Carew et al., 2009). Carew et al. investigated engineering academics’ experiences of teaching graduate attributes and systems thinking. ‘Systems thinking’ equates with the ‘integration of concepts’ threshold concept, which falls under the ‘shaping the world as an engineer’ heading in the inventory. Systems thinking also requires mastery of some of the threshold concepts for ‘thinking and understanding like an engineer’ including ‘modelling’ and ‘system identification’. Graduate attributes, such as communication and teamwork, appear among the identified threshold concepts required to ‘learn to become an engineer’.

Carew et al. found that academics frequently act in isolation or over short periods to teach systems thinking and graduate attributes. This project’s findings reveal that these are threshold concepts or capabilities, and many students find them troublesome. Based on threshold concept theory and capability theory, it can be expected that students will take a long time, possibly years, to develop threshold concepts and capabilities. Therefore, sustained approaches throughout a curriculum and taken by many teachers, rather than isolated teachers over short periods, will be necessary to help students develop systems thinking and some graduate attributes.

Similarly, Cameron investigated synergies between engineering practice and engineering curricula. Cameron recognised the importance of providing ‘spaces’ and time for students to develop. Aspects of these spaces include resources and people. This philosophy is consistent
with the threshold concept framework idea of providing extended opportunities for students to pass through the ‘liminal space’—the state experienced by a student when a threshold concept has come into view but remains troublesome (Meyer & Land, 2005)—as well as to develop understanding and capability in the identified threshold concepts for learning to become an engineer (e.g. teamwork), thinking and understanding like an engineer (e.g. modelling), and shaping the world as an engineer (e.g. design). Passing through the liminal space is uncomfortable and takes time, like learning to ride a bike or to speak in a foreign language. Therefore space and time for students to develop are essential features of any engineering curriculum.

Advances in methodology

The approaches used by other researchers to identify and investigate threshold concepts are numerous (Male & Baillie, 2011a). A rigorously developed, tested, and described methodology had to date not been established and widely adopted. In this project, the team developed a methodology for identifying and investigating threshold concepts (Male & Baillie, 2011b) and described it in a guide for others to adopt or adapt. The methodology is outlined later in this report and has the benefits of providing:

- opportunity to collect deep understanding about students’ experiences of concepts
- opportunity to identify previously unidentified threshold concepts
- flexibility to include capabilities and concepts
- engagement with students and teachers
- negotiation to reveal interdisciplinary concepts.

The ALTC supported the project ‘Using Threshold Concepts to Generate a New Understanding of Teaching and Learning Biology’. Charlotte Taylor, who was project lead on the project on threshold concepts in biology, also served on the reference group for this project. Jan Meyer, consultant to this project, also brought insights from the project in biology. These were valuable when planning the regional workshops held as an integral part of this project. For example, the consultant advised that it was important to ensure that group negotiations were captured and that summaries were shared between groups. Consequently, conversations were recorded with an audio recorder, in hand-written notes, and on group handouts. In addition, groups reported in a facilitated discussion, and groups’ main ideas were summarised on butchers’ paper or whiteboards for continuing discussion between groups during breaks.

Advances in theory and pedagogy

Threshold concept theory can be used as a framework for identifying concepts on which teachers and students must focus attention. Such a theoretical framework explains how students experience threshold concepts as troublesome and why it can take a long time for students to develop understanding and acceptance of some concepts that are critical to their progress. The theory helps to explain how the backgrounds of students can affect how they experience concepts and describes critical features of the transformation that can be experienced by students as they develop understanding of threshold concepts. These aspects of the theory and recommendations arising from them are described in the Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts, which was prepared as an outcome of this project and is available on the project website <ecm.uwa.edu.au/engineeringthresholds>.

However, threshold concept theory alone does not indicate how to teach threshold concepts. In this project, threshold concept theory was combined with capability theory and variation theory (Bowden & Marton, 1998). Capability theory proposes that university students should develop capabilities for unknown futures. In an unknown future situation, graduates must be able to reflect on what they know, devise a strategy to find out what
they need to know and address the situation. During this project, Baillie, Bowden and Meyer (2012) developed a ‘threshold capability theory’ by combining threshold concept theory and capability theory. Within this framework, thresholds are capabilities rather than concepts.

