Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning

Male, Sally Amanda; Bennett, D.

Published in:
Australasian Journal of Engineering Education

DOI:
10.7158/D14-006.2015.20.1

Licence:
Other

TITLE PAGE

This is an Accepted Manuscript of the following article:

Male, S. A. & Bennett, D. 2015, "Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning", *Australasian Journal of Engineering Education*, Vol. 20, No. 1, pp. 59-69, http://dx.doi.org/10.7158/D14-006.2015.20.1.

Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning

Sally A. Male BE(Hons) PhD FIEAust [a] Dawn Bennett PhD MA(music) GradDipEd FTCL [b]

[a] *School of Electrical, Electronic and Computer Engineering, The University of Western Australia, Crawley, Western Australia*

[b] *Research and Graduate Studies, Curtin University, Perth, Australia*

Sally Male (corresponding author): sally.male@uwa.edu.au

Dawn Bennett: dawn.bennett@curtin.edu.au

Threshold concepts in undergraduate engineering: Exploring engineering roles and value of learning

Threshold concepts are transformative disciplinary concepts. They are critical to students' progress and often troublesome for students. In this study we explored two potential threshold concepts: namely 'roles of engineers' and 'value of learning'. Adopting a workshop format, the study trialled strategies that might help students overcome these threshold concepts. During the workshops, second-year students at an Australian university were considered their motivations for studying engineering, their perceptions of engineering work, and their life and career identities at that point and into the future. Questions aligned with each activity were designed to determine whether students found these considerations transformative or troublesome. Analysis of students' responses using a threshold concept framework revealed the students to be troubled by their lack of insight about the characteristics of engineering work. Students were also troubled by perceived gaps between the attributes of engineers and their own personal attributes. Further, students sensed a lack of alignment between engineering work, their career goals, and components of their engineering studies. The study draws attention to the need and opportunities for engineering educators to facilitate the development of students' career preview, and to enhance their motivation to learn by linking career relevance to each unit of study.

Keywords: threshold concepts; identity; motivation; engineering education, curriculum development

1. Introduction

This is the second in a series of papers that explores students' development as engineers during the undergraduate engineering degree. As we have argued previously (Bennett and Male, under review), engineering educators and their students have access to a vast array of online and offline resources. As such, valuable class time can and should move beyond information transfer and towards student development through interactive experiences.

Given that students' development of self and knowledge is socially constructed (Wenger, 1998), it is unsurprising that there is increasing interest in research into class-based experiences that might enhance learning. As Land et al. (2006) argue, identifying threshold concepts can focus curriculum and help students overcome the most critical and troublesome concepts. Logically, these concepts then become the focus of class time. This paper draws on threshold concept theory as a framework in which specific concepts are thought to form disciplinary thresholds to learning.

In many disciplines the identification of threshold concepts is an on-going concern. In this paper we explore two recently identified threshold concepts and argue that these should receive greater attention. The study contributes to growing interest in the development of engineering students' skills and knowledge, and also of their selves and identities (Meyer and Land, 2006, Brophy, 2013).

We begin by establishing the rationale for the study. We then introduce threshold concept theory and Parkinson's (2011) study in which the new engineering threshold concepts were proposed. This is followed with discussion of established threshold concepts in engineering. The approach and theoretical framework of the study leads to analysis and discussion of the findings.

1.1. Rationale for the study

This study built on previous research in which engineering educators and students identified potential threshold concepts in an engineering foundation program (Male and Baillie, 2011a, Male, 2012b, Parkinson, 2011). Three of the potential threshold concepts were: 'roles of engineers', the 'value of learning', and 'self-directed learning'. In this study we explored the first two of these threshold concepts to better understand how they were troublesome and how educators might help students overcome them.

We recognised the potential for the earlier findings to improve engineering students' engagement and motivation. To explore this potential we investigated students' identities and motivation through three frameworks. The first of these was the 'possible selves' framework, through which individuals consider desired, expected and undesired conceptions of self and career (Markus & Nurius, 1986). The second was a motivation and identity framework, through which we linked learning, motivation, self-concept and self-efficacy. This paper reports our investigation based on the third framework: threshold concept theory.

1.2. Theoretical framework: threshold concept theory

Meyer and Land (2003) propose that many disciplines have concepts that are critical to students' studies and future work. These concepts are transformative epistemologically because they reveal new ways of thinking and understanding. They are also transformative ontologically, as they can reposition a student's sense of self. Due to the transformative nature of these concepts, however, many students find them troublesome. Concepts can be troublesome for any reason that makes them either difficult to understand or accept: for example, because they are tacit, inert or conceptually difficult, because they use unfamiliar language, or because they invoke fear of uncertainty (Perkins, 2006, pp. 37-41, Male and Baillie, 2014, pp. 395-397, Baillie and Johnson, 2008, pp.137-8, Meyer and Land, 2003, pp. 8-9). The often-prolonged state experienced by students when a threshold concept comes into view but has not been resolved is known as the 'liminal space' (Meyer & Land, 2005, p. 375).

