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Is the Drawing of Free Body Diagrams a Threshold Concept?

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Summary

This extended abstract is the starting point of ongoing empirical research, which aims at challenging the claim that the concept of a Free Body Diagram (FBD) in engineering mechanics is a threshold one. In the abstract, we first discuss the notion of threshold concepts, including making references to literature claiming that FBD is a threshold concept. We critically discuss this literature. As a first step in discussing if FBD is indeed a threshold concept, we perform a test to students after following a course teaching the students FBD, among other things. We did not yet succeed in verifying that drawing FBDs is a threshold concept.

Keywords: threshold concepts, problem-based learning, free body diagrams, engineering mechanics

Type of contribution: Research extended abstracts

1 Introduction

Many authors claim to have identified so-called threshold concepts in various fields, including engineering mechanics. This extended abstract is the starting point of an ongoing empirical research, which aims at challenging the claim that the concept of a Free Body Diagram (FBD) in engineering mechanics is a threshold one. Threshold concepts were introduced by Meyer and Land in their foundational paper (Meyer & Land, 2003). They defined the notion of threshold concepts to describing and analyzing specific aspects of university student learning: “A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress” (p. 1). According to Meyer and Land, threshold concepts must have five characteristics. These are:

- Transformative: A significant change occurs from understanding the threshold concept. It can change how learners think about the discipline, about themselves, or about the world.
- Irreversible: Once a threshold concept is understood, it is not likely that it will be unlearned or forgotten.
- Integrative: The students suddenly see how details make sense and fit into a large picture. This is also described by Zepke (2013) as: “Once understood, it enables students to knit dissimilar elements of a subject together” (p. 100).
- Bounded: In the sense that “any conceptual space will have terminal frontiers, bordering with thresholds into new conceptual areas” (Meyer & Land, 2005, p. 8).
- Troublesome: Threshold concepts are troublesome in the sense that they are difficult for students to understand, as they appear counter-intuitive and not easily understood when first encountered.

There are many concepts in engineering that students must understand and some of these concepts can be regarded as building blocks which should be mastered if the students are to succeed in their studies. An example of such concepts is the ability of students to idealize a mechanical system and draw its free body diagram (FBD) to determine the forces acting on it. A free body diagram is a representation of the external forces and moments acting on a physical object. The effects of all external connections and supports are replaced by the forces and moments that those connections and supports can impart (Rosengrant et al., 2009). Thus, “A thorough understanding of how to draw a free-body diagram is of primary importance for solving problems in both statics and strength of materials” (Hibbeler, 2019, p. 177). Therefore, we decided to focus on FBDs in this paper. The participants of our investigation are 1st year students, enrolled in the study program “Sustainable Design” at Aalborg University, Denmark. The main research question of our full paper is: Assuming that FBDs is a threshold concept, how well do the students perform on a longer term on a test checking their understanding of FBDs?

2 The concept of ‘threshold concepts’

According to Shryock and Haglund (2017), engineering faculty members who teach introductory engineering mechanics courses find that the ability of students to idealize a mechanical system and draw its FBD is a threshold concept that, once mastered, can transform the student’s understanding. They developed an instrument for FBDs containing both free response and multiple-choice questions. Shryock and Haglund have identified strengths and weaknesses of their students related to FBDs. Using this information, faculty members can better modify instruction in the classroom related to FBDs. McCarthy and Goldfinch (2012) developed an online FBD quiz that detects students who understand this concept and those who have difficulties with it. They found that the FBD quiz is a good predictor of future performance in subsequent engineering mechanics courses. Prusty and Russell (2011) report that adaptive tutorials, which provide interactive learning tools for students, help them practice applying concepts and skills in engineering mechanics, where they get immediate feedback on how well they understand and apply basic concepts. Moreover, the adaptive tutorials enable teachers to track where students are having difficulties with basic concepts in the course. Based on this, we can conclude that a vast amount of literature claims that FBDs is indeed a threshold concept. However, we wish to argue that we do not find the conclusions of these studies convincing. For instance, Shryock and Haglund merely asked faculty members, not students about this, and there was no testing of students or monitoring of their learning process. We find that in order to determine if a concept is indeed a threshold concept, deeper studies are needed.

