Student Experiences of Threshold Capability Development in a Computational Fluid Dynamics Unit Delivered in Intensive Mode

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SESSION

C1: Integration of theory and practice in the learning and teaching process

CONTEXT

This study focuses on the student experience of passing through critical transformational thresholds, in a Computational Fluid Dynamics (CFD) unit delivered via intensive mode teaching (IMT) at a research intensive university. We define IMT as facilitated learning activity or classes delivered over fewer days and for longer each day than is traditional for the discipline. IMT is becoming increasingly common across the university sector as more students balance study and work, technology enables more options to access learning outside class-time, and universities teach offshore. Despite this popularity, best practice IMT has not been well understood.

PURPOSE

We sought to explore how features of IMT influenced students' threshold capability development in a CFD unit, and to identify, apply, and evaluate good practices for the delivery of a CFD unit in this mode.

APPROACH

The study is framed by the theories of threshold concepts and capabilities. We followed an exploratory phase with students and teachers, with a student survey. Based on findings, the unit was modified a year later, and qualitative data collection repeated.

RESULTS

Students' responses revealed that their experiences of threshold capabilities were not always as intended by academics – in particular, students focussed on issues associated with learning the CFD software package, rather than focussing on learning and applying the underlying theory, models, initial conditions and boundary conditions to develop valid models. As a result, the unit was re-designed to include a CFD software "boot camp" and weekly CFD software exercises, and the data collected from students in the modified unit indicated that the students were focusing on the intended threshold learning.

CONCLUSIONS

We recommend that educators identify the thresholds they hope that students will experience and investigate the students' experiences of thresholds in their units. If these differ teachers may be able to support students to more quickly overcome trouble that is not intended to be central to the unit.

KEYWORDS

Computational Fluid Dynamics, Intensive Mode Teaching, Threshold Concepts, Threshold Capabilities.

Introduction

Intensive mode teaching (IMT), namely facilitated learning activity or classes delivered over fewer days and for longer each day than is traditional for the discipline, is commonly used in industry. It is becoming increasingly common across the university sector as more students balance study and work, technology enables increased options to access learning outside class-time, and universities teach offshore. Despite this popularity, best practice IMT is not well understood. Therefore it was important to investigate how the practice affects student learning.

This study focuses on the student experience of passing through critical transformational thresholds, in a Computational Fluid Dynamics (CFD) unit delivered via IMT at a research intensive university.

Context

The unit is “Transport Phenomena”, and is intended as an advanced unit following on from fundamental units dealing with the traditional “transport” processes of Fluid Mechanics, Heat Transfer and Mass Transfer. The unit focuses on numerical solution of the Transport Equations and multiphase flow, with learning elements evenly divided between the underlying fundamental theory, and practical approaches and tools. The unit is designed primarily as a core unit for Chemical Engineering students in the penultimate or final year of a professional engineering degree (the 4^{th} or 5^{th} years of a 3x2 BS/MPE degree plan). During the years reported on here, the unit was offered as an elective, and was taken by 11-15 students; it has subsequently become a core unit in the chemical engineering program. The unit was also offered to Mechanical Engineering students as an elective.

This study is part of a larger project in which multiple intensive and matched non-intensive units were studied (Male et al., 2016).

The IMT model used in the unit

The first author developed and taught the unit. During the period considered, the unit was delivered over 8 weeks, with one full day workshop each week. While attendance was not monitored, attendance over the full class time was essential. The workshop sessions were not recorded, and there were in class assessments each week. Preparatory reading was assigned each week. The weekly workshops were structured (flexibly) as follows:

- The workshop started with a written test on the preparatory reading (30 minutes)
- The instructor then delivered lecture material on the week’s topic (60 – 90 Minutes)
- Peer briefings would follow, in which individual students briefed small groups. The briefings are assessed via students responding to instructor questions orally and on whiteboards in front of the class group (45-60 minutes).
- Group exercises would follow, designed according to the material covered that week – this could include formulation and calculation of 1D finite volume solutions of the transport equations, research exercises to identify literature (usually relevant to pending assignments), or exercises in designing model domains and meshes (60 Minutes).
- Finally, time would be allocated to work with the CFD software package used for teaching in the unit (ANSYS/FLUENT). In 2015, these exercises were largely self-directed; In 2016, a week 1 Fluent “Boot Camp” was implemented, and the instructor led skill development exercises in subsequent weeks (2-3 hours).