1.3. Background: previous research on which this study builds

The study that underpinned the current research (Parkinson, 2011) identified the threshold concepts experienced among 435 first-year engineering students (Male, 2012a). The two threshold concepts that concern us here are the 'role of engineers' and the 'value of learning'. Parkinson's research contributed to a large project that sought to identify and investigate threshold concepts within an integrated engineering foundation course (Male et al., 2012, Male and Baillie, 2011b). Later research within the project refined the initial concept of the role of engineers to incorporate multiple roles, and the concept 'value of learning' was rethought as a threshold concept required for the overarching concept 'self-directed learning' (Male, 2012b, p. 12). On the basis that capabilities may allow students to respond to unseen problems, Baillie, Bowden and Meyer (2012) have since proposed threshold 'capabilities' as a variation of threshold concepts.

In this study we considered concepts and capabilities as possible thresholds in engineering higher education. We investigated the two new threshold concepts and considered how understanding the value of learning might help students develop their capabilities as more self-directed learners.

1.4. A focus on ontological transformation

Investigations of threshold concepts in related fields have studied the epistemological transformation more comprehensively than the ontological transformation (Zander et al., 2008, McCartney et al., 2009). This is the first study of threshold concepts in engineering to focus on an epistemological transformation as an ontological transformation. Previous engineering studies have focussed on technical concepts in, for example, foundation electronics (Harlow et al., 2011, Smaill et al., 2012), electrical engineering beyond the foundation year (Flanagan et al., 2010, Carstensen and Bernhard, 2008), and mechanics (Ben-Naim and Prusty, 2010). Collectively, these concepts can be thought of as thresholds for 'thinking and understanding like an engineer' (Male, 2012b, p10).

In the inventory of threshold concepts within a foundation engineering program, developed in the project of which Parkinson's study formed a part, awareness of cultural influences on identities and practices fall into the categories labelled 'learning to become an engineer' and 'shaping the world as an engineer' (Male, 2012b, pp.10). The current study focuses squarely on the former category: namely, the transformation required for a student to have the attitudes and identity to overcome the thresholds required to learn to think and understand like an engineer.

1.5. Research Questions

In this study we addressed the following questions in relation to the potential thresholds known as 'roles of engineers', and 'value of learning':

Q1: Is there evidence of either concept being transformative for students?

Q2: Is there evidence of either concept being troublesome for students?

Q3: Is there evidence of conflict between students' self-concept and their perceived characteristics of an engineer (being an expected source of troublesomeness)?

Q4. What are students' concerns after considering perceptions of engineers and their desirable selves as engineers (representing any other form of troublesomeness)?

Q5: For each concept is there evidence of students being in a pre-liminal, liminal or post-liminal state?

2. Methodology

The study aimed to develop and test strategies that might help students identify and overcome the potential threshold concepts. To achieve this we engaged students in a variety of activities in which they had to think about their future lives and careers. During these activities we collected data relevant to potential threshold concepts, possible selves (Markus & Nurius, 1986), motivation, and engagement. This paper focuses on data relating to the threshold concept framework. Data collection and analysis within this framework related to students' understanding of the roles of engineers and value of learning and the extent to which they experienced the potential threshold concepts as transformative and/or troublesome.

3. Method

In a large Australian university, 49 undergraduate engineering students attended one of two, two-hour workshops conducted at the start of a foundation unit on motion. Students completed activities designed to focus their thinking on the potential threshold concepts, and they were invited to submit responses for analysis. The research was explained to the students at the commencement of the workshop and their confidentiality was assured. Although one of the researchers was in the same faculty as the students, neither researcher had any teaching or managerial role that related them to the students, except as facilitators in the workshop. The students voluntarily returned a total of 38 valid responses to one or more written questions and all 49 students participated in the activities conducted as a whole class. Activities conducted orally incorporated short-answer written questions undertaken as part of each activity, whilst the written activities incorporated closed and open-ended questions, the latter requiring responses up to a paragraph in length. A researcher not otherwise involved with the case study removed identifiable data.

The students were in their second or third year of study. Two participants did not identify their ages and the remaining students were aged from 18 to 21 years. Five participants (13%) were female. The analysis of data within the threshold concept framework involved identifying responses consistent with students finding concepts troublesome or transformative.