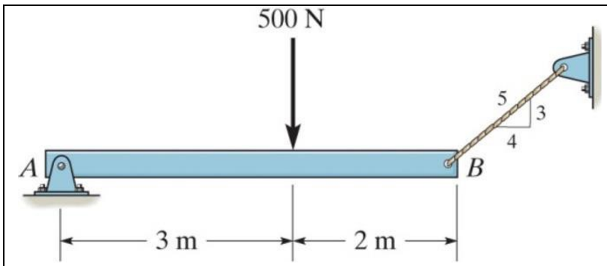
In terms of ways to teach students threshold concepts, a study by Doody (2009) explored the idea of a threshold concept in computer science. He examined the effect of using PBL on teaching an introductory software development course. His findings indicate that PBL was effective in helping the students master threshold concepts in computing and that the use of PBL to teach novice learners may also help to improve the students’ ability of retention. Furthermore, regarding the relation of threshold concepts to PBL, the book *Threshold Concepts in Problem-based Learning* (Savin-Baden & Tombs, 2018) claims to address a gap in research and the authors maintain that PBL and threshold concepts are natural partners and argue that teaching threshold concepts enhances the students’ understanding and practice of PBL. For the purpose of this research, we regard PBL as an educational framework that also aligns well with the concept of *lived knowledge* from Variation Theory (Kullberg et al., 2017). The lived knowledge refers to what the students actually learn as a result of a learning situation – in this case a PBL learning situation. In this study, we do not intend to *test* to what extent PBL *caused* a certain learning outcome in the students. Rather, we study the students’ lived knowledge of FBDs after the end of a course to help us answer to what extent it is reasonable to assume that a FBD is a threshold concept.

3 Methodology

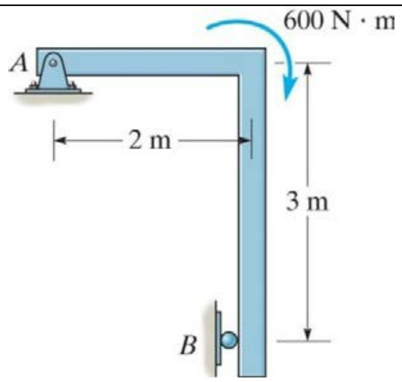
The preliminary investigation was conducted in January 2022 in the form of a written test, right before the students began their 2nd semester on 1 February (Spring 2022). The students were given a closed book, closed notes test in drawing FBDs of various objects. Drawing FBDs is a topic the students met in the beginning of

Fall 2021 in an introductory course in engineering mechanics, that includes statics and strength of materials. At the test, the students were physically present, sitting by themselves without the opportunity to receive help from each other or the lecturer. The same test will be repeated in January 2023 for the new students enrolled in the same study program. Moreover, interviews with the new students will be conducted in Fall 2022, right after they are introduced to FBDs. The subject of the interviews is to explore the students' experiences and obstacles in learning the concept of FBD. In the years 2018-2021, the first author used Problem-Based Learning (PBL) as a method to teach the basic concepts of the course. The PBL implementation in the course is fully described in Abou-Hayt et al. (2020). The textbook by Hibbeler (2019) is used throughout the course, in addition to notes and slides, which are made accessible on Aalborg University's learning management system, *Moodle*. The course problems were deliberately chosen in such a way that, on the one hand, they were *related* to the students' first semester project, where they should design (or redesign) equipment for a playground for children, and on the other hand, all the central topics of statics and strength of materials were represented in the questions asked in the formulation of the problems (Abou-Hayt et al., 2020).

The participants of the test are 23 out of 33 1st year students, enrolled in the "Sustainable Design" engineering bachelor study program at Aalborg University. The students have already followed a PBL-implemented course in statics and strength of materials in Fall 2021, and were chosen for convenience, since the first author is also their instructor in the course. Not all students in the class were present for the test, as participation in courses is not mandatory. The test was part of an exam brush up session, and it can therefore be assumed that students who felt in need of a brush up would attend. The test given was anonymous; it consisted of six figures of various objects and the students should draw the FBD of each, by hand. The duration of the test was 15 minutes. The first author told the students that the aim of the test was to investigate how well they still *remember*, *understand,* and *apply* (Anderson & Krathwohl, 2001) the principles and methods of drawing FBDs as well as to *improve* the future teaching of the course. In view of this, the first author has got permission from the students to use the tests for research. A correct FBD for each object is worth one point, giving a total of **6** points for the whole test. Each object has two constraints. If the forces or moments are drawn correctly on only one constraint, the student will get a half point. If a support requires two forces and the student draws only one, no credit will be given. The responses of the students were collected and graded, and the students' scores were analyzed using descriptive statistics. The results of the tests would also function as feedback for the instructor on how to improve the teaching and learning of FBDs in the next offering of the course. The objects of the test are shown in Figure 1.