In both years, the major assessment items included:

- An assignment in which students developed a MATLAB code to undertake a finite volume solution of a problem involving transport of a scalar solely by diffusion (heat conduction in both instances).
- A Computational Fluid Dynamics (CFD) assignment, in which students developed a model for a well established case, evaluating the boundary condition and turbulence closure models, and validating their work against the published literature.
- A written exam, focusing on the fundamental theory of the finite volume method and multiphase flow. The written exam was closed book.
- A practical exam, requiring students to individually formulate and execute a Fluent CFD model in a set time (5 hours). The practical exam was open book and open internet (with the exception that students could not communicate with other parties during the exam).

Previous recommendations for best practice IMT

There are few studies on IMT. However authors have commonly recommended: front-loading the program with difficult and important concepts, supporting active learning involving practice and feedback, and encouraging peer interaction (e.g., Kops, 2014; Lee & Horsfall, 2010; Scott, 2003).

Methodology

We describe here the theoretical framework and how this influenced the research design. This study was framed within the theory of threshold concepts (Meyer & Land, 2003) and threshold capabilities (Baillie, Bowden, & Meyer, 2013). Threshold concepts are critical to future learning and practice in the discipline. Understanding of a threshold concept is transformative - opening up new ways of thinking and understanding, and therefore almost always troublesome. Common troublesome features are identified by Perkins (2006) and include complexity, requiring foreign ways of thinking, being abstract, and using new language. Threshold capabilities are similarly critical to future progress, transformative, and often troublesome, and usually require understanding of one or more threshold concepts. We use the term 'thresholds' to refer to threshold concepts and threshold capabilities.

Threshold concept theory is considered valuable for refining cluttered curricula (Cousin, 2006). By identifying threshold concepts and threshold capabilities curriculum developers can focus class time and students' attention on the concept that are most critical to learn and for which students are most likely to need support. Similarly, we investigated curriculum features that influenced students' learning, by focusing participants on the learning they experienced as most critical and troublesome by focusing their responses on thresholds they had experienced.

Method

In 2015, the second author held an in-class workshop with students taking the intensive CFD unit on the final day of teaching in the unit. After an introduction to the theoretical framework, students completed written questionnaires in which they focused on a threshold that they had experienced in the unit, and identified how it was troublesome and how they overcame it. They then responded to questions about features of the unit and their personal characteristics that had hindered or supported them in overcoming their identified thresholds (Male et al., 2015).

The second author interviewed the first author to identify the intended thresholds in the unit and to understand features that the students had described.

In response to findings improvements were made to the unit in 2016, and the in-class workshop repeated in the final class. The qualitative findings are reported in this paper.

Participants

In 2015, 11 (73.3%) of 15 students in the class consented to participate in the study. Their ages ranged from 19 to 26 at their last birthday (*M* = 22.0, *SD* = 1.9). In addition to basic demographic data, we were interested in demands on students' time because we expected this to contribute to students' learning in intensive mode. All 11 students were studying at least three units concurrently with this unit and one student studied four units concurrently with this unit.

In 2016, 16 (94.1%) of 17 students consented to participate. Their ages ranged from 21 to 38 at their last birthday (*M* = 23.3, *SD* = 4.2). Thirteen students were studying three units concurrently with this unit. Two were studying only two additional units and one student was studying four additional units concurrently with this unit.

One student each year worked for more than 20 hours in an average teaching week. Other participant characteristics are presented in Table 1.

