UNDERSTANDING THRESHOLDS IN FIRST YEAR ENGINEERING: DIGging Beneath Mohr’s Circle

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Abstract: Meyer, Land and others (2005) asserted that there are “threshold concepts” that open up required ways of thinking in a discipline, yet are troublesome for students. Understanding aspects of a curriculum that serve as such “thresholds” can assist with designing curricula, teaching methods and assessment approaches. This paper develops the work of threshold concepts in 1st year engineering by combining the results of research programmes in three institutions: the University of Oxford, the University of Western Australia and the University of Birmingham. We look at the case of Mohr’s Circle (a graphical representation of the state of stress at a point in a material). While students and tutors initially suggested it as a potential threshold, there are other, more conceptually troublesome issues that underlie it. We identify those troublesome aspects. In particular, we use this case to show what the general thinking processes of engineering identified in the project (including understanding the relationship between mathematics and the physical world) mean in the context of a particular example. The paper also illustrates methodologies developed by the team for investigating thresholds in engineering. We conclude by briefly considering some potentially useful teaching and learning approaches for addressing such thresholds.

Keyword: threshold concepts, engineering education, higher education, Mohr’s Circle, thinking processes, abstraction.

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1. INTRODUCTION

Meyer, Land and others (2003; 2005) asserted that there are “threshold concepts” that open up required ways of thinking in a discipline, yet are troublesome for students. They thought ‘threshold concepts’ were “akin to passing through a portal” that opens up “previously inaccessible way[s] of thinking about something” (Meyer and Land, 2003). Thresholds are generally thought to be transformative in that they open up new ways of thinking and of viewing the world; integrative in that they bring together concepts that otherwise seem unconnected; and troublesome (Perkins, 2006) in that they are challenging for students because they are complex, foreign, counter-intuitive, abstract, or use new language.

The notion of threshold concepts has been applied to a variety of disciplines, including economics, computer science and biology, where it has been influential in creating a dialogue of educational enhancement (J.H.F. Meyer, Feb 2011, personal communication). It is a powerful
way of engaging academics in discussions about teaching because it starts with the teaching of
specific content to specific groups of students. Academics, particularly at research universities,
are more tightly identified with their disciplines (Clark, 1987) and, thus, more comfortable
talking about, their disciplines than general processes of teaching and learning. As such, asking
academics to discuss threshold concepts in their disciplines can stimulate content- and context-
rich pedagogical discussions.

Threshold concepts are valuable because they help focus students’ and teachers’ attention and
prioritise teaching time in overcrowded curricula (Cousin, 2006; Land et al., 2005; Meyer et al.,
2006). Since the notion of “concepts” is sometimes critiqued for being too narrowly focused, we
are using the term “thresholds” as it is more inclusive of both content, thinking processes and
broad transformations, as well as highly specific ideas within a discipline.

Studies of engineering students’ thresholds to learning have focused on specific concepts (Kabo
and Baillie, 2009; Sibanda et al., 2011), techniques (Carstensen and Bernhard, 2008), or units of
courses (Scott et al., 2010; Harlow et al., 2011). However, we have taken the approach of
attempting to identify thresholds across the entire first-year curricula in both Engineering and
Materials Science courses taught at three different universities. In this paper, we explore Mohr’s
Circle (a graphical representation of the state of stress at a point in a material) to illustrate how
an analysis of the troublesome, integrative and transformative aspects of a suggested threshold
illuminate how teachers might help students to “think like an engineer” through a particular,
troublesome concept.

2. METHODS

This paper integrates findings from three separate projects at three different universities
(University of Oxford (OX), University of Birmingham (UB) and University of Western
Australia (UWA)). Each project used somewhat different research approaches to identify
threshold concepts in engineering or materials science according to teachers and students
(through interviews and focus groups) and to analyse input from participants.

At each site, teachers and students of first year engineering or materials science were interviewed
and/or participated in focus groups and workshops. Each site took a different approach to the
data collection. For instance, at UWA, interviews built on previous conversations, so that there
was an evolving inventory of possible threshold concepts which were brought into subsequent
interviews for input. At OX, however, interviewees were not made aware of what their
colleagues said or asked initially to react to ideas identified by others. At UB, the focus was on
specific modules within the first year materials curriculum (e.g. crystallography). The three
different settings allowed for triangulation of findings between the three teams. Each team, too,
took a slightly different approach to the analysis of results. For instance, the UWA team kept an
evolving inventory of concepts that emerged and summarized each interview. The OX team
looked across all their transcripts, coding for key themes that emerged across each of the
independent interviews. The UB team integrated ideas from textbooks on key subjects with ideas
drawn from the interviews, allowing the identification of gaps in textbooks. All three teams
experimented with concept maps (Novak, 1990) as a tool for representing the conceptual links
among various ideas identified by participants. While concept maps have been used - primarily
in science education - as a learning tool, as a curricular development tool and even for evaluation of student understanding (Kharatmal and Nagarjuna, 2009), we used concept mapping as a tool to aid data analysis, reduction and representation.