3.1. Materials

Each interactive workshop incorporated multiple activities lasting 20 minutes or less, and the workshops were identical in format. The workshop was designed to put students at ease, to give them time for individual reflection, and to provide opportunities for open discussion. As such we were careful to limit the challenges associated with self-report and to ensure that students were comfortable in their engagement. The activities included whole-class discussion, reflection, group work within and outside of discipline groups and a two-minute paper. The workshop was developed specifically for this study, drawing from and refining existing measures that have accepted reliability for research purposes (Bennett, 2012). In this paper we analyse responses to the four activities that evidenced transformative or troublesome experiences. The structure of each workshop is summarised as follows:

Workshop summary

Activity 1: Introduction and whole-class activity. (10 minutes)

- What do you love to do? (personal)
- Why are you here, taking this course/unit? (value of learning)
- In what ways might it be useful in the future? (as above)

Activity 2: Individual activity with a focus on aspirations, followed with discussion. (5 minutes)

- Write down the one thing you want to be remembered for/to achieve as an engineer.

Activity 3: Individual self-reflection on career preview and relevance of study. (75 minutes)
After discussion with students in the same engineering discipline, students summarised the characteristics of an engineer and presented them as a group.

- What does an _____ engineer look like? (career preview) (Students inserted their discipline.)
- What differences are there (if any) between the above characteristics and you as a person? (preview, self-concept, self-efficacy)
- What do you see as the roles of an engineer? (roles of engineers)
- What will your personal role be? (aspirational, career preview)
- How will the learning in this unit contribute to your development as an engineer? (value of learning)
- Imagine yourself in 15 years' time. What will you be doing? (personal, aspirational, career preview)
- In a sentence, describe what you dream you will have achieved as an engineer over this time (aspirational, self and career).

Activity 4: Creating a High-Achieving Group (not discussed in this paper). (25 minutes)

Activity 5: Adapted Two-Minute Paper (Individual reflection). (5 minutes)
The paper was designed to determine whether students experienced threshold concepts during the session. The paper asked:

- Have you learnt anything transformative in this session? (Y/N)
    - If so, what?
- Do you feel a need to think further about anything raised in this session? (Y/N)
    - If so, what and why?

To help the students understand the meaning of 'transformative', which is a term used in threshold concept theory, in Activity 5 we explained to the students that by transformative we meant something that made them see things differently from before or opened a new way of thinking.

4. Findings and Discussion

The number of responses to each activity is summarised below at Table 1.

Table 1: Number and percentage of responses for each activity

Activity	Description	Valid responses
1	Whole class activity (discussion)	49 (100%)
2	Imagining career goals	32 (65%)
3.1	What does an engineer look like?	37 (76%)
3.2	Roles of engineers (threshold concept)	34 (69%)
3.3	Career preview	34 (69%)
3.4	Value of learning (threshold concept)	35 (71%)
3.5	Looking back on a future career	36 (73%)
4.1	Reflection on workshop: Was anything transformative?	37 (76%)
4.2	Reflection on workshop: Does anything require further thought?	32 (65%)

4.1. Activity 1: whole-class activity (discussion)

Asked: ‘Why are you here, taking this course/unit?’ some students responded that they were attending to get ‘credit points’. This is consistent with Lindsay et al. (2008) in that students were thinking as ‘engineering students’ rather than ‘student engineers’ who might have referred to developing knowledge and skills for their future careers. The students’ comments indicate that the perception of ‘value of learning’ can be limited to short-term gain, consistent with a ‘surface approach’ to learning (Ramsden, 2003, pp.47). The comments also suggested ‘pre-liminal variation’, which is variation in the backgrounds or tacit knowledge of students before they become aware of a threshold concept (Meyer and Land, 2005, pp.384).

4.2. Activity 2: imagining career goals

Students were next asked to scribe what they wanted to achieve as an engineer, and 32 students submitted their responses for analysis. The three common themes were job satisfaction, making a difference and reputation. Students who shared these aspirations in later discussion often referred to what had inspired them. This included significant others such as schoolteachers and family.

Students divulged that the task of imagining career and career goals was new for most of them. It was seen as a valuable task, noted by eleven students in the later two-minute paper. We had anticipated that the task would be new to many students; Australasian Survey of Student Engagement data from 2012 reveal that of almost 35,000 Australian students, 31% (10,850) had never talked about career plans during their studies (Australian Council for Educational Research, 2014). The development of career preview receives little attention within higher education, and for many of the students in this study the 'roles of engineers' had barely come into view as a concept.