Table 1: Participant characteristics (N_{2015} = 11; N_{2016} = 16)

		2015		*2016*	
Demographic Characteristic	*Values*	*N*	*%*	*N*	*%*
Sex	Female	4	36.4	2	12.5
	Male	7	63.6	14	87.5
English as a second language	With English as a second language	2	18.2	5	31.2
	Not with English as a second language	9	81.8	11	68.8
Domestic or international enrolment	Domestic	8	72.7	13	81.2
	Exchange	1	0.1	0	0.0
	International	2	0.2	3	18.8

Analysis

Following each workshop, the second author identified themes in the students' responses by question. Codes were informed by known troublesome features of threshold concepts, such as complexity and new language. Themes were also identified directly from the data. Codes were shared with the first author and we reduced the themes.

Findings and Discussion

Table 2 presents the themes that were identified in the workshop responses from students in 2015. The 2015 workshops returned an important finding – namely, that the dominant threshold reported by students was learning how to use the CFD software package. This was not the intended outcome – the focus should be on the fundamental theory of the finite volume method and its use to solve transport equations. Understanding the theory is essential to making the correct choices (model configurations, turbulence models, boundary conditions) when using the software package. The students, however, reported being more focused on the "mechanics" of the software package (how to create geometry, how to define a mesh, which controls to use). Drawing an analogy to algebra – this is akin to students focusing more on learning how to use their calculator than on learning how to manipulate equations.

Table 2: Themes among student responses in 2015

Threshold Concept or Capability	*Sample Comments*	*Comments*
Using CFD software to build meshes or solve problems	*Successfully building model using the required software.*	10
	Solving problems using ANSYS Fluent.	
How to use CFD software	*Learning how to use the software*	7
Theory of meshing for CFD	*How to discretise a space into "finite volumes" and iteratively solve for each element, and choosing an appropriate approach to solve.*	4
	Thinking in iterative method/control volume sort of way.	
Troublesome Features of Threshold Capability	*Sample Comments*	*Comments*
Taking time to develop	*It is learnt by experience and that means time, which is very limited.*	4
	It was like learning a new language. Needed to put in a lot of time understanding and practising.	
Foreign	*I never worked with the software. It was like learning something new. Also it was required to integrate the software modelling with the theory learnt in the class.*	3
Complex	*If wrong inputs are used, results generated by the software can differ largely from the analytical solution or diverge from real-world results. Thorough understanding of the models and the variables was required to successfully solve the problem.*	2
Features of the Unit that Hindered Learning	*Sample Comments*	*Comments*
Insufficient time for the necessary learning	*It is too short on TIME. Learning software takes experience and with only three weeks effectively to learn Fluent it is not enough.*	5
	Intensive mode didn't give me much time to learn as much as I would have liked because there was too little time.	
Having to learn to use the software independently	*There was no set way to learn the software-it involved individual research and was largely self-taught.*	3
How Students Learned	*Sample Comments*	*Comments*
Learned from online resources	*Online tutorials*	9
Practice	*Practice with the software and keep a diary with notes, relating each option of the software with theoretical understanding*	4
Interacting with peers	*Discussions with classmates*	2

Students reported having to learn to use the software independently as hindering their learning. Independent learning should generally be encouraged. However, it was taking too much time. Students reported using online resources to learn to use the software, and not having enough time to learn in the unit.

Based on the findings of the 2015 workshop, for 2016 more emphasis was placed on developing skill in the use of the Fluent software package. This started with a week 1 “boot camp”, where students were led through an introductory tutorial exercise. A weekly in-class skill development exercise was also introduced – the instructor would lead the group through new skills each week, though as the semester progressed the extent of “leading” diminishing and students were more independent. Each of these exercises were assessed via the submission of a particular model result – the selection of the result submitted was also a way to introduce new skills (animation, analysis, etc).

The effect of this change was immediate – it is plain from the 2016 workshop findings that while the software package remains problematic for some students, it was no longer identified as one of the most dominant thresholds, and students were focusing more on the underlying theory, as intended in the original unit design. Improvement was also evident in student performance – in 2015 two students failed the unit by failing to both complete the CFD assignment, and failing to submit any results in the practical exam. In 2016 all students successfully completed the practical exam. The small sample size cautions against drawing absolute conclusions, and this apparent improvement will be monitored in subsequent years. Themes among responses collected from students in 2016 are reported in Table 3.