3. RESULTS

3.1 An inventory of possible engineering thresholds

The research at UWA yielded a comprehensive inventory of possible thresholds in engineering. All identified concepts are organised around three thematic areas: energy, motion and materials, which match the organisation of a new curriculum being constructed around the thresholds identified through the UWA research. Their research also revealed a set of general engineering thresholds that include thinking processes, transferable skills such as teamwork, and values related to sustainability. Figure 1 shows a concept map illustrating one portion of the general thresholds related to the topic of this paper. Unless arrows indicate otherwise, it is read from top to bottom.

![Figure 1 Engineering thresholds identified by UWA, exploding a subset of general threshold concepts.](image)

3.2 “Thinking like an engineer”

The OX academics emphasised aspects of these general thresholds and, in particular, thinking processes involved in “thinking like an engineer”. For instance, the most common thresholds identified at OX were about connecting the maths and the physical world. Interviewees described this as: “translating the abstract ideas into maths”; “mathematical representations of
physical problems” and “putting information into mathematical form”. Closely related to these skills was the need for students to learn “estimation”, “back-of-the-envelope calculations” and approximation, as well as “modelling”. These major ideas are also represented on the UWA map. Figure 2 represents some of the key processes involved in “connecting maths and the physical world”, derived from OX tutor interviews.

Figure 2 A concept map illustrating processes involved in connecting maths to the physical world.

While the overall concept map pictured in figure 1 illustrates some of the hierarchical relationships between key ideas and processes, it cannot show all the interrelationships between content and process, particularly where the same general skills (e.g. connecting maths and the physical world or approximation or modelling) apply to different topic areas. Figure 2 explodes the overarching general idea of connecting maths to the physical world, but in a way that disconnects it from the content through which this way of thinking needs to be demonstrated. While this is a general way of talking about transformative and integrative elements of an engineering curriculum, we need a more specific way of illustrating how such thinking processes are actually taught in the classroom, anchored within the context of a particular concept.

Thus, we examine the case of Mohr’s Circle – a graphical method of representing stress in a material – drawing particularly on five academics’ views (4 UWA academics; 1 OX academic) and three students’ discussions. This concept was chosen as it was identified as a possible threshold by several students and academics independently of one another, at both OX and UWA.

While the UB project did not yield data that addressed the topic of Mohr’s Circle, the team at UB analysed the UWA and OX interview transcripts, and independently combed through undergraduate textbooks on the topic. Based on both the textbooks and the transcripts, they represented the key ideas underlying and related to Mohr’s Circle in the map in Figure 3. The shaded boxes capture ideas that emerged from the interviews at OX and UWA, while the unshaded boxes are drawn from other sources. This analysis highlights how academics experienced in teaching Mohr’s circle emphasise the position (horizontal and vertical) of planes and rotation of angles. This analysis prompts one to question the extent to which typical textbooks explanations are sufficient to address the conceptually difficult underpinnings of tools and techniques in the field.
Figure 3 Interviewee’s characterisation of Mohr’s Circle-related concepts (shaded) compared to textbook representations (unshaded).

3.3 Digging below the presenting idea: what’s troublesome about Mohr’s Circle?

While Mohr’s Circle was initially proposed (both at OX and UWA) as a possible threshold in first year engineering, it appears that there are other issues that underlie it. The civil engineering academic in the second UWA interview in which the concept was discussed emphasized that Mohr’s Circle was not the threshold, it was merely a “technique” and that other, underlying ideas were fundamental to it and posed the barrier to learning:

*The stress is fundamental. It is a fundamental concept. If a student does not understand stress, the Mohr’s circle technique becomes empty, just something to memorise and to be confused.*

Applying Perkin’s (2006) notion of troublesome knowledge, the above could be classified as complex knowledge. The hierarchical nature of understanding is also clear from this academic’s comment; understanding the Mohr’s Circle technique is impossible if the student has not already grasped the concept of stress. Earlier in the interview the participant had described the complexity of stress:

*What is stress? Stress is difficult because stress is a combined entity - it’s a combined notion consisting of two entities, force and area and both are vectors, so it is that: a double vector. It’s not easy. It’s not possible to draw it. You can draw one vector. [But] Two vectors and it becomes difficult. And from there, okay, you have an area. You have normal stress. You have shear stress. You change the area and the stress changes.*

