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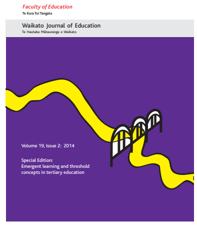

Modularisation of learning outcomes in terms of threshold concepts

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Abstract

This paper addresses the proposed development, and the beginning of the implementation of the restructuring, of an engineering undergraduate curriculum in Australia, into a series of concept modules.

We propose a transposition of curriculum design by starting with smaller modules. Each module addresses precisely defined learning outcomes but no more than one identified transformative threshold concept. These modules can be delivered in a coherent sequence of focused themes. The coherence can be determined by academics, such that sets of modules that address the same concepts can be delivered in parallel, to offer an opportunity for students to choose a context specific to a discipline. The benefit of this module approach is a succinctly defined focus on the required concepts at key points throughout the program. The precise definition of each module focuses academics, tutors and teaching effort on the required concept covered by the module. This ensures the integrity of the overall curriculum for all stakeholders.

The top-down design specifies the learning outcomes for the degree program in terms of accreditation requirements for specific engineering disciplines. The program is delivered by semesterised teaching units. At this intermediate level, a teaching unit addresses a single transformative threshold concept in a coherent sequence of concept modules informed by the threshold concept. Each module is a self-contained teaching unit focused on a clearly identified skill and knowledge concepts in the context of the students' chosen engineering discipline, for example, mechanical engineering, electronic engineering.

Keywords

Threshold concepts, engineering education, curriculum design, integrated engineering, concept modules

Introduction

During a review of our university's engineering program, we have sought to prioritise students' thinking and understanding and draw in didactic teaching of knowledge only to set a context for the discussion. The design and presentation of a traditional engineering program is focused on the delivery of a body of knowledge (BoK). This approach places a priority on the coverage of information, often at the expense of understanding. The implementation is a collection of teaching units that each deal with a multitude of difficult concepts that underpin a specific topic. Threshold Concept Theory (TCT) provides a useful basis for better defining the learning outcomes.

Our solution to this tension between BoK instruction and the pedagogical opportunities of threshold concepts, as outlined by Meyer and Land (2003) and Cousin (2006), is to permit the implementation of more focused themes and learning outcomes based on threshold concepts. That is, to present threshold concepts within a modular framework. One significant result from this approach has been the development of a finer grained framework of the curriculum with clearly articulated learning outcomes due to the closer integration of the learning outcomes within the modular framework.

The role of understanding in learning has driven our research program and our examination of the idea of threshold concepts. The application of threshold concepts is being broadly considered in many professional disciplines and has received considerable development in the area of electronic engineering education (Meyer & Land, 2005, 2006; Land, Cousin, Meyer & Davies, 2005; Atherton, 2013). Atherton makes the point that getting a student to "think like an engineer…may be the ultimate goal" (Atherton, 2010). We believe that the discussion in this article is applicable to all fields of education that have required learning outcomes.

We make a distinction between threshold concepts and what we identify as "key concepts". While the number of threshold concepts within a whole curriculum is arguably limited—we believe there are perhaps ten within the whole engineering curriculum—these are supported by a sequence of key concepts. For our discussion, we consider threshold concepts to be *transformative* in that they radically challenge and change the students' approach to the BoK, whereas a key concept is of an *associative* nature, in that it is closely aligned to, and supportive of, the threshold concept being developed.

This paper is a developmental discussion of the modularisation approach and we expect that further work will refine the elements and approaches being deployed. We believe, however, that our approach is innovative and has the potential to contribute to issues associated with the broader debate on contemporary pedagogy in the engineering field.

The next section provides background to implementing a flexible, integrated curriculum in large classes. Then section 3 critiques the existing BoK approach and introduces a new threshold concept approach. This is followed by a theoretical discussion before section 5 proposes the idea of concept modules to implement the new approach.

Background

The motivation for addressing the shortcomings of current curriculum design in the engineering faculty are: rapid growth in student numbers, and a decision to offer an engineering program with a foundation that integrates several discipline areas of engineering. The early phase of the re-development of this program presents significant challenges but also offers opportunities for innovative curriculum development. With rapid cohort growth and integration come new staff, demands on flexibility, and opportunities for implementation of alternative delivery modes.

The objectives that have been set for the development of our program are integration of mechanical and electronic fundamentals, identification and provision of flexible student pathways, and accommodation of increased class sizes.

