ENGAGING STUDENTS IN ENGINEERING CURRICULUM RENEWAL USING THRESHOLD CONCEPTS

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ABSTRACT

In 2009 the University of Western Australia announced a transition to a new Bologna-style ("3+2") course structure, and began planning for implementation in 2012. In this structure, professional qualifications such as engineering would be completed in a two year masters programme, following an undergraduate programme that balances depth with breadth. The Faculty of Engineering, Computing and Mathematics recognised this as an opportunity for generational change in its programmes. Had the attributes and competencies required evolved since the current courses were designed, and what would be the best practice course for coming decades? In answering these questions we brought to bear ideas from a range of engineering education literature and expertise, including CDIO and problem-based learning, studies of graduate competencies, input from accreditation bodies including Engineers Australia, and threshold concept theory [1-5]. A key principle of the new engineering course design was that students should develop a rigorous mastery of engineering fundamentals and a shared common experience, before proceeding to discipline-specific studies. To achieve this, we developed a set of integrated engineering foundation units, complemented by studies in mathematics, computing, physics and chemistry. A key approach to the integration of the engineering foundation material was the use of threshold concept theory. This is a new theory in higher education, which recognises that many disciplines have key concepts that form a barrier to progress, but once mastered are transformative: they can be thought of as gateways to student progress [6]. This can be used to improve student learning, and also focus an otherwise crowded curriculum [7]. We engaged students and academics in improving engineering education in the foundation units. The approach could be used to focus any engineering curriculum. One of the most interesting results observed in the workshops with both students and staff was the cross-disciplinary nature of the thresholds that emerged. By identifying threshold concepts we have focused lessons on the concepts most transformative and troublesome for students. The paper describes how we identified the threshold concepts, some of the threshold concepts and insights that were identified by students, and curriculum features resulting from the threshold concept approach.

KEYWORDS

threshold concepts, curriculum development, engineering education, student engagement

INTRODUCTION

In 2009 The University of Western Australia (UWA) announced a transition to a new Bologna-style ("3+2") course structure, and began planning for implementation in 2012. In this structure, professional qualifications such as engineering would be completed in a two year masters programme, following an undergraduate programme that balances depth with breadth.

Members of the Faculty of Engineering, Computing and Mathematics at UWA recognised this as an opportunity for generational change in its programmes. In particular it was seen as an opportunity to look at the proliferation of some 13 engineering programmes and majors and identify the core concepts and skills that engineers needed to understand, and the degree of commonality between disciplines. Had the attributes and competencies required evolved since the current courses were designed, and what would be the best practice course for coming decades?

In answering these questions we brought to bear ideas from a range of engineering education literature and expertise, including CDIO and problem-based learning, studies of graduate competencies including the views of engineers, input from accreditation bodies including Engineers Australia, and threshold concept theory [1-5].

Threshold concept theory is a new theory in higher education, which recognises that many disciplines have key concepts that form a barrier to progress, but once mastered are transformative: they can be thought of as "gateways" to student progress [6]. This can be used to improve student learning, and also focus an otherwise crowded curriculum [7].

A key principle of the new engineering course design was that students should develop a rigorous mastery of engineering fundamentals and a shared common experience, before proceeding to discipline-specific studies. It has been found that engineers require sound fundamental competencies in engineering disciplines beyond their own [8]. To achieve this, we developed a set of integrated engineering foundation units, complemented by studies in mathematics, computing, physics and chemistry.

The threshold concept framework was well-suited to developing the integrated foundation engineering units because it helped us identify concepts that are manifested in more than one engineering discipline, such as system identification, abstraction, and dimensional reasoning [9]. Other researchers have previously identified threshold concepts in specific units or disciplines of engineering such as mechanics, electronic fundamentals, and computer science [10-12]. Our study is the first to identify threshold concepts across an integrated foundation engineering curriculum.

We engaged students and academics as participants in research that identified and investigated threshold concepts to inform the development of the foundation units. This paper describes our approach, focusing especially on student engagement, and the features of the curriculum that arose from the threshold concept approach. The approach could be used to focus any engineering curriculum.

METHODOLOGY

In this section we explain how our approach is consistent with the theoretical framework. The following section 'Method' describes the procedure. Threshold concept theory describes how some concepts, namely 'threshold concepts' can be transformative and troublesome for students. The focus of the theory, and therefore the focus of our approach to identifying threshold concepts, is students' experiences of concepts as they come into view and as they become understood and accepted by students.