An important element of capability theory is variation theory (Bowden & Marton, 1998). In this theory, Bowden and Marton propose that students learn by discerning differences. Therefore, one way to teach students is to give them opportunities to experience structured variation. Further explanation is presented in the Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts.

Variation theory is an established method for teaching threshold concepts (Booth, 2004). For example, in a project supported by the ALTC, variation theory was used to teach one threshold concept each in law and physics (Akerlind, McKenzie, & Lupton, 2010). The Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts describes how variation theory could be used by engineering educators to teach engineering threshold concepts.

Summary of Outcomes

The project was designed to achieve the outcomes listed below, as identified in the project proposal.

1. Engineering Science major foundation at UWA based on sound pedagogical principles, which can act as a model for other institutions and disciplines.
2. Inventory of threshold concepts and ways of thinking within core engineering introductory courses.
3. A guide for engineering lecturers based on knowledge about the factors, which are shown to create these thresholds, as well as teaching approaches and assessment practices to support students’ passage through the thresholds.
4. A dedicated website ‘Engineering Thresholds’ for the inventory and guide to be easily accessible and for discussion and debate about the thresholds.
5. Three regional ‘knowledge-creation’ workshops, to identify thresholds in WA, NSW/ACT and SA and three to disseminate the guide and gain feedback, in VIC/TAS, NT, QLD.

An outline of the achievement of each of these outcomes is provided later in this chapter.

Approach and methodology

The approach for the project involved seven phases and as indicated in Figure 1 below, the structure was not linear. For example, phases three and four, in which potential threshold concepts were identified and negotiated, occurred over a similar period and relevant items in the inventory were presented to participants during phases three and four. In keeping with this non-linear structure, the inventory of threshold concepts was developed iteratively. As outlined earlier, the inventory identifies the concepts, how they can be transformative and troublesome for students, and suggests curriculum features to help students overcome the thresholds.

Detailed information on phases two to five can be found below and in the Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts.
Phase 1. Identification of learning outcomes

Learning outcomes were identified by the Foundation Teaching Team of 10 academics, including at least one academic from each engineering discipline in the faculty (Male & Baillie, forthcoming). These outcomes were negotiated within each school.

Phase 2. Development of methodology to identify and investigate threshold concepts

The methodology to identify and investigate threshold concepts was developed to be consistent with threshold concept theory (Male & Baillie, 2011b). The researchers refined the method taking into account advice from the reference group, project consultant, project evaluator, collaborators at the Universities of Birmingham and Oxford, and international visitors with experience in threshold concepts.

Phase 3. Diverging phase—identification and investigation of potential threshold concepts

In the diverging phase, students or teachers from one discipline at a time identified concepts that were transformative and troublesome, and provided evidence for these based
on their experiences. The phase included interviews, focus groups, and student feedback surveys (Table 1). Data were collected as transcribed recordings, hand-written notes, and survey responses. By analysing the responses, the researchers identified potential threshold concepts and built and expanded the inventory of threshold concepts.

<table>
<thead>
<tr>
<th>Interviews</th>
<th>Focus groups</th>
<th>Surveys</th>
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<tr>
<td>4 interviews with 5 civil engineering academics</td>
<td>1 focus group with 7 chemical engineering students and 1 chemical engineering academic</td>
<td>A one-minute paper completed by 349 first-year students taking ‘Engineering Global Challenges’</td>
</tr>
<tr>
<td>6 interviews with 5 mechanical/chemical engineering academics</td>
<td>1 focus group with 5 dynamics student tutors and 1 mechanical engineering academic</td>
<td>Feedback survey completed by 357 first-year students taking ‘Engineering Global Challenges’</td>
</tr>
<tr>
<td>5 interviews with 5 electrical engineering academics</td>
<td>1 focus group with 3 electrical fundamentals student tutors, 2 electrical engineering academics, and 1 mechanical engineering academic</td>
<td></td>
</tr>
<tr>
<td>1 interview with 1 environmental engineering academic</td>
<td>1 focus group with 3 materials student tutors and 1 mechanical engineering academic</td>
<td></td>
</tr>
<tr>
<td>1 interview with 2 tutors for the unit ‘Introduction to Professional Engineering’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 interviews by final-year and postgraduate students with 5 first-year students taking the unit ‘Engineering Global Challenges’</td>
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Phase 4. Integrating phase—negotiation and investigation of identified potential threshold concepts