Integration

Integrating disciplines into one program of study is at odds with the desire to deliver discipline specific bodies of knowledge. Integration implies a fair portion of common teaching units, so specialisation in terms of the BoK must be limited. However, Engineers Australia's (Bradley, 2008) guidelines recommend that only one fifth of the program is specialisation specific, so the remaining four-fifths would, on the face of it, be presented as an integrated offering. The implication is that four-fifths of the curriculum should be taught in common to all engineering students. While there is a significant portion of clearly shared learning outcomes, such as those related to professional practice and a component of obviously shared science background, the remainder is usually presented in discipline specific contexts.

The problem is that in practice, less than four-fifths of the curriculum is taught in the same classes. For example, it is usual to stream mechanical students into a class dealing with oscillating springs and electrical students into a class dealing with tuned circuits. Although the technical context of these streams is quite different, they both deal with the shared concept, 'second-order excitation of systems.' Therefore, although less than four-fifths of the classes may be in common, four-fifths of an integrated program can be designed to share the same threshold concepts.

Integration of disciplines into one program can be readily envisaged in terms of shared threshold concepts. The requirement for a significant commonality in an integrated program can be articulated in terms of themes and learning outcomes defined by threshold concepts. The result is that coherent streaming of the BoK accommodates diversity of specialisations within the development of the shared threshold concept.

Flexibility

Traditional engineering foundation units include a non-negotiable mix of fundamental science background and broader cultural and institutional induction. However, the foundation should accommodate students entering the program with various levels of prior learning, such as trade qualifications, transfers from other degree programs, or international qualifications. Achieving flexible student pathways through the foundation requires close matching of future and previous studies. A one-size-fits-all approach is not able to achieve this, so some flexibility in choice is required.

Separating the foundation concepts into modules provides flexibility to offer alternative bridging options to students with prior learning. To achieve this, there needs to be room for choice of options within teaching units. The nature and definition of each module need to be considered.

Threshold concepts provide a natural basis for defining modules. Teaching units designed in terms of threshold concepts enables easier delineation of previous learning modules. Moreover, students can readily transfer between engineering disciplines, such as Mechanical and Electrical, with a surety that they have encountered the necessary threshold concepts, albeit in a different context.

Large class sizes

To maintain the small-group interactions with students, as cohort sizes increase, requires a structured approach to teaching assistance and support. To achieve the learning outcomes, the teaching staff—tutors, demonstrators and guest lecturers—need a clearly and precisely defined curriculum. Prescribing a single threshold concept can focus the teaching assistant's efforts more clearly than a list of informative topics.

Engineering program design

Traditional engineering program design (BoK) considers the level of qualification relative to duration of study. The typical four-year engineering program is traditionally packaged into a set of teaching units over eight semesters. Under the Australian Qualification Framework (AQF Council, 2013), the last year of study is at graduate (AQF8) level, so the first three years can be considered as an undergraduate program (AQF7). These two levels of qualification are achievable within different time frames. The program design must also consider the learning outcomes and objectives. For accredited programs, the overall learning outcomes must conform to Engineers Australia's Stage 1 Competencies, Engineers Australia (Bradley, 2008). This imposes a course structure where learning outcomes and teaching praxis are implemented in terms of required competencies and body of knowledge (Bradley, 2008).

Program design must also consider implementation. Programs of study are delineated into teaching units defined by discipline and areas of study. For example, these programs would comprise elements of introduction to electricity, calculus, project management, advanced telecommunications, and others. The program structure ensures that the required units are delivered to meet the overall learning outcomes (Parker & McGill, 2009).

The challenge in the traditional design of a program is the management of large numbers of learning outcomes. This problem is further explored in the following section prior to proposing a solution to reduce the number of outcomes that need to be managed at the program level.

Traditional body of knowledge (BoK) approach

At the intermediate, or unit level, there is a requirement to meet the program objectives at an appropriate level. Thus, learning outcomes for individual teaching units are typically defined by a required set, or list, of knowledge concepts consistent with Engineers Australia's Stage 1 Competencies. That is, the outcome is defined in terms of a required body of knowledge. The aim of the unit becomes the presentation of knowledge and assessment at the required level.

The standard BoK approach tends to be characterised as a process of teaching to a prescribed list of information that is imparted directly to the students. Consequently, assessment tends to be in the form of demonstrating recall of information in an examination of that teaching unit. We believe that the success of a unit, delivered according to this approach, has often been measured by the academic's coverage of topics, rather than the student's learning of what is being taught; none of which is helpful to the student in achieving the required learning outcomes.