Table 3: Themes among student responses in 2016

Threshold Concept or Capability	*Sample Comments*	*Comments*
Finite volume method	*Discretisation of differential equations that can be used to numerically solve equations* *Finite volume method* *CFD modelling*	11
Understanding the mathematics underlying CFD	*Understanding the models behind the software with the theory*	5
Modelling CFD equations in the software package	*Taking a problem geometry/domain and creating a working CFD model (including meshing and setting up boundary conditions)*	4
Using the specific CFD software	Using the software package ANSYS Fluent.	4
Troublesome Features of Threshold Capability	*Sample Comments*	*Comments*
Complex	*It involves complex math and there are multiple models/variations to learn.* *Requires strong understanding of calculus*	5
Textbook	*Initially just from reading the text I had no idea what was going on.*	3
Foreign	*Unexperienced with the program*	2
Language	*Language could be a problem to understand, need more time to study and get the theory*	2

Features of the Unit that Hindered Learning	*Sample Comments*	*Comments*
Issues with computing	*The program ANSYS is very user unfriendly and temperamental. The program often didn't work and you would waste hours on it and get frustrated.*	4
	Delays with computers/network/storage issues were frustrating when they affected my grade	
Heavy workload	*Large work volume and with many complex topics makes it difficult to keep up or pick an appropriate scope of understanding*	3
How Students Learned	*Sample Comments*	*Comments*
Interacting with peers	*Afternoon tutorials gave time to talk to peers about the program and resolve any issues I had*	8
	Peer briefings	
Practice	*Start with simple geometry/problems, adding more complexity or relaxing assumptions*	8
	Doing weekly fluent exercises	
Reading	*Read recommended textbook/resources to refresh knowledge and recommended resources that can help develop the software skills needed*	3

In discussing the features that helped students overcome thresholds, in 2016 not one student mentioned the weekly written quizzes, but the peer briefings were mentioned by several students. This indicates that in the presence of the peer briefings, which carry the strong motivating factor of having to speak in front of the group, the weekly written quizzes have become superfluous. They have accordingly been eliminated from the unit for 2017. Peer interaction and practice have frequently been reported as used by students to support their learning in the intensive and other units studied in the overarching project (Crispin et al., 2016; Smith, Compston, Male, Baillie, & Turns, 2016) and recommendations for IMT (e.g., Lee & Horsfall, 2010; Scott, 2003). In transitioning to a conventional teaching mode in 2017 (due to an increase in class size to 70), a modified workshop structure has been retained to maximize peer interaction within the larger group.

Theoretical explanation

Within the framework of threshold concepts and threshold capabilities, students are understood to experience a liminal space when the student is struggling with the threshold concept or capability (Meyer, Land, & Davies, 2008). In 2015 students were not entering the liminal space for the intended thresholds involving finite volume analysis. Students were struggling with the software and this created a barrier to the intended threshold learning in the unit. The findings collected in 2016 are consistent with the software boot camp in 2016 having supported students to enter the liminal space for the intended thresholds.

New recommendations for IMT

Previous studies recommended teaching the most difficult concepts early when using IMT. We found that additionally it was necessary to support students over unintended barriers to entering the liminal space for the intended thresholds.

Limitations and recommendations for further research

A limitation in the study is the small sample sizes due to low student numbers in the units. A limitation in the action taken to improve the unit based on feedback is that no action was taken to reduce the number of students concurrently taking three traditional mode units. This could be addressed in future work.

The introduction of the software boot camp highlighted the range of student capabilities, which makes leading group software exercises challenging. Handling this is a challenge for further research.

Conclusion

We recommend that educators identify the thresholds they hope that students will experience and investigate the students' experiences of thresholds in their units. If these differ teachers may be able to support students to more quickly overcome trouble that is not intended to be central to the unit.

Teaching strategies to ensure that students experience the intended transformative learning are good practice in any mode. However best practice may be even more important in intensive than other modes, and indeed aspects of best practice teaching such as peer interaction are facilitated by the extended continuous class-time available in intensive mode.

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