Modularisation of learning outcomes in Engineering curriculum

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Structured abstract

BACKGROUND
A four-year Engineering program is traditionally packaged into large teaching units that imposes a coarse structure to the implementation of learning outcomes and teaching praxis. A finer framework will permit implementation of a larger number of more focused themes and learning outcomes. This paper addresses the restructure of the Engineering undergraduate curriculum into a sequence of modules that are each equivalent to only 4% of a student's annual load.

PURPOSE
The aim of modularisation is to ensure that the threshold concepts required to qualify for Stage 1 Engineering Competencies are addressed in the Engineering Degree. Module design and delivery aims to provide a single clearly stated learning outcome for all aspects of instruction, praxis, and assessment at every stage in the program.

DESIGN/METHOD
A coherent structure is achieved by the sequential and individual treatment of each module with concise and discrete learning outcomes. A range of modules is thematically grouped into umbrella teaching units that coordinate the student's choice into a coherent sequence of learning activities. Each module comprises a key learning outcome that addresses a single precisely defined threshold concept. At key points, the student may choose from a range of modules that present same threshold concept in different disciplinary contexts.

RESULTS
Modularisation of the curriculum ensures learning outcomes are achieved by precisely defining a single aim in a discrete package of activities. This approach transposes the traditional primacy of teaching the body of knowledge into a program that takes students through a series of threshold concepts underpinned by the body of knowledge. Threshold concepts become the precise and clearly defined outcome for learning, teaching, and assessment at every stage in the program. This finer granularity more readily accommodates flexibility, so that students experience a rigorously defined learning narrative articulated through a palette of modules offering a variety of pathways depending on their choice of discipline.

CONCLUSIONS
Basing the design of an Engineering degree on threshold concepts packaged into a set of modules ensures that each step in the teaching process has a clearly articulated aim and theme, which guarantees an understanding of the purpose of the module for both teacher and student. Offering a range of modules that focus on the same concept at key points in the program provides flexibility in terms of discipline choice while maintaining program integration.

KEYWORDS
Curriculum design, threshold concepts, flexible pedagogy

Introduction

The traditional primacy of designing teaching program in terms of a body of knowledge imposes a coarse structure to the implementation of learning outcomes and teaching praxis. A finer framework will permit implementation of a larger number of more focused themes and learning outcomes. Threshold concepts provide a natural basis for defining these outcomes.

The background to the development of threshold concepts derives from a research program examining the practice of “strong teaching and learning environments in the disciplines for undergraduate education” Cousin (2006). The application of threshold concepts is being broadly considered in many professional disciplines, Atherton (2013). Atherton makes the point that getting a student to “think like” an engineer, a nurse, an economist—even, heaven help us, a lawyer—may be the ultimate goal. This is the acquisition of a “way of thinking and practicing,” Atherton (2010).

This approach has received considerable development by Erik Meyer and Ray Land (2003, 2005, 2006) in the area of Electronic Engineering education.

This paper addresses the restructure of the Engineering undergraduate curriculum into a series of threshold concepts underpinned by the body of knowledge. Each threshold concept is addresses in a self-contained teaching module. The program is implemented by offering twenty-four modules per academic year.

Background

The motivation for addressing the shortcomings of current curriculum design here are rapid growth in student numbers and a decision to offer an integrated Engineering program. The early phase of this program re-development presents significant challenges but also offers opportunities for innovative curriculum development. With rapid cohort growth and integration comes new staff, demands on flexibility, and opportunities for implementation of alternative delivery modes.

The objectives that have been set for the development of the new 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 body of knowledge must be limited. However, Engineers Australia’s 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.

To provide more specialisation specific treatment, common outcomes are typically streamed, so as to be treated in the context of a specific discipline. There is a significant portion of clearly common outcomes, such as those related to professional practice and a component of obviously shared science background, the remaining can be presented in discipline specific contexts. An example would be, second-order systems in the context of springs versus tuned circuits. Thus, the body of knowledge delivered for the Electronic specialisation differs from that for Mechanical specialisations by far more than one-fifth of the program.

In terms of threshold concepts, however, the Electronics and Mechanical specialisations have far more in common. For example, whether treated with springs or circuits, the concept of ‘second-order systems’ is clearly common to both specialisations. Indeed the requirement for an understanding of second-order systems applies to all engineers, so that a Mechanical engineering graduate would be able to easily appreciate an electrical equivalent of a second-order mechanical system, or vice versa. Thus, in terms of themes and learning outcomes defined by threshold concepts, diverse specialisations will easily require four-fifths commonality.

Integration of disciplines into one program can be readily envisaged in terms of key threshold concepts. The requirement for a four-fifths commonality in the integrated program can be specified threshold concepts outcomes. This still accommodates streaming of bodies of knowledge.