A small number of students had defined their career goals, and these students caught the intense attention of their peers when they shared them. These students may have been in the liminal or even 'post-liminal' space in terms of the concept 'roles of engineers', but they remained troubled when it came to understanding the 'value' of their learning in relation to achieving their goals (research questions 2 and 5). Indeed, students noted that they were unsure their engineering program would help. One student was passionate about clean energy but did not think it possible to study this during his degree. This was troublesome for the student and yet was easily addressed by raising it with the academics. This reinforces that the explicit discussion of career was a new experience for students.

4.3. Activity 3: roles of an engineer

Activity 3 built on Parkinson's 2011 research. Students completed a self-reflection on career and self before discussing their responses in discipline-based groups, with the goal of reaching a consensus about what an engineer in their discipline might look like. In the 34 valid responses, engineers were most commonly described as innovative/creative, knowledgeable, intelligent, leaders, independent, and team players. Thirty-three students went on to identify differences between their description of an engineer and themselves as individuals.

Knowledge was a common response: for example, "*Lacking strong engineering fundamentals – that's why I'm at Uni".* Design also featured strongly and was linked with technical aspects of engineering. For example: *"Hopefully designing robots of some sort"* (Mechatronic); *"I would travel around the world to design water management systems to increase the wellbeing of people"* (Civil). In contrast, and highly relevant to our focus on threshold concepts and (research question 3) possible conflict, 65% of the students planning to study mechanical or mechatronics engineering believed that they did not have the necessary creativity. Moreover, they believed that creativity was an innate skill that it is not possible to develop. We found that the students had recently viewed a video on creativity. No one had considered that the concept of creativity might be troublesome for students, and this highlighted that educators do not always know what will be troublesome. (Bennett and Male, under review). We do know that the belief that something is unachievable can cause students to doubt the value of their learning. This is consistent with the concept being experienced as troublesome within the threshold concept framework.

Students were asked: *What do you see as a role of an engineer?* Most responses linked to technical requirements and specialisations. The students' focus on technical aspects of engineering is consistent with Trevelyan's (2011) supposition that students develop misperceptions about engineering practice during their undergraduate studies which emphasise engineering science and neglect other aspects of engineering practice. This is concerning because the misconception that engineering practice is mostly technical can cause identity confusion upon entering the profession, when graduates can find their primarily technical image of engineering practice to be at odds with the realities of work (Faulkner, 2007).

Our study supports the recommendations by Trevelyan and others for authentic curricula in which students work in teams on problem- and project-based learning with uncertainty and social, economic, and environmental factors (Palmer, 2007, Sheppard et al., 2009). Resources to support authentic curricula were developed as part of the Australian Council of Engineering Deans' national project 'Enhancing Industry Engagement in Engineering Degree Programs'. As part of this project, seven universities in collaboration with industry developed industry-inspired projects designed to be used in engineering units (Tuladhar et al., 2014, Male and King, 2014b). The materials for these authentic projects are available for others to use and provide a valuable resource in helping students to develop more accurate perceptions of engineering practice.

When asked what their personal role might be, a number of students failed to answer this question despite responding to the other questions. It is possible that the concept of roles of engineers was experienced as troublesome (research question 2), and this warrants further research. In contrast, the remaining responses reveal that students had now started to think about 'roles of engineers' and also about how the knowledge and design, leadership, teamwork, and communication skills developed during their studies might be beneficial: namely the 'value of learning'. This is consistent with a transformation from identifying as engineering students at the start of the workshop; as they began to think about their futures as engineers, students progressed towards identifying as student engineers. This beginning of an ontological transformation could indicate that students had entered the 'liminal space' for the threshold concepts of roles of engineers and value of learning (research question 5).

Although students had started to think as student engineers, troublesome aspects of this remained for many students, and therefore these students had not yet passed through the liminal space. Students had started to think about roles of engineers for themselves but needed to know more. Additionally as noted above, students had started to see the value of learning but were troubled by weaknesses in skills that they believed were important to engineering but which they doubted they could develop. As students had started to think differently but many remained challenged by the concepts, it is likely that many of the students were in a liminal space with respect to the concepts of roles of engineers and value of learning.

4.3.1. The value of learning

Students were asked to consider how the learning within their foundation unit (motion) would contribute to their development as engineers. We have previously discussed responses in relation to understanding possible selves (Bennett and Male, under review), but they also have relevance to threshold concepts.

Responses to the previous question suggested that students had entered the liminal space where the concepts of roles of engineers and value of learning had come into view at a broad level. However, considering research question 2 the ‘value of learning’ to students’ future roles as engineers was troublesome in practical terms. This became clear when students could not identify the relevance of their foundation units. For example, students aligned the motion unit’s relevance to things that move, such as ‘racing cars’ and ‘fluids’. Otherwise, they could not see its relevance. One civil engineering student commented that the unit was merely a broadening unit because of its focus on things that move. This was particularly concerning because it was one of four foundation units directly relevant to all engineering disciplines and yet we realised that students did not understand this. The concepts were troublesome because students did not understand the unit’s intent or content—a problem that could be addressed by educators early in the unit—and because they did not understand the roles of engineers.