Our new approach conflates cognate topics from the BoK into each teaching unit without compromising clarity in the development and presentation of the curriculum. Traditionally, these are developed sequentially along with, possibly several, relevant threshold concepts.

The BoK approach also leads to a focused teaching within the individual unit, and away from the role of the unit within the program. In seeking to deliver a comprehensive BoK, the unit can stray from the requirements of the overall program. This diversion can displace aspects of understanding required for subsequent units in the program, which leads to a loss of program integrity. A consequence is that a student may not develop a critical understanding of the aims of each unit within the program.

Program design needs to ensure that the integrity of the program objectives is guaranteed, that there is a measured development of threshold concepts, and that the aims are clearly and accountably visible to the student and the teaching staff.

Threshold concept approach

The solution proposed here is that the top-down design of engineering programs should be carried out in terms of a deliberate focus on threshold concepts. This approach addresses the issues of program integrity of delivery, integration, flexibility, and student learning outcomes.

The idea is to structure all aspects of program design and teaching around threshold concepts. The basic teaching module should consider only one main threshold concept supported by a series of key concepts. In this way, the program should be considered as a coherent set of threshold concept-focused modules.

Understanding over knowledge

Delineating threshold and key concepts into modules throughout the program places an emphasis on understanding each concept. This mandates the clear articulation of the concepts required in the whole of the program, their context at each position in the program, and the specific concept that is to be developed at each and every point in the program.

Topics from the BoK are incorporated taking into consideration the threshold concept being taught and the position of the module in the program. At each point in the curriculum, a learning outcome is precisely specified, developed, and assessed within the concept module.

The key innovation of this approach is that the curriculum is delivered as a structured sequence of modules that develop concepts. These concepts and the associated required BoK are conditionally linked to the appropriate transformative threshold concepts. The consequence is that emphasis is placed on understanding through development of threshold concepts rather than coverage of an undifferentiated list of topics.

Theoretical discussion

Research indicates that it is better to teach only one threshold concept at a time (Scott & Harlow, 2012). In our engineering program, there is a requirement to meet the program objectives at an appropriate level and the learning outcomes for each unit or subject are typically defined in terms of a required BoK. However, we want to avoid situations where too many threshold concepts are developed at one time.

It is not possible for students to effectively engage with more than four or five threshold concepts at any one time. In the teaching semester, where students are engaged in four parallel units of study, the implication is that each unit should deal with no more than one threshold concept at any one time. We believe that in terms of a student's cognitive learning, teaching at this limit would be continually pushing students at full capacity. However, the number of threshold concepts is limited, so the normal teaching pattern should be that, at any one time, the four units each deal with a single "threshold concept" and others support this with additional "key concepts" that are not 'threshold' in nature.

A consequence of the need to manage the roll-out of key concepts and threshold concepts is that their role in the overall program of each teaching unit and their relationship to each other must be clearly articulated. Defining these roles simply in terms of an area from a BoK leads to teaching focused within the discipline of the individual unit, and away from the purpose of the unit within the program.

This is because the aim becomes the delivery of a comprehensive BoK rather than the mastery of concepts required for overall program.

Program modularisation

The solution proposed here is that the top-down design of engineering programs should be carried out by structuring all aspects of program design and teaching around threshold and key concepts. The program should be considered as a coherent set of concept modules following a developmental sequence of threshold concepts and the basic teaching module should consider only one main threshold concept. This approach addresses the issues for program integrity of delivery, integration, flexibility, and student learning.

Macro-level program structure

The typical BoK that can be accommodated in a program could comprise some 600 or more topics on the basis that only one is introduced in each lecture. Teaching two or more engineering disciplines in parallel streams adds even more topics. The notion of managing and accounting for a thousand odd topics would be overwhelming for both students and teachers for any coherent program of study. At the macro-level, the program must be managed more broadly.

In the BoK approach, the task is managed by grouping topics into subject areas and listing several specific learning outcomes for each teaching unit. Although this prescribes the high-level grouping to be delivered, it does not mandate every single topic from the BoK.

A better perspective from which to manage the program of study at a macro-level is to identify a list of concept modules essential for the qualification. The topics from the BoK can then be grouped in terms of these modules and thus there is also no requirement to address every single one.