Flexibility

A well designed Engineering program should enable students to enter the program with various levels of prior learning, such as trade qualifications, transfers from alternative degrees, or international qualifications. Achieving flexible student pathways 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.

Traditional foundation units include a non-negotiable mix of fundamental science background and broader cultural and institutional induction. Separating these aspects into modules provides flexibility to exempt students from either while requiring the other. To achieve this, there needs to be room for choice of options within teaching units. The nature and definition of each module needs to be considered.

Threshold concepts provide a natural basis for defining modules. Teaching units designed in terms of threshold concepts modules enables easier delineation of previous learning. Moreover, students can readily transfer between disciplines; say Mechanical and Electrical, with a surety that they have understood 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. For effective and guaranteed outcomes, the teaching assistants – 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.

Traditional Engineering program design

Traditional engineering program design considers the level of qualification relative to duration of study. For a 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 is a graduate (AQF8) level of study, so the first three years can be considered as an undergraduate program (AQF7). Two levels of qualification are achievable at different time periods.

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 (2011). This imposes a coarse structure to the implementation of learning outcomes and teaching praxis 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, etc. The program structure ensures that the required units are delivered to meet the overall learning outcomes, Parker and McGill (2009).

At the 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 and 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. This is a body of knowledge approach.

Body of knowledge approach

The body of knowledge 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 being able to recall the information in an examination of that teaching unit. Often, the success of a unit is measured by the academic's coverage of topics rather than the student's understanding of concepts.

This approach conflates cognate topics from the body of knowledge in to each teaching unit. Traditionally, these are developed sequentially along with, possibly several, relevant threshold concepts. A lesson that comes from the idea of 'threshold concepts,' however is that is better to develop only one at a time, Scott and Harlow (2012).

The body of knowledge approach also leads to teaching focused within the individual unit, and away from the role of the unit within the program. In seeking to deliver a comprehensive body of knowledge, the unit can stray tangentially 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's experience of a critical understanding of the aims of each unit within the program is somewhat elusive.

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 threshold concepts. This approach addresses the issues of program integrity of delivery, integration, flexibility, and student experience.

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. In this way, the program should be considered as a coherent set of threshold concept modules.

Understanding over knowledge

Delineating threshold 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.

At each point the curriculum, a threshold concept is precisely specified, developed, and assessed within the teaching module. Topics are incorporated from the body of knowledge taking into consideration those that exemplify the concept being developed and those that are appropriate to position of the module in the program relative this this and previously developed concepts.

The key innovation of this approach is that the curriculum is delivered as a structured sequence of threshold concepts. The required body of knowledge is conditionally linked to the appropriate threshold concepts. The consequence is that emphasis is placed on understanding through development of threshold concepts rather than wholesale coverage of a list of topics.

Threshold concept modules

The proposed curriculum is a structured sequence of teaching modules that develop the required threshold concepts.

Each module should develop only one threshold concept. The teaching emphasis, assessment, and student learning should be focused on that precisely defined threshold concept.

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 and Harlow (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 teaching block with a student load of forty-five hours.

Once a teacher is assigned to a module they become responsible for development and presentation of that module's single precisely defined threshold 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, 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 here and in the workshops that development of the 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.

The focus on teaching in the module is its precisely defined threshold concept, which informs each activity and the assessment. Success is measured by the development of the understanding of the threshold concept. Assessment is designed such that familiarity with the body of knowledge is necessarily explicit in the ability to demonstrate understanding of the threshold 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 focus on the development of relevant topics from the body of knowledge.

Program implementation

To illustrate the modularisation of our Engineering program, consider the three-year undergraduate component. The typical body of knowledge that can be accommodated would comprise some 600 or more topics on the basis that one is introduced in each lecture.

Streaming more than one discipline adds even more topics. The notion of managing and accounting for a thousand odd topics would be overwhelming for both students and teachers.

In the body of knowledge 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 body of knowledge.

In contrast, for the core Engineering portion of our program there are only 63 modules to account for and administer in a threshold concept approach. These are grouped in three-credit point units of three modules, so that there are only three prescribed high-level outcomes per unit. The topics from the body of knowledge are effectively grouped in terms of the threshold concepts and thus there is also no requirement to address every single one.

Students are presented with a significantly more accessible statement of 63 outcomes that they need to attain, so their understanding of the structure and direction of their program is more clearly articulated. The emphasis of threshold concepts equips the students for lifelong learning, which enables them to independently fill gaps and further develop the body of knowledge.