4.3.2. Looking back on a future career

The final questions asked students to imagine themselves in 15 years' time and write what they would be doing at that time and what they 'dreamt' of having achieved as engineers. The responses were high level rather than specific:

> *"I would have done something to better the environment".*
> *"Achieved respect from colleagues and helped to design and complete successfully a project".*
> *"Work on the management team in an engineering firm".*

Again, several students (16% of the sample group) were unable to imagine their future careers, returning comments such as "*I don't really know"*, or: "*It's impossible to say"*. This could reflect troublesomeness (research question 2) and is likely to link with a diffuse career identity.

In terms of career aspirations, students most commonly reported a leadership role. They also mentioned work-life balance, enjoyable work and mental stimulation. Responses to this final two-part question are understandably very high level. This reveals one of the troublesome features of the two concepts insofar as students' roles as engineers will only be realised years into the future. Whilst it is difficult to understand the value of learning in advance of engineering practice, students will begin to make these links if they develop career preview through initiatives such as more (and earlier) industry experience, industry mentors, and guests lectures (Cameron, 2009, Sheppard et al., 2009, King, 2008).

4.4. Activity 5: adapted minute paper

The final activity involved a short paper, for which students were asked to write for no longer than one minute on each of two questions aligned with research question 1: Is there evidence of either threshold concept bring transformative for students? The questions were: (1) *Have you learnt anything transformative in this session? (If so, what?)* (2) *Do you feel a need to* *think further about anything raised in this session? (If so, what and why?)* Both questions are relevant to the question of threshold concepts and we explore the students' responses below.

4.4.1. Was anything transformative?

Thirty-seven students returned their papers, and twenty-four of them indicated that something had been transformative. Ten students wrote about the skills required for engineering in relation to their individual strengths and weaknesses: for example,

> *"[I] need to think more about my strengths/weaknesses and how to improve them."*
> *"I feel like I should learn what my strengths and weaknesses are and what I enjoy to do."*
> *"I will need to put myself into more situations where these skills are necessary in order to develop them."*

Students wrote about the need for career awareness (9) and self-awareness (8), working with others (3) and the need to identify goals (2). The comments suggest that students were motivated to think further about the relevance of their studies: "*It's made me think properly about my actual intentions as an engineering student*". Students were pleased to identify their strengths and they recognised that they needed to work on their weaknesses, illustrating how understanding the 'roles of engineers' links with understanding the 'value of learning' and with 'self-directed learning'.

The act of considering the 'roles of engineers' and one's individual goals was transformative because the adoption of a new way of thinking presented a new approach to learning. In the following comments, students evidence the link between understanding 'roles of engineers', 'value of learning, and 'self-directed learning'.

> *"It is important to think about where we would like to be in the future so we can get the most out of our education to lead us there."*
> *"This activity clarified my role as an engineer and highlighted my strengths and weaknesses, which I can adapt to and be aware of in the future."*

4.4.2. The need to think further

To identify whether anything had been troublesome, students were asked to identify anything about which they would need to think further. Thirty-two students responded, and of this number 26 students indicated issues needing further thought. Ten responses focused on improving personal skills and attributes, and six on establishing goals and achievements. Eleven students identified the need to think about their career and life goals. Their comments indicate transformation in the form of seeing the world differently from before: by 'redefining' engineers, thinking about career, thinking in the longer term, and establishing personal goals: for example,

> *"What I have learnt in this lesson redefined what an engineer is."*
> *"The scope of my career does not reach far enough. What if I am a success and have amassed money, what will I do then?"*
> *"Yes, I will need to think about goals in my life, particularly to do with chemical engineering."*
> *"Further thought will need to be put into what I want to do when I leave Uni and what I want to achieve in my life."*
> *"Yes, exactly what I want to achieve from my career, how I want to be remembered and how to achieve that. Being challenged to think further than the next 5 years."*
> *"Feel like I need to think a lot more about future aspirations and what I really want to get out of this degree! There's so much I still have to learn!"*
> *"Yes, as this will also affect the paths I will take during my career/life."*
> *"Thinking about life in terms of what you wish to achieve rather than just thinking about your career."*

The issue was all the more difficult for students because the deadline for selecting an engineering study discipline was fast approaching. This was on the minds of the students who made the following comments:

> *"I still need to decide what area of civil engineering I would want to do."*
> *"Possibly more research into the different fields of engineering as I am not sure what I want to do."*

> *"Maybe think further in what field of engineering I want to study to be sure that I have made the right decision in the future.*

In the first question of the paper, where students were asked to identify anything transformative in the workshop, the first student had linked this with weak career preview:

> *"Yes, that I have no idea what job opportunities (are) available for my chosen profession."*

This student was finding the threshold concept 'roles of engineers' severely troublesome. It was troublesome because she felt she had insufficient knowledge about roles of engineers, and it was troublesome because she perceived a lack of fit between 'roles of engineers' and her personal interests.