Threshold concepts for whom?

Threshold concept theory emerged from the phenomenographic approach to educational research [13]. This approach traditionally explores levels of conceptual understanding of a concept among students. Therefore, researchers using the threshold concept framework expect students to experience and understand concepts differently. We understand threshold concepts to be experienced by students, not only due the nature of disciplinary concepts, but also arising from characteristics of students including their educational backgrounds. Further, we understand that students' experiences of concepts, as threshold or otherwise, are influenced by curriculum. Therefore we expected that students' experiences of concepts, and whether they experience concepts as thresholds, would differ across individual students, cohorts, and universities.

Our approach was developed to identify concepts commonly experienced as thresholds by students, in order to inform curriculum development. We first identified potential threshold concepts, experienced by at least one student. Participants then negotiated these in workshops in order to identify concepts experienced by many students as thresholds.

Our research to identify threshold concepts used qualitative methods including interviews, focus groups, and workshops. Participants in interviews and focus groups were asked to identify potential threshold concepts by referring to their experience as or with students, or based on assessments, to provide evidence that students find the concept transformative and troublesome. Students described concepts they experienced as thresholds and reasons related to the nature of the concept, previous learning, or the engineering curriculum. Teachers described examples of concepts students asked about, times when students had not understand questions, and mistakes students had made. In doing so, teachers and students referred to students' experiences of concepts as thresholds. Students often referred to their own experience and student tutors referred to groups of students. Academics often estimated that high percentages of students (e.g. 90%) had experienced the concept as a threshold. In no case could it be concluded that an identified threshold concept was threshold to every student. However, in every case, an identified threshold concept was experienced a threshold to at least one student. Hence through interviews and focus groups we identified 'potential' threshold concepts.

In workshops, participants negotiated the previously identified potential threshold concepts. Through this process our inventory of potential threshold concepts was refined because concepts underlying several previously identified concepts were recognised. Through this process we also confirmed that concepts previously identified by possibly just one student, were considered to be threshold by other participants based on their experiences of other students.

Through our methodology we have developed a negotiated inventory of threshold concepts likely to be experienced by many students as transformational therefore worth learning, and troublesome therefore likely to require considerable attention from teachers and students.

METHOD

Semi-structured interviews and focus groups were held with participants involved in individual disciplines or units at our university, to identify potential threshold concepts. Workshops were held with participants from across disciplines at our university and across universities, in Perth, Adelaide and Melbourne. At the workshops participants negotiated potential threshold concepts and identified further potential threshold concepts.

Most interviews and focus groups were undertaken by the first author, who has a background in electrical engineering and PhD in engineering education. Five interviews with first year students were undertaken by a final year student and a postgraduate student. Workshops were facilitated by members of the research team. All have engineering backgrounds and several have extensive experience in research in engineering education.

Participants

We held interviews or focus groups with 15 engineering academics at UWA, 12 students, and 13 student tutors. Academics were interviewed individually and in one case in a pair. Students were interviewed in focus groups, where possible, as we considered these less daunting. Student tutors were interviewed in four groups of tutors for each of our four first year units. Most interviews and focus groups were about an hour long, some up to 90 minutes. Three of the focus groups with student tutors were also attended by the unit coordinator.

At UWA we held a student workshop attended by 15 students, and a student-staff workshop attended by 7 of the same students and 8 teachers. In Perth, Adelaide, and Melbourne, 43, 12, and 21 engineering teachers respectively attended workshops. Participants were from 15 universities. Twenty participants from our university then attended a workshop to further negotiate the negotiated threshold concepts. Except students, workshop participants were mostly engineering academics and also included 15 postgraduate students, three academics from mathematics, two from computing, and one from chemistry.

Protocols

The interview and workshop protocols have been described elsewhere [14]. Every data collection event began with an introduction to the project and to threshold concept theory for the participants. Any relevant threshold concepts already identified were noted. In the interviews and focus groups participants were then asked to identify threshold concepts and explain, using evidence from their learning or teaching, why they considered the concepts to be transformative and troublesome. Participants were also invited to suggest ways to help students overcome the thresholds and to assess the transformation. The protocol for the interviews with first year students was slightly different as the theory was not explained and terminology related to the theory was avoided.