Teaching units

For pedagogical and administrative convenience, modules are packaged into a single administrative teaching unit with one convenor, formal examination, study guide, and academic result. The modules may have different teachers and continuous assessment activities. The may also be alternative modules covering the same threshold concept in different disciplinary contexts.

Cognate modules are grouped into a unit thematically, such as project management, dc circuits, materials, statics, etc.

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 program, some flexibility in disciplinary choice can be accommodated within the three module grouping. For example, one of the threshold concept outcomes can be delivered in two disciplinary contexts, Mechanical versus 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.

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.

There is an induction module that is present to every student in the first weeks 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.

In addition, key modules can be repeated throughout the year to assemble bridging units to effectively dovetail with the prior learning background.

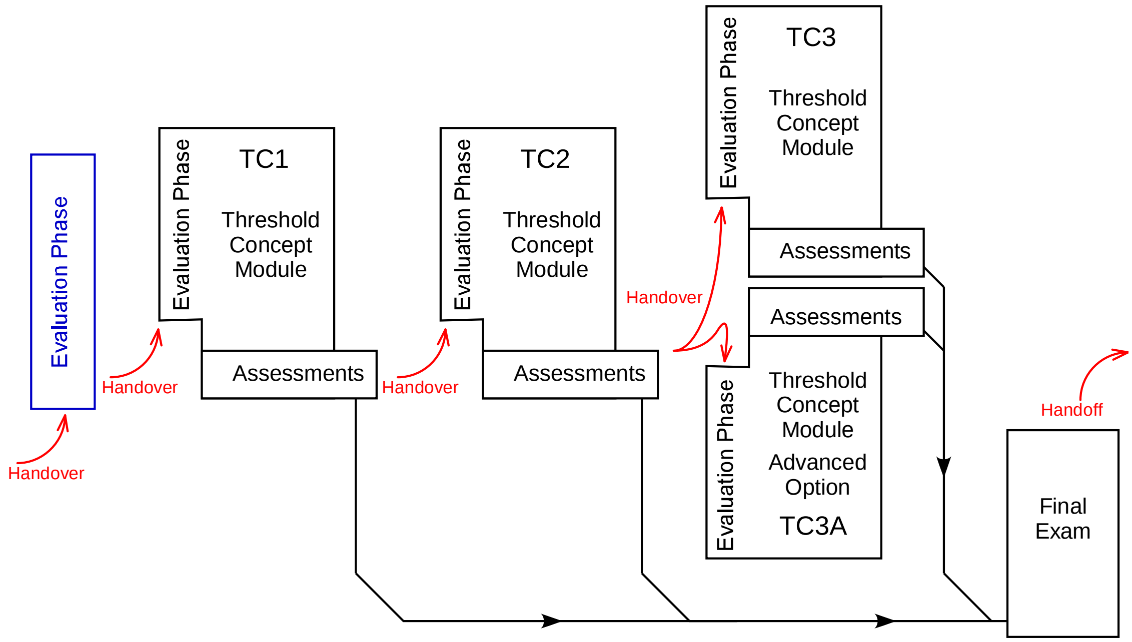

Figure 1: Teaching Unit Structure

Student Pathway

Figure 1 shows the conceptual structure for a teaching unit accommodating a sequence of three threshold concept modules and an optional module. 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 handoff to subsequent teaching units.

In this diagram the student completes the first two modules, TC1 and TC2 and can then follow either TC3 or TC3A. This allows 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 TC2 could be implemented by offering alternatives TC2E and TC2M.

In the handovers, information regarding student preparedness and teaching progress from preceding modules or units is passed on. At the start of each module, this information is used to adapt the teaching activity and to direct individual students through appropriate streams.

Further Steps

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

It may be that in the early stages the use of less mature ‘key’ concepts are 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

Proposed here is the use of threshold concepts as the pedagogical basis for the innovative top-down design of an Engineering degree. This approach transposes the traditional primacy of teaching the body of knowledge into a program that takes students through a series of threshold concepts underpinned by the body of knowledge. Threshold concepts become the precise and clearly defined outcome for learning, teaching, and assessment at every stage in the program.

Delineating threshold concept outcomes into modules provides a readily definable teaching package. Although each module is discrete in terms of student evaluation, assessment, and reporting, they are sequenced and grouped into administrative teaching units. Each unit can accommodate a range of modules on offer to allow streaming and flexibility of student needs.

The clearer prescription of a module's learning outcome ensures that all members of a teaching team have a shared understanding of their responsibilities for the module. This is practically relevant to the coordination of teachers working across large cohorts and transcends to accountability of learning outcomes across teaching units and across the entire program.

The threshold concept approach places an emphasis on understanding over knowledge, such that the student develops the threshold concepts and skills necessary for the life-long learning to build a growing body of knowledge.

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