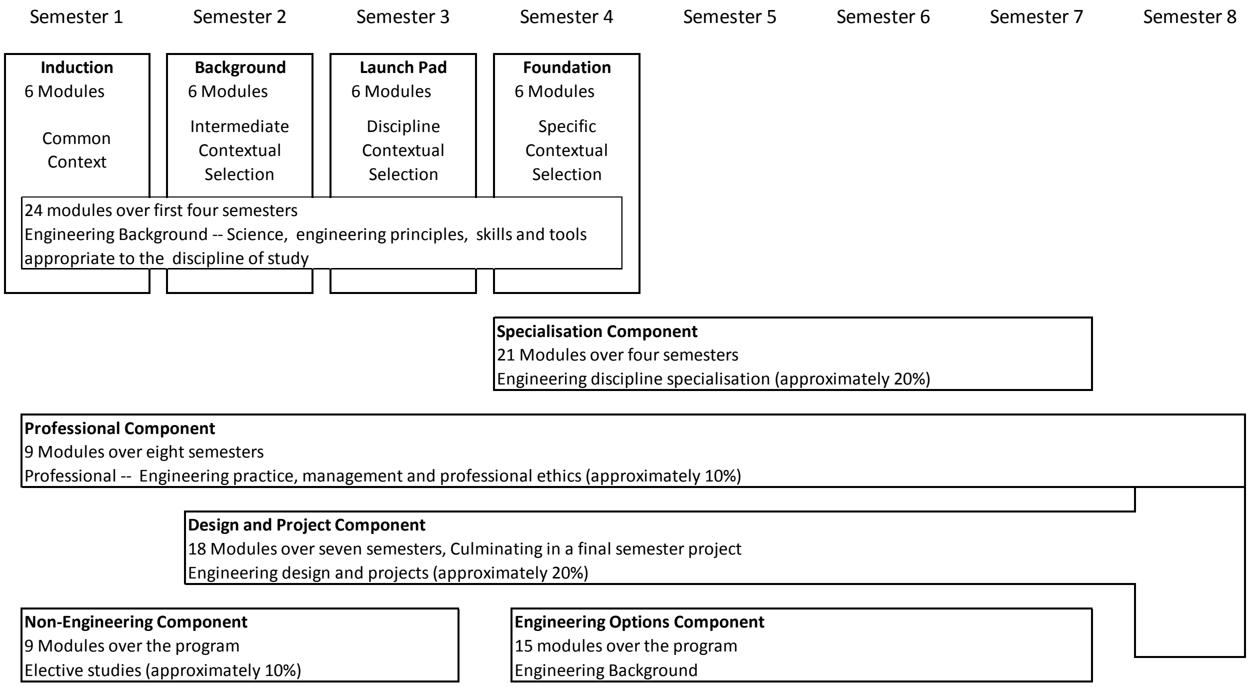

Figure 1. Macro-structure of an engineering program

Figure 1 illustrates a structure for a four-year engineering program divided into the components that satisfy the accreditation requirements of Engineers Australia. One quarter of the program comprises the induction, background, launch pad and foundation components. The student transitions through fundamental concepts, into intermediate concept development through to discipline specific foundational concepts, from which they move formally into an advanced specialisation stream. This is implemented across the first four semesters as:

- Induction Component: This first semester presents concepts in fundamental areas essential and common for all students in the program.
- Background Component: Develops fundamental areas essential to a broad but not comprehensive selection of discipline focus.
- Launch Pad Component: Further develops concepts required as background for a selected cognate discipline.
- Foundation Component: Consolidates the background concepts required for a specific discipline.

As the student progresses through this sequence, their selection of modules should reflect a refinement of focus towards a specific discipline.

- The foundation sequence prepares the student for the *Specialisation Component,* which develops and consolidates concepts in a specific engineering discipline. This culminates in an in-depth treatment in a technical context.
- *The Professional, Design and Project Components* deliver the concepts essential for a professional engineering qualification. These are common to all disciplines. The first of these modules is an induction module that is presented to every student in the first weeks as they arrive at the university regardless of the time of year. This focuses on the threshold concept of ‘expectations of a new learning environment.’ It provides an introduction to the entire program and sets the stage in terms of the learning expectations and aims.

- The *engineering options component* provides an opportunity for students to pursue either a second specialisation or add breadth or depth to their program.
- A rounded education is completed with the *non-engineering component.*

At the macro level, students are presented with a significantly more accessible statement of their learning outcomes, so their understanding of the structure and direction of their program is more clearly articulated. The emphasis on threshold concepts equips the students for lifelong learning, which enables them to independently fill gaps and further develop the body of knowledge.