In the integrating phase, potential threshold concepts were negotiated at knowledge-creation workshops by students and/or teachers from multiple disciplines or universities. Underlying, overarching and additional threshold concepts were identified. Data were collected as transcripts of discussions, hand-written notes, and responses on workshop handouts. The researchers analysed the data to revise the inventory iteratively.

Workshops in the integrating phase are listed in Table 2. All workshops combined data collection with dissemination through engagement in the project. At all workshops, except those including students, participants were academics and postgraduate students—teachers in engineering and the related disciplines of physics, mathematics, computing, or chemistry.
In addition to the workshops in Australia, with additional support, knowledge-creation workshops were held at the Universities of Oxford and Birmingham in England in January 2011, Lund University in Sweden in February 2011, and at Auckland University in New Zealand in June 2011.

Phase 5. Curriculum development to help students overcome thresholds and assess evidence of transformation

The curriculum development team, led by the project lead and including members of the project team, mapped the threshold concepts to the learning outcomes previously identified. They then designed curriculum features, a pedagogical approach, and assessments to focus teachers and students on threshold concepts and help students develop understanding of identified threshold concepts. Variation theory was adapted as part of this process (Bowden & Marton, 1998). Troublesome features and suggestions for helping students, as listed in the threshold concepts inventory, were relevant in this phase. Listed transformative features of threshold concepts were relevant to designing assessment to collect evidence of students’ transformation.

Phase 6. Dissemination through stakeholder engagement

A web discussion forum was established on the project website <ecm.uwa.edu.au/engineeringthresholds>. Regional knowledge-creation workshops held in Australia in the integrating phase were promoted and reported on the project website and web discussion forum.

Engineering teachers were also introduced to the threshold concept inventory and methodology at three regional dissemination workshops in Brisbane, Sydney, and Darwin. Participants followed a brief guide to the methodology during the workshops.

Some data were collected during these dissemination workshops and consequently the inventory was further refined. These dissemination workshops are listed in Table 3.

### Table 3: Regional dissemination workshops in Australia

<table>
<thead>
<tr>
<th>Workshop Location</th>
<th>Date</th>
<th>Number of participants</th>
<th>Number of universities represented among participants</th>
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<tbody>
<tr>
<td>Brisbane</td>
<td>11 April 2012</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Sydney</td>
<td>13 April 2012</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Darwin</td>
<td>1 June 2012</td>
<td>15</td>
<td>1</td>
</tr>
</tbody>
</table>

Additional dissemination workshops were held outside Australia. Dissemination workshops were facilitated by the project lead and international collaborators in Birmingham in November 2011, and Oxford in January 2012. A dissemination workshop at which participants shared methodologies to identify threshold concepts was facilitated by project team members at the Australasian Association for Engineering Education (AAEE) Conference in Perth in December 2011. This was attended by 22 academics from 14 universities.
Phase 7. Dissemination by providing information

The Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts and the Integrated Engineering Foundation Threshold Concept Inventory are available on the project website.

Other forms of dissemination are discussed under Outcome 6 below and in Chapter 2.