Analysis of the comments in response to this final question in the workshop helped in addressing the final research question: *For each concept is there evidence of students being in a pre-liminal, liminal or post-liminal state?* Many students identified careers and personal goals as concepts that required more thought. They had moved into a liminal space where the roles of engineers (career preview) had come into view and/or their future roles as engineers (and consequently the relevance of their engineering studies) had come into view. However, students had not addressed either issue to their satisfaction. We expect that many students need considerably more time and support to traverse these liminal spaces; and yet we found that a well-planned and interactive two-hour workshop was sufficient to spark their interest and engagement.

5. Limitations and Recommendations

If engineering educators do not help students to understand their possible future roles as engineers and, hence, the potential value of their learning, students will be dependent on possibly limited and inaccurate knowledge of engineering roles developed outside their courses. This means that students who do not have engineering in their families or networks could be unnecessarily disadvantaged. At the time of the study, students who were not already passionate about an engineering goal, and who had not developed career preview elsewhere, were at risk of remaining in the pre-liminal space for understanding ‘roles of engineers’ and the ‘value of learning’. There was evidence of students being in a pre-liminal or liminal state (question 5). Our workshop is one strategy to help bring the threshold concepts into view. By their very nature, however, threshold concepts take time to overcome; multiple experiences are necessary for students to understand roles of engineers, value of learning, and self-directed learning.

The troublesome features of ‘roles of engineers’ would be partly addressed with greater exposure to engineering practice early in engineering programs. Students would also benefit from more specific examples of roles in each engineering discipline. The accreditation guidelines for engineering programs in Australia list ways to achieve this including guest lectures, site visits, interviews with professional engineers, and industry-based projects (Bradley, 2008, p18). Furthermore, guidelines for enhancing industry engagement in engineering degree programs were recently developed by Male and King (2014a, 2014b). More widespread exposure to engineering practice throughout engineering programs is recommended.

Some of the troublesome features of ‘value of learning’ could be addressed by giving engineering students opportunities to ask questions about how their programs are relevant to their engineering goals. Students who are passionate about an engineering goal need to know whether and how their studies will be relevant. Open discussion of goals and aspirations is an effective strategy for students to look at engineering practice from multiple perspectives, and unit co-ordinators should explain the relevance of their unit to engineering practice. In our study, this would have addressed the assumption that a core foundation unit was merely a broadening unit. Moreover, establishing relevance would have prompted students to engage in the unit at a deeper level.

Future research needs to build on these findings with further iterations of the workshop strategy and the formation of resources that support students through and beyond the liminal space. More research data would also enable analysis at the level of discipline. Further exploration of the troublesome and transformative nature of these concepts will help engineering educators to support engineering students in the transformation necessary for self-directed 'learning to become an engineer' (Male, 2012b, pp.10).

6. Conclusions

In this study we investigated the previously identified threshold concepts, roles of engineers and value of learning. We collected data consistent with students entering or being in a liminal space in which the concepts had come into view but students were still finding the concepts troublesome (research question 2 and 5); and students beginning the transformation from engineering students to student engineers (research question 1). At the start of the workshop, many students were pre-liminal with respect to the concept 'value of learning' and in the liminal space with respect to 'roles of engineers'. By the end of the workshop there was evidence that students were thinking about their potential roles as engineers and seeking the relevance of their learning to those futures. By identifying roles of engineers and the weaknesses they might address in order to align their strengths with roles of engineers, and identifying relevance of learning to their futures, the students had started to take responsibility for their learning. In so doing they were beginning to think as self-directed learners.

Some students were comfortable with their understanding of the roles of engineers, and some were passionate about their future goals; however, for others the concepts were troublesome. The concept 'roles of engineers' was transformative because it opened for students the possibility of thinking about their learning in terms of its relevance to their future careers and personal goals (research question 4).

The new way of thinking raised questions and concerns. Some students were troubled by their limited knowledge about the roles of engineers. Others found the concept troubling because they believed their skills to be deficient. One student was troubled by the concept because she was unsure that engineering had been the right career choice, and many students expressed concern about career choice or course choice in relation to self (research question 3).