Concept modules

At the micro-level, the curriculum is a structured sequence of key and threshold concept framed within clearly defined and articulated modules that are grouped into program components. As described above, each concept module should develop no more than one transformative threshold concept and these transformative threshold concepts are supported by strategically aligned associative key concepts

The sequencing of each module is informed by previous modules and forms the basis for subsequent modules in the program. For example, a module on the threshold concept of 'Thévenin's theorem' needs to be preceded by a module on the concept of 'circuit networks,' and is prerequisite to a module on 'dynamic resistance' (Scott, Harlow, Peter & Cowie, 2010).

Module structure

For our implementation, there is a natural division of each thirteen-week semester into twelve modules each corresponding to one credit point. There are four units of three credit points per semester. The convenient shape of each module is therefore a four-week teaching block with a student load of forty-five hours.

Once a teacher is assigned to a module they become responsible for the development and presentation of that module's single precisely defined concept. This implies that the teacher must assess the student's level of preparedness at the start and the level of outcome achieved at completion. The latter informs teachers of subsequent modules. This allows the success or otherwise of individual modules to be accommodated throughout the delivery of the overall program.

There are teaching activities within each module:

- Weekly lectures of equivalent unilateral delivery of information such as a reading list or online media.
- Weekly tutorials or small-group interaction sessions to develop the threshold concept.
- Regular laboratory or workshops to develop practical skills.

The threshold concept approach places a necessarily important emphasis on the interaction sessions within the module. It is here, and in the workshops, that development of the threshold concepts takes place. A communication channel from students to teachers is fundamental to ensure the continuity of information throughout the module. Key to the success of this process is the interaction of teaching assistants with the teachers, and the responsiveness of teachers to feedback.

Teaching in the module focuses precisely on the defined concept, which informs each activity and the assessment. Success is measured by evidence of the understanding of the threshold concept. Assessment is designed such that familiarity with the BoK is necessarily explicit in the ability to demonstrate an understanding of the concept.

The four-week module involves stages of

- Evaluation during the first week in which understanding of prerequisite concepts is determined;
- Content development and praxis in the body of the module; and

- Reporting and assessment in the last stages of the module.

All of these draw on relevant topics from the BoK.

Student pathway

Concept modules need to be delivered in teaching units. Each unit should deal with one identified transformative threshold concept and introduce, develop and consolidate that concept through a sequence of concept modules. This provides a narrative scaffold for sequencing concept modules. Cognate modules are grouped into a unit thematically, such as project management, dc circuits, materials and statics.