Achievement of project outcomes and amenability to implementation elsewhere

Outcome 1. Engineering Science major

The complete Engineering Science major foundation was introduced in semester one, 2012. The threshold concept inventory was used by the curriculum developers. The first of the new units, ‘Engineering Global Challenges’, was implemented in semesters one and two, 2011. In semester one, 2012, all four engineering foundation units, ‘Engineering Global Challenges’, ‘Materials’, ‘Motion’, and ‘Energy’, were taught in classes of 20 to 30 students by facilitators. Lists of main threshold concepts in each unit were prepared for students. The facilitator training included training in threshold concept theory and facilitators used the lists of main threshold concepts to practice facilitating discussions. Before the start of semester two, 2012, new facilitators were trained in threshold concept theory and in teaching threshold concepts using variation theory.

Outcome 2. Guide for engineering educators

On the advice of members of the reference group, the guide for engineering educators describes an approach that can be transferred to varying extents. It is not necessary for educators to be developing or renewing an entire curriculum in order to adopt the approach. Instead, the guide is written such that it could be used by educators to renew a single topic, a unit, or a program. Furthermore, the guide describes the methodology so that engineering educators teaching higher levels and other educators, whose programs might have different or additional threshold concepts, could use the methodology for renewing their courses.

Outcomes 3 and 4. Website and web discussion forum

The dedicated project website has been live since 12 October 2010 <ecm.uwa.edu.au/engineeringthresholds>. The inventory and guide are on the website, along with a project summary, links to the Flanagan bibliography (M. Flanagan, 2011), and a list of publications. The website also includes a web discussion forum with 40 members to date. Anyone can join and post, and project updates are regularly posted to the forum. The discussion is likely to be valuable to any researchers or curriculum developers using threshold concept theory.

Outcome 5. Regional workshops

Three knowledge-creation workshops were held in Perth, Adelaide, and Melbourne in 2011. Three dissemination workshops were held in Brisbane, Sydney, and Darwin in 2012. Detailed information on the conduct and outcomes of these workshops can be found in the guide.

Outcome 6. Publications

One journal paper in Higher Education, a book chapter in the forthcoming Cambridge Handbook of Engineering Education Research, four refereed international conference papers, and two refereed national conference papers have resulted directly from this project (Baillie et al., 2012; Hesterman et al., 2011; Male, forthcoming; Male, 2011; Male &
Baillie, 2011a, 2011b; Male, Guzzomi et al., 2012; Male, MacNish et al., 2012). The papers were presented in Europe and Australia, and four of these were presented at engineering education conferences. One each was presented at the International Conference of Women Engineers and Scientists 2011, and the Higher Education Research and Development Society of Australasia (HERDSA) Conference 2012.

Additionally, a refereed conference paper was presented based on a collaboration between researchers on this project and researchers from the Universities of Birmingham and Oxford in England (Quinlan et al., 2012). In this collaboration the researchers in England adapted the methodology developed in this project. A manuscript from this collaboration is currently under review. Both papers discuss methodology and threshold concepts identified.

The diversity of publications is an indicator of the broad relevance of the contributions of the project. The identified threshold concepts and resultant curriculum developments are directly relevant to engineering educators and researchers in engineering education. Additionally, the methodology could be applied in other fields of higher education.

Priority areas addressed

The project addressed the priority area of ‘curriculum renewal’. Under this priority, the project developed ‘future directions and coverage of programs of study’ and ‘re-positioning and re-shaping discipline based courses’ (ALTC, 2009, p.5). Additionally, several of the suggestions for helping students overcome threshold concepts will improve curriculum ‘inclusivity’. Specifically, the project addressed curriculum renewal in two ways. First, the project developed a new methodology to assist curriculum design or renewal. This approach is based on a threshold concept framework, outlined earlier. Second, the project developed the first ever integrated engineering foundation threshold concept inventory. These are now described.

Methodology for curriculum development

The project established a methodology for using a threshold concept theoretical framework to assist curriculum design, which was used at UWA in the curriculum design for the integrated engineering foundation. This approach engages teachers and students in identifying concepts that are most transformative and troublesome for many students and therefore should be given attention by teachers and students. It could be used to refine part or all of an existing curriculum and has many strong features, as identified below.