The workshops followed a similar structure to the interviews. However, participants negotiated identified threshold concepts in groups. Except at the student workshop and student staff workshop, each group had a nominated facilitator, preferably a member of our project team, who had been prepped. The roles of the facilitator included keeping the discussion on potential threshold concepts rather than on the theory, ensuring everyone participated, ensuring notes were taken, and asking probing questions.

Data collected included notes, transcribed recordings, and completed questionnaires used in the workshops. These questionnaires listed questions similar to those used in the interviews.

ANALYSIS

Data were analysed to gather evidence of threshold concepts, how they are transformative, how they are troublesome, and suggestions for helping students overcome them. An inventory of threshold concepts was developed iteratively. Each item identifies the concept, how it is transformative (i.e. how it is important), how it is troublesome (i.e. how it causes of difficulties), and any suggestions to help teach the concept. Transcripts were analysed holistically to understand each participant's view rather than by coding isolated words or phrases of responses.

FINDINGS AND IMPLICATIONS ARISING FROM ENGAGEMENT WITH STUDENTS

Identified threshold concepts were inter-related. Some were very specific, such as the physical significance of solutions to differential equations, and others, such as modelling, were higher level and required understanding of several specific threshold concepts. Furthermore, it was deemed likely that many students would take years to develop a strong understanding of the high level threshold concepts such as modelling. Therefore course structures must provide extended opportunities for students to develop understanding of some threshold concepts and it is not realistic to stipulate ideal numbers of threshold concepts per unit.

The focus of this paper is the findings arising from engaging with students in the process outlined above. We identified several findings that have arisen from our engagement with students. First, students provided a first-hand impetus for curriculum change. Second, students revealed ways teachers have unwittingly created threshold concepts that could be made less troublesome. Third, students identified threshold concepts, many with very specific examples, that teachers were later able to recognise as manifestations of underlying threshold concepts. Fourth, students gave us understanding of the feelings that students can experience when they are struggling with a threshold concept. Fifth, students also helped us understand some of the sources of threshold concepts. Sixth, and finally, students were able to suggest ways to help them overcome threshold concepts. Examples are presented below.

Elephants in the Curriculum

First, students uncovered the 'elephants' in the curriculum. The first quotation below revealed a student tutor's experience of insufficient opportunity for students to explore a concept before lessons moved onto the next topic. The second quotation drew attention to assigned problems that tested ability to apply an equation, but did not test or encourage development of understanding of concepts.

> And it kind of feels like … this is where we're going with it but we're going to stop you off just as you are kind of getting into it. (student tutor)

> a lot of students weren't encouraged to actually think about the concept, but managed to get by by applying different equations and understanding what the equations meant. Yeah. Which you'll find students will tend to do. (student)

Implications

Many academics were aware of the above possible problems. However, without hearing the student voice, it can be easy to pretend the issues are not real. The above comments reminded us of potential problems with traditional crowded engineering curricula.

Unwittingly Created Threshold Concepts

Second, students revealed unnecessary difficulties they experienced [15]. One student noted that students were assumed to have computing knowledge that some did not have, and a unit in which many students using new computing skills also required students to apply engineering science they were learning at the same time. Hence threshold concepts were clustered unnecessarily.

Implications

By consulting with students we revealed potential problems that we might have missed and which can be relatively easily remedied. Problems such as those identified above could be sources of great frustration for first year students. Engineering courses in Australia still have high attrition rates. Therefore identifying simple sources of unnecessary difficulty for students is critical. Our threshold concept approach provides a better structure to focus students on learning issues, than might a more general opportunity for students to comment.

Threshold Concepts on which to Focus

Third, students and student tutors identified potential threshold concepts and even specific difficulties experienced by students that prompted teachers to recognise underlying threshold concepts, or were consistent with teachers' thoughts. An example of a concept that was agreed upon by teachers and students, and emerged in the student staff workshop is the concept of computer programming as a reference activity rather than a memorising activity. This was seen to open up a sense of ability to learn to program, where the importance of grammar is understood to be significant but the overwhelming initial conception that every command must be memorised is overcome. Other concepts clearly agreed upon were dimensional reasoning including dimensional scaling, and modelling and abstraction. Examples of concepts that were identified as very specific examples by students are the representation of a circular vector as a vector along the axis of rotation, and the difference between change in speed and acceleration in circular motion. These were identified by a student in the student workshop, and by dynamics tutors. They were later recognised in the Perth workshop among teachers from various disciplines, as specific difficulties arising from the threshold concept of vectors [16].