The evidence suggests that students find connecting the 'roles of engineers' to the 'value of learning' troublesome for the following reasons:

- Limited awareness about the characteristics of engineering practice;
- Insufficient knowledge on which to select an engineering discipline;
- Inadequate explanation of the value of learning in relation to students' future careers, at the level of either unit or course;
- An inadequate and/or inaccurate career preview compromises the ability to imagine and plan possible future lives and careers;
- Personal weaknesses are viewed as innate or not developable within the student's engineering program; and
- Uncertainty that the engineering program will prepare students to achieve their engineering goals.

By identifying the transformative value of the threshold concepts 'roles of engineers' and 'value of learning' in helping students become 'self-directed learners', this study adds weight to calls for engineering educators to help students overcome them. Identifying the reasons for which the concepts are troublesome should inform the design of curricular interventions that help students undergo the transformation required to identify and overcome the thresholds required to learn to think and understand like an engineer.

Acknowledgements

This paper builds on David Parkinson's final-year research project, for which he is thanked. Caroline Baillie and Sally Male supervised David's project. We are grateful to the students who participated in the workshops, to coordinators Dianne Hesterman and Andrew Guzzomi, and to the unit's workshop facilitators.

References

.

AUSTRALIAN COUNCIL FOR EDUCATIONAL RESEARCH 2014. Findings from the Australian Survey of Student Engagement (AUSSE). Melbourne: Australian Council for Educational Research.

BAILLIE, C. & JOHNSON, A. 2008. A threshold model for attitudes in first year engineering students. *In:* LAND, R., MEYER, J. H. F. & SMITH, J. (eds.) *Threshold Concepts within the Disciplines.* Rotterdam & Taipei: Sense Publishers.

BEN-NAIM, D. & PRUSTY, B. G. 2010. Towards a Community of Practice Concerning the Use of Adaptive Tutorials in Engineering Mechanics. *In:* GARDNER, A. & JOLLY, L. (eds.) *21st Conference of the Australasian Association for Engineering Education Conference.* Sydney: Faculty of Engineering & Information Technology, University of Technology Sydney.

BENNETT, D. 2012. A creative approach to exploring student identity. *The International Journal of Creativity & Problem Solving* [Online], 22. Available: http://creativity.or.kr.

BENNETT, D. & MALE, S. A. under review. An Australian study of possible selves perceived by undergraduate engineering students.

BROPHY, J. 2013. *Motivating Students to Learn,* Abingdon, Routledge.

CAMERON, I. 2009. Engineering Science And Practice: Alignment And Synergies In Curriculum Innovation. Strawberry Hills, NSW: Australian Learning & Teaching Council.

CARSTENSEN, A.-K. & BERNHARD, J. 2008. Threshold concepts and keys to the portal of understanding: Some Examples from Electrical Engineering. *In:* LAND, R., MEYER,

J. H. F. & SMITH, J. (eds.) *Threshold Concepts within the Disciplines.* Rotterdam: Sense Publishers.

FAULKNER, W. 2007. "Nuts and Bolts and People": Gender-Troubled Engineering Identities. *Social Studies of Science,* 37**,** 331-356.

FLANAGAN, M. T., TAYLOR, P. & MEYER, J. H. F. 2010. Compounded Thresholds in Electrical Engineering. *In:* MEYER, J. H. F., LAND, R. & BAILLIE, C. (eds.) *Threshold Concepts and Transformational Learning.* Rotterdam: Sense Publishers.

HARLOW, A., SCOTT, J., PETER, M. & COWIE, B. 2011. 'Getting stuck' in analogue electronics: threshold concepts as an explanatory model. *European Journal for Engineering Education,* 36**,** 435-447.

KING, R. 2008. Addressing the Supply and Quality of Engineering Graduates for the New Century. Surrey Hills NSW: Carrick Institute for Learning and Teaching in Higher Education.

LAND, R., COUSIN, G., MEYER, J. H. F. & DAVIES, P. 2006. Implications of Threshold Concepts for Course Design and Evaluation. *In:* MEYER, J. H. F. & LAND, R. (eds.) *Overcoming Barriers to Student Undersanding, Threshold Concepts and Troublesome Knowledge.* London and New York: Routledge.

LINDSAY, E., MUNT, R., ROGERS, H., SCOTT, D. & SULLIVAN, K. 2008. Engineering students or student engineers? *Annual Conference of the Australasian Association for Engineering Education.* Yeppoon: Australasian Association for Engineering Education.

MALE, S. & KING, R. 2014a. Best Practice Guidelines for Effective Industry Engagement in Australian Engineering Degrees. Available: http://www.arneia.edu.au/resource/59 [Accessed 16 June 2014].