Concepts that might otherwise be overlooked by curriculum designers can be identified. Curricula can be structured to give students considerable opportunity to develop understanding of each threshold concept, without threshold concepts being clustered too close together. Overcrowded curricula can be renewed, by focusing students’ and teachers’ class time on developing understanding of the most transformative and troublesome concepts—in this way, troublesome features of concepts can be investigated and addressed. Assessments can be refined to collect evidence of students’ transformation, rather than ability to mimic understanding. Educators from many disciplines, not only engineering educators, can learn about the methodology by reading the Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts.

The methodology proved effective at achieving two additional curriculum development goals: an integrated curriculum, and engagement with students. Using the methodology, the new UWA engineering foundation curriculum was designed. This curriculum integrates disciplines of engineering into one foundation, whereby threshold concepts central to a foundation for all engineering disciplines receive attention (Male, Guzzomi et al., 2012). For example, modelling and system identification are taught in their different manifestations across engineering disciplines in the new curriculum. In traditional curricula, the synergies across disciplines are not necessarily experienced by students.
Using the methodology, the project also engaged students and student tutors in curriculum development (Male, MacNish et al., 2012). Students were interviewed individually and in a focus group, and were also engaged in a student workshop and a student–staff workshop. Student tutors participated in focus groups. The benefits of these processes included insights into threshold concepts and trouble experienced by students, which would not otherwise have been noted.

For example, students noted how the assumptions which apply to problem-solving in physics at high school are not necessarily made explicit to them in that learning setting. As such, when coming to solve problems in first-year engineering, the awareness of these assumptions is not in place and this causes difficulty and weakens confidence for first-year engineering students. Students noted that in the old curriculum, threshold concepts in computing were confounded in assignments in which students were expected to develop understanding of computing simultaneously with other threshold concepts in engineering science. Responses from students in the first new engineering foundation unit revealed that ‘roles of an engineer’ had been experienced as a threshold concept for many students.

Student engagement also assisted with improving curriculum ‘inclusivity’. For example, students noted that some students did not have the computer knowledge that was assumed in one of the previous first-year units. Several inclusivity issues and solutions raised by students had been previously identified as part of initiatives to improve gender inclusivity in engineering programs (Male, 2011).

Integrated Engineering Foundation Threshold Concept Inventory

As mentioned earlier, the researchers on this project developed the first ever Integrated Engineering Foundation Threshold Concept Inventory, available on the project website. Each item in the inventory includes text to identify the concept—as well as the ways participants have indicated that the concept can be transformative, ways it can be troublesome, and suggestions from participants on how to help students overcome the threshold.

Engineering educators could apply this information to their own curriculum development by using all or part of the inventory as a list of potential threshold concepts to begin discussions and negotiations about threshold concepts in their curricula. Alternatively, engineering educators could access one or two items in the inventory to discover how the particular concepts they teach can be transformative and troublesome for many students and make use of the suggestions for helping students overcome the thresholds. Transformative and troublesome features can be used by educators to help design curriculum developments to improve students’ progress through courses. As noted above, transformative features can be used to develop assessments to collect evidence of transformative aspects, rather than ability to mimic understanding. The Guide for Engineering Educators on Curriculum Renewal using Threshold Concepts suggests some approaches.

Factors that were critical to the success of the approach and factors that could have impeded success

Factors critical to success

Participation from volunteers was critical to the success of this project. The project depended heavily on volunteers’ willingness to contribute to improving engineering education and their faith in the project. Participation from students and teachers at UWA, around Australia, and in New Zealand, England, and Sweden was invaluable. Leaders in the student societies generously helped recruit student participants. Unit coordinators were also instrumental in helping to recruit tutors and in attending focus groups with tutors.
Networks were critical to participant recruitment and collaboration. The project lead’s international network and reputation in engineering education research were beneficial. Her contacts initiated and supported workshops in England and Sweden. Similarly, the project manager’s experience in three schools of the engineering faculty simplified the process of recruiting participants. Her network across Australia—developed through involvement in Engineering Australia, the AAEE (Western Australian) Teaching and Learning Forums, and HERDSA—was beneficial when recruiting participants and organising the regional workshops. HERDSA and AAEE also helped to promote the regional workshops.