The third interview in which Mohr’s Circle was discussed at UWA was with a mechanical engineering lecturer, who agreed that Mohr’s Circle was a “tool” rather than a “concept”:

*Mohr’s circle is a tool, it’s not a concept. I think the concept is what's called stress transformation and that’s the concept… because that’s basically what it says that you have the same force, but you look at different sections, different oriented, you have different stresses.*
Engineering students at a workshop at UWA also identified Mohr’s Circle as a threshold concept:

*I think the problem with Mohr’s circle isn’t just necessarily that there may or may not be lacking a basic understanding of what the stress strain and principal stress and strains mean. But also the transferring of that knowledge to a completely different way of presenting it. So say you even understand it as a model of taking an atom, or as we often did, like a little square of whatever the member is and then relating the stresses to that. But then transferring that information into representing a completely different way and understanding what that means in regards to the previous understanding.* [UWA engineering student 1 in student workshop]...

[...] *what I think [fellow student interviewee] is trying to get at is understanding what the graphical, what the circle itself represents.* [UWA engineering student 2 in student workshop]

The above comments offer evidence of troublesomeness due to foreign knowledge, to new language and abstraction. An OX academic also highlights the difficulties that abstraction poses for some students:

*The difficulty tends to be with the [students] who are comfortable with trying to visualise a problem but are uncomfortable going to the abstract maths [...] they’re uncomfortable with just letting go of the physical picture and just letting the maths do the work. And that’s a general problem, I find actually. I mean, that occurs in a lot of the courses I teach – those that have these abstract concepts. People will say something like…”What does Mohr’s Circle actually mean?” and you…sort of say well, it’s actually just a construction and we’re just plotting the graph of this type of stress versus this type of stress on these two axes and it kind of rotates around and does that, but … they’re almost wanting to have […] it being a representation of some physical thing, rather than just being purely a construct that helps – it’s a tool that we use ...to solve the problem.* [OX materials science tutor interviewee]

Students at OX also highlighted the difficulty of abstract thinking – when they cannot easily visualize what is happening in a given scenario:

*I don’t think I can visualize what a tensor does…you can visualize a vector, because it’s just something with a direction and a length…so you can think about that. But then, I guess, a tensor is just …the next level up, isn’t it? I’m quite comfortable to use them, but if you said draw a diagram of it or explain it in pictures, I don’t [know how I would]…it is abstraction again.*

According to both students and academics, the challenges of abstract thinking appear in other topic areas, such as magnetic fields, electricity and electromagnetism.

Another aspect of troublesomeness is elaborated by an OX materials science tutor talking about the difficulties that can be created for students by the ways language is used by tutors to communicate the concept of stress:

[...] *you might say a “normal stress” and that immediately means that you’ve got an area that this force is being applied to, and the area is perpendicular to that force, whereas we might say, okay, well, there’s shear stress in a certain direction, and that, by implication, means that the...*
force direction now lies in the plane that we’re applying it to, and so there’s always an implication there. But [...] often, you’ll see people referring to a “stress direction”. It’s almost guiding the students back into their comfort zone of treating it as a vector and then....and then mishandling it as a mathematical quantity.

4. DISCUSSION

Through this paper we have illustrated how the general thinking processes of engineering (including understanding the relationship between mathematics and the physical world) are illustrated in Mohr’s Circle, a particular, troublesome aspect of typical first year engineering curricula. Students may initially be bewildered at the unfamiliar conceptual terrain of stress tensors, matrix transformations, and graphical representations of these concepts; but they can eventually “get it” through a combination of teaching and learning approaches. Many student interviewees in the OX project indicated that it helps them to understand troublesome concepts if they explain (or attempt to explain) difficult concepts to their peers and hear their peers’ explanations of these concepts, as well as those of experts.

Tutors and students both found it helpful when tutors pushed students to think about why certain concepts or aspects of a concept are important and how these things work. Such exchanges involve not just telling the students something but pushing them to work it out for themselves. Targeted pressure in the right direction leads students to make a leap in understanding for themselves, and this leap may be the essence of the “irreversible” aspect of thresholds. Another teaching tactic focused specifically on the troublesome aspect of the language involved in the concepts related to Mohr’s Circle. An OX materials science tutor spoke of using “deliberately sloppy” language about stress directions in order to “trick” the students and provoke them into asking questions that both “reinforce the message” and reveal any persistent gaps in a student’s understanding. In doing so, he is calling explicit attention to - and raising students’ awareness of - a critical feature of this concept’s troublesomeness.

If teachers are conscious that they are teaching thinking processes such as “thinking like an engineer” or “trusting the maths” at the same time as they are teaching content, they can be more intentional about the connections, opening up their expert thinking for students to model (Collins et al, 1991).

5. REFERENCES