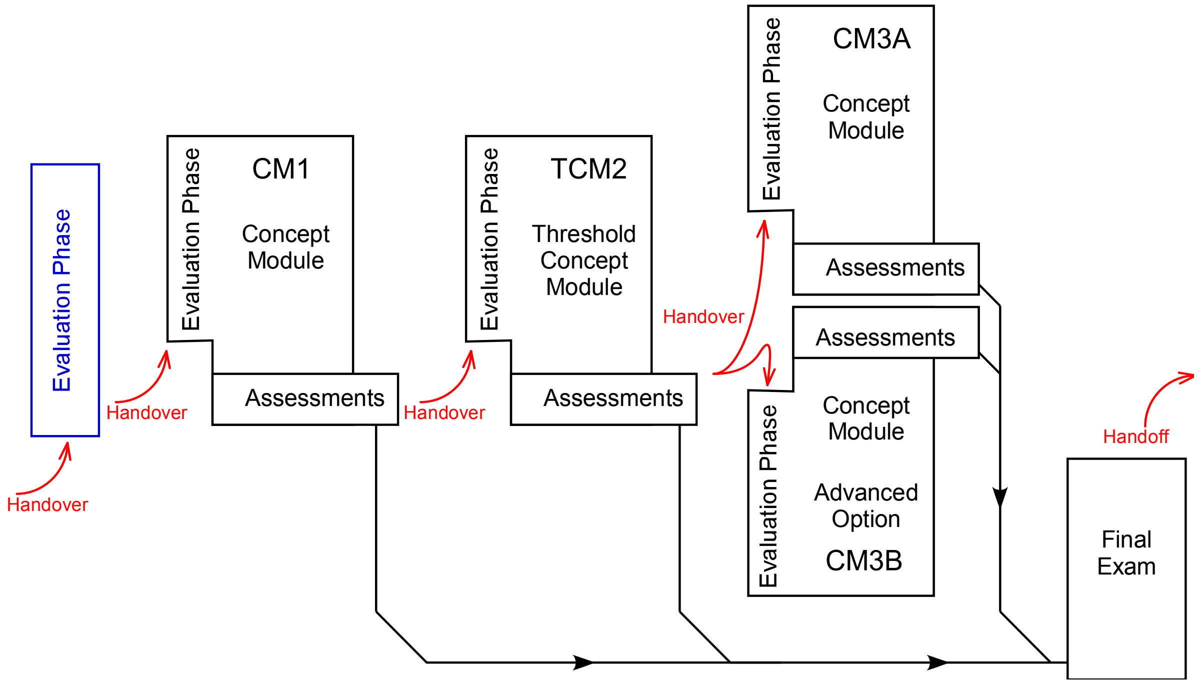

Figure 2. Teaching Unit Structure

Figure 2 shows the conceptual structure for a teaching unit accommodating a sequence of three concept modules of which one deals explicitly with an identified threshold concept. In this example, there is a choice of context for the third concept. The figure shows the transition from initial handover at the start through to an evaluation phase and subsequent handover to the first module. Similarly, each module has an evaluation phase and handover. A final examination precedes handover-to subsequent teaching units.

As the diagram shows, the student completes the first two modules, CM1 and TCM2 and can then follow either CM3A or CM3B. This allows for streaming of students, say, into an advanced option depending on progress. The modules could also be streamed into discipline specific areas; for example, an Electrical or Mechanical version of TCM2 could be implemented by offering alternatives TCM2E and TCM2M.

For pedagogical and administrative convenience, the teaching unit provides a single administrative structure with one convenor, study guide, formal examination and academic result. The modules may have different teachers and continuous assessment activities. There may also be alternative modules covering the same threshold concept in different disciplinary contexts. As mentioned before, in the handovers, information regarding student preparedness and teaching progress from preceding modules or units is passed on. This information is used to adapt the teaching activity and to direct individual students through appropriate streams.

The unit is delivered over thirteen weeks with the first week set aside for evaluation and streaming of students through their choice of modules, which correspond to each student's disciplinary focus. This achieves the required specified outcome while enabling the allocation of specific topics from the body of knowledge to each student.

Integration and streaming

An objective for the program is to integrate the Electronics and Mechanical disciplines in the first three semesters through a pattern of common units. In this early stage of the curriculum, some flexibility in disciplinary choice can be accommodated within this three-module grouping. For example, one of the threshold concept outcomes can be delivered within two disciplinary contexts, say, Mechanical or Electronics, using parallel modules that students choose between. Coherence of the integration of the disciplines is achieved by maintaining common modules for the other concepts.

Further steps

There is considerable work yet to be done in the development and implementation of this innovative approach to the engineering program. The incorporation of identified threshold concepts for each module is something that should be seen as an ongoing task that requires continual redefinition especially as the program develops and a more detailed curriculum mapping is articulated.

The process of implementing the modularisation of teaching units has begun in our electronics stream and our first-year induction unit. For the induction unit we have identified `transition to university' as the threshold concept and developed three modules with key concepts of university environment, independent learning, and learning skills and practices. These modules introduce, develop and apply the threshold concept as the unit progresses.

For the second year Electronics unit of second-order systems, we have observed that the standard textbook simultaneously treats 'circuit equivalence' and 'reactive power,' which are two identified threshold concepts (Scott et al., 2010). To address the student difficulty with this approach, we modularised the content into two units so as to develop only one concept at a time as has been suggested by Scott and Harlow (2012). The technical content was actually easy to segregate in this way and allowed us to expand the teaching content to include associative concepts that are traditionally held over to a latter year, such as ports and networks. These are latter-year topics that do not draw on other threshold concepts. Other units are continuing to be modularised as part of our ongoing review.

It may be that in the early stages the use of less mature 'key' concepts is used. These higher-level artefacts could provide an initial point of engagement for teachers less aware of the use of threshold concepts in an engineering curriculum. We anticipate there is significant research to be undertaken in this emerging field.

Conclusion

This article has proposed that the engineering undergraduate curriculum should be restructured into a series of threshold and key concept modules. Each threshold concept module is a self-contained teaching unit focused on a single concept as a priority with appropriate elements from the BoK selected as a context.

This innovative approach delivers the curriculum as a structured sequence of threshold concepts. At each point in the curriculum, a threshold concept is precisely specified, developed, and assessed within the teaching module. The required BoK is linked to the appropriate threshold concepts. The consequence is that emphasis is placed on understanding through development of threshold concepts rather than on wholesale coverage of a list of topics.

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