The project lead and project manager invited visitors to UWA, who met with the project team and held workshops. The collaboration and the discussions with visitors helped the researchers to question aspects of their approach that they had not previously considered. The workshop on sharing methodologies held by members of the project team at the AAEE Conference 2011 in Fremantle also provided opportunities for this.

The advice from the project consultant was invaluable. He had experience on many projects using threshold concept theory, and knowledge about studies using threshold concept theory. This was critical in the design of the methodology, the workshop protocols, and reassurance about the approach to the analysis. Similarly, the reassurance and advice from the reference group was important.

The Australian Council of Engineering Deans (ACED) provided support for disciplinary academics from the project team to co-facilitate the workshops. As discussed in the guide, this improved the flow of the workshops and quality and quantity of data collection.

Sustained engagement from the project team was critical. The project manager’s position was research-intensive and it was inspirational and satisfying for her to hear from project team members about reflections on their teaching related to the project, and their experiences teaching the new units. Experiences discussed—such as a student’s misperception developed through unintended interpretation of variation—were used as examples in the regional workshops.

Factors that could have impeded success

As is often the case with research projects conducted over a long period and involving many contributors, this project was faced with the issue of change in availability of personnel at times. Goodwill, flexibility, planning, and ability of the researchers to work independently and beyond their formal roles when necessary, overcame this potential impediment.

Three members of the project team left UWA early in the project. This could have been a problem. However, fortunately three valuable new members joined the team.

Workshop participant numbers were excellent. Despite this success, it was disappointing that many people registered and did not attend. The reference group confirmed that this is a common issue.

The web discussion forum initially received spam. New members must now request membership and indicate their position and organisation before they can post a message. Spammers are now blocked.
Chapter 2. Dissemination

The recommended OLT strategy of both ‘engaged’ and ‘information provision’ dissemination mechanisms (ALTC, 2008) was adopted and applied to Outcomes 1–5 of the project, as outlined below.

Identification of potential users

Outcome 1

For outcome 1, the ‘Engineering Science major at UWA’, the users are identified as the engineering staff who teach and students who learn on the new UWA program.

Outcomes 2–5

For outcomes 2–5, the inventory, guide, website and workshops, the users are identified as all engineering lecturers teaching similar subject areas within Australia and beyond. The methodology could be used by university curriculum developers in engineering and other disciplines.

Strategy to engage users

Outcome 1

Engineering students and teachers at UWA were engaged as participants throughout project development, enabling them to become aware of the potential outcomes. To assist this, the protocols for interviews with teachers and focus groups with students included the facilitator introducing the theory, the project, and relevant previously identified threshold concepts (Male, forthcoming; Male & Baillie, 2011b; Male, MacNish et al., 2012).

An indicator of the effectiveness of this strategy with respect to students was the willingness of students who attended the student workshop, to go on to attend the student–staff workshop. This willingness was stated by a student on a participant evaluation questionnaire for the student workshop.

An indicator of the effectiveness of this strategy with respect to teachers is the adoption of threshold concept terminology among teachers in the engineering faculty at UWA, and the initiation of research on threshold concepts in higher level engineering units by two academics (Male, forthcoming).

Outcomes 2–5

Engineering educators around Australia and in New Zealand, England, and Sweden participated in knowledge-creation or dissemination workshops in this project. In the workshops they learnt about threshold concept theory and the concepts already identified, and then engaged in identifying, justifying and negotiating threshold concepts and discussing curriculum features to help students overcome thresholds. An email received from a regional workshop participant stated:

Just a quick note to say thank you for the workshop experience this morning—the overview of the threshold concepts was just what I needed. It’s going to help reshape my teaching for next year.
Strategy to provide users with information

Outcome 1

As discussed, prior to first and second semester 2012, the project team introduced the theory, the project, and the threshold concepts in the training for facilitators teaching the engineering foundation units. For each engineering foundation unit, a list of the main threshold concepts was prepared for the students and also used in an exercise in the facilitator training. In the training for second semester, the facilitators also practised developing an activity based on variation theory, which was combined with threshold concept theory in the curriculum development.