MALE, S. & KING, R. 2014b. Improving Industry Engagement in Engineering Degrees. *Australasian Association for Engineering Education Conference.* Wellington, New Zealand.

MALE, S. A. 2012a. Engineering Thresholds: an Approach to Curriculum Renewal Final Report. Sydney: Australian Government Office for Learning and Teaching.

MALE, S. A. 2012b. Integrated Engineering Foundation Threshold Concept Inventory. Sydney: Australian Government Office for Learning and Teaching.

MALE, S. A. & BAILLIE, C. A. 2011a. Engineering Threshold Concepts. *SEFI Annual Conference.* Lisbon: European Society for Engineering Education.

MALE, S. A. & BAILLIE, C. A. 2011b. Threshold Concept Methodology. *In:* HERNANDEZ, W. (ed.) *Research in Engineering Education Symposium.* Madrid: Universidad Politécnica de Madrid.

MALE, S. A. & BAILLIE, C. A. 2014. Research guided teaching practices: Engineering thresholds; an approach to curriculum renewal. *In:* JOHRI, A. & OLDS, B. (eds.)

Cambridge Handbook of Engineering Education Research. Cambridge University Press.

MALE, S. A., GUZZOMI, A. L. & BAILLIE, C. A. 2012. Interdisciplinary threshold concepts in engineering. *In:* BROWN, N., JONES, S. M. & ADAM, A. (eds.) *Research and Development in Higher Education: Connections in Higher Education.* Hobart: Higher Education Research and Development Society of Australasia.

MCCARTNEY, R., BOUSTEDT, J., ECKERDAL, A., MOSTRÃ¶M, J. E., SANDERS, K., THOMAS, L. & ZANDER, C. 2009. Liminal spaces and learning computing. *European Journal of Engineering Education,* 34**,** 383 - 391.

MEYER, J. H. F. & LAND, R. 2003. *Enhancing Teaching-Learning Environments in Undergraduate Courses Occasional Report 4* [Online]. Centre for Teaching, Learning and Assessment, The University of Edinburgh. Available: http://www.etl.tla.ed.ac.uk/docs/ETLreport4.pdf [Accessed 31 May 2010.

MEYER, J. H. F. & LAND, R. 2005. Threshold concepts and troublesome knowledge (2): Epistemological considerations and a conceptual framework for teaching and learning. *Higher Education,* 49**,** 373-388.

MEYER, J. H. F. & LAND, R. (eds.) 2006. *Overcoming Barriers to Student Understanding: threshold concepts and troublesome knowledge* London and New York: Routledge.

PALMER, S. 2007. Authenticity in assessment: reflecting undergraduate study and professional practice. *European Journal for Engineering Education,* 29**,** 193-202.

PARKINSON, D. 2011. *Investigation of Experiences of Threshold Concepts by Engineering Students* BE Final Year Project Thesis, The University of Western Australia.

PERKINS, D. 2006. Constructivism and troublesome knowledge. *In:* MEYER, J. H. F. & LAND, R. (eds.) *Overcoming Barriers to Student Understanding: Threshold concepts and troublesome knowledge.* London and New York: Routledge.

RAMSDEN, P. 2003. *Learning to teach in higher education,* London and New York, RoutledgeFalmer.

SHEPPARD, S. D., MACATANGAY, K., COLBY, A. & SULLIVAN, W. M. 2009. *Educating Engineers Designing for the Future of the Field,* San Francisco, CA, Jossey-Bass.

SMAILL, C. R., ROWE, G. B., GODFREY, E. & PATON, R. O. 2012. An Investigation into the Understanding and Skills of First-Year Electrical Engineering Students. *IEEE Transactions on Education,* 55**,** 29-35.

TREVELYAN, J. P. Are we accidentally misleading students about engineering practice? *In:* HERNANDEZ, W., ed. Research in Engineering Education Symposium, 4-7 October 2011 Madrid. Universidad Politecnica de Madrid.

TULADHAR, R., PANDEY, G. R., CHRISTIE, D. & TURNER, P. 2014. Turning Tedious to Terrific: An Authentic Learning Experience to Engage Engineering Students in

Project Management. *Australasian Association for Engineering Education.* Wellington.

WENGER, E. 1998. *Communities of Practice - Learning, Meaning and Identity,* New York, Cambridge University Press.

ZANDER, C., BOUSTEDT, J., ECKERDAL, A., MCCARTNEY, R., MOSTROM, J. E., RATCLIFFE, M. & SANDERS, K. 2008. Threshold concepts in computer science: a multi-national empirical investigation. *In:* LAND, R., MEYER, J. H. F. & SMITH, J. (eds.) *Threshold Concepts within the Disciplines.* Rotterdam & Tapei: Sense Publishers.