Implications

Identifying threshold concepts is the main point of this project. We have focused the new curriculum on negotiated threshold concepts. We have drawn students' and teachers' attention to the threshold concepts and ensured that they are well-spaced in the curriculum. Students are expected to learn about simple concepts in their own time. Class time is spent on interactive opportunities to explore the threshold concepts.

Understanding How Students Can Feel

Fourth, engaging with students helped us understand students' experiences in ways that we could access in no other way. In the student workshop one student described how he did not pay enough attention to mathematics when it was taught early in his course because he thought it was not relevant to his engineering units. One of the dynamics student tutors described how it was especially disconcerting to struggle in dynamics having taken pride in aptitude for physics at school. Without engaging with students, curriculum planners would not be aware of issues such as these.

Implications

Students' feelings are central to threshold concept theory. While a concept is troublesome the student has not yet experienced the transformation to have capability to apply the concept in an unfamiliar context. The student must not only understand the concept, but also accept the new understanding. It is critical that we are aware of students' reasons to be disconcerted in order to help students overcome troublesome features of a concept.

Sensitivity to students' feelings could also help us minimise attrition. For example, if a teacher can normalise feelings of angst around a threshold concept then the student might be less likely to individualise his or her feelings and feel able to ask for help.

Sources of Threshold Concepts

Student tutors in dynamics were able to help us understand how concepts taught in physics at school were different from the more generic models that must be developed in university. One of our academics had noticed that students assumed beams were simply supported and drew free body diagrams assuming this. The tutors confirmed this suspicion and also described other similar examples. Surprisingly, one student tutor had not studied physics at school and felt this was an advantage to her in engineering.

Implications

The insights students can provide about sources of threshold concepts are invaluable. These insights help teachers to design learning opportunities that help rather than hinder students to overcome threshold concepts

Suggestions to Help Students Overcome Threshold Concepts

Students had many ideas about how to help students overcome threshold concepts. They recommended that mathematics be taught with engineering examples to reveal the application and motivate students to learn. They noted from experience that they were better tested by assessment questions that demanded explanations rather than substituting given values into equations. The quotation below describes the value of learning together through discussing different approaches.

> Most tutorials tend to just be: there's a tutor, 'This is the problem. This is how you do the problem. Any questions. OK, see ya.' I find the better ones are definitely where they say, 'OK this is the problem. You can approach it in different ways. Discuss it. Work it out… in the engineering world, that's what would happen.' You would be given a problem…You would share your ideas. You would work out how to solve it using the tools around you, not 'here you go. This is how you do the problem. Please do the maths and give me the answer.' (student)

Implications

Students' reflections on their experiences about curriculum development must be combined with teachers' reflections and educational theory to inform curriculum development.

Curriculum Development

Findings made by engaging with students and academics to identify and investigate threshold concepts have helped the team of people developing the first two years of the new engineering science major with their curriculum development. Threshold concepts are explicitly taught in the curriculum. Lesson time focuses on interactive learning experiences to help students develop understanding of identified threshold concepts, and troublesome features identified by students are addressed. This has fitted well with features aligned with CDIO and problem based learning. In each of the four foundation engineering units students have two interactive two-hour sessions in groups of about 25 students each week. One of these sessions is practical. Students undertake practical projects in groups in each of the four units. In the Global Engineering Challenges unit students conceive, design and implement a design to address an engineering challenge such as waste in one of three contexts. This has features of problem-based learning. In the Motion unit students conceive, design, implement, and operate a rocket.

CONCLUSIONS

By engaging students in identifying, exploring, and negotiating threshold concepts, we have discovered features of students, concepts, and the curriculum that lead to threshold concepts. We have used this to improve learning and assessment of the concepts that are most significant to future learning and demand the most attention from students and teachers.

Findings of the nature we made by engaging with students are likely to be found by curriculum developers elsewhere. The specific findings, such as the sources of threshold concepts for a particular cohort of students or curriculum in place at a university, are likely to be different from our findings. We recommend the threshold concept approach we have developed as a way to effectively engage students in curriculum development. Findings can inform curriculum development that fits within approaches such as CDIO and problem-based learning.

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