Outcomes 2–5

Potential users will be able to access the methodology for curriculum development using threshold concepts, as well as details about the identified threshold concepts and suggestions for helping students overcome them in the guide and the inventory (Male, forthcoming; Male, forthcoming). They will also be able to read the 10 publication notes provided in Chapter 1. All publications are listed on the project website with links to papers where available.

Engineering educators and others interested can join the web discussion forum, which currently has 40 members.

An indicator of the success of the dissemination is the strong interest the project lead has received from potential collaborators for future research. In response to this interest, a ‘Community of Collaborators’ is now published on the project website. The list identifies the names, email addresses, and fields or topics of research of people who are interested in collaborating on research into threshold concepts in various fields or topics of engineering. The current version is listed in Appendix A.
Chapter 3. Linkages

The researchers have established links between this project and an OLT fellowship, and collaborated with universities in England, as described below.

An OLT Research Fellow, Dawn Bennett, at Curtin University, and the project manager recognised a link between this project and the Research Fellow’s research ‘Reinvigorating student learning: embedded learning and teaching strategies that enhance identity development’. In this project, two identified threshold concepts were ‘roles of engineers’ and ‘self-driven learning’ (Male, forthcoming; Parkinson, 2011). The Research Fellow and project manager have collected data to further investigate these two threshold concepts and their relationships within the framework of the Research Fellow’s research in other disciplines.

A UWA Research Collaboration Award supported collaboration with researchers at the Universities of Oxford and Birmingham. In this collaboration, researchers in England adapted the methodology developed in this project. The researchers compared methods and findings and also analysed some of the transcripts across universities to better understand differences and similarities between the data collection and analysis techniques at the different sites (Quinlan et al., forthcoming; Quinlan et al., 2012).
Chapter 4. Evaluation

The project evaluator undertook both formative and summative evaluation. He attended the first and the final project team meetings at UWA. In the first meeting, Outcome 2 was revised to the version reported in Chapter 1. The original version referred to ‘all threshold concepts and ways of thinking within core engineering introductory courses’. On the advice of the project evaluator, the word ‘all’ was removed to ensure that the project was achievable.

The project evaluator attended the first regional knowledge-creation workshop in Perth and the regional dissemination workshop in Sydney. For all other regional workshops, including the June 2011 workshop in Auckland and the December 2011 workshop at UWA, the project evaluator designed a participant evaluation questionnaire and collated responses. The project evaluator prepared reports on all of these workshops.

The report on the Perth workshop discussed how participants identified and negotiated overarching threshold concepts, of which previously identified items were examples, and how they also identified underlying threshold concepts that were sources of trouble in these previously identified threshold concepts (Male & Baillie, 2011b).

The researchers used the reports on each workshop to refine the future workshops and also to inform recommendations about the method in the guide. Examples of refinements are noted in the guide (Male, forthcoming).

Further, once Emeritus Professor John Bowden was appointed as the ALTC project evaluator, he personally attended as many of the project meetings as possible and interacted by teleconference in other meetings. His involvement was in keeping with the choice made that his evaluative approach would be formative. As well, he interacted directly – in person, by email and by telephone – with the Project Leader. During all such activities he raised questions about aims and processes, made suggestions about strategy, and conducted formal evaluations of sessions involving university teachers. His analysis reports on such feedback have been included in this Report.
References


Appendix A. Communities of Collaborators
Investigating Threshold Concepts in Specific Fields of Engineering or Related Disciplines in Higher Education

Updated 7 August 2012
<ecm.uwa.edu.au/engineeringthresholds>

This list is managed by members of the Engineering Education Research Theme at The University of Western Australia. The purpose is to provide an opportunity for potential collaborators to find each other.

Chemical engineering

Computer programming

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Computer engineering

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Control systems

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Design

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Unconscious bias

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