Part (a)



Part (b)

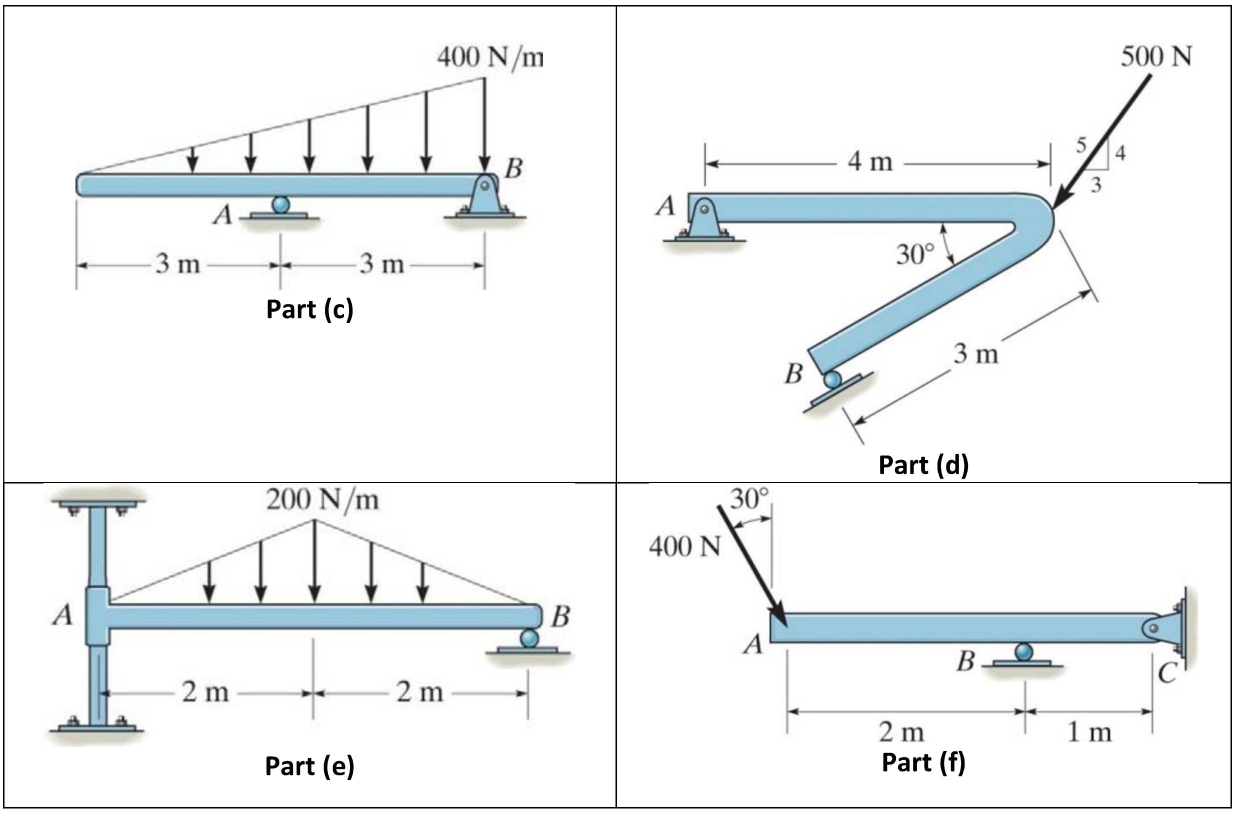


Figure 1: The six parts of the test given to the students.

In addition, the test will also be used to analyze the students' lived knowledge of FBDs as well as to enable us to see if the students had any a long-term retention of the knowledge of FBDs, since a test given directly after the lesson is not an indicator of long-term change in the students' experience. The objects of the test were deliberately chosen so that they involve the most used types of supports and connections encountered in engineering practice. Moreover, drawing the FBDs of these supports and constraints is a prerequisite for a successful application of the equations of equilibrium in engineering mechanics.

4 Results

The test is graded according to the scheme mentioned above. The performance of the students is shown in Table 1 and Table 2. The results show that many students still can remember drawing FBDs and most of them are able to differentiate between the different kinds of constraints and supports given.

Table 1: Students' performance on the individual parts of the test.

Part	Number of students who score 1	Number of students who score 0.5	Number of students who score 0	Average
(a)	10	11	2	67%
(b)	16	5	2	80%
(c)	16	6	1	83%
(d)	16	5	2	80%
(e)	2	19	2	50%
(f)	15	7	1	80%

In Table 1, we notice that only very few students scored 0 points at any parts of the test and that the average score is quite high, apart from part **(e)**.

Table 2: Students’ performance on the whole test.

Number of students	Average student score per part	Average student grade of the test	Standard deviation of the average grade
23	73%	4.4	0.1163

Table 2 showed the overall student performance on the test, which with 73% and an average grade of the test as 4.4 (scale 1-6), would on average have given the students a high mark, had this been a regular exam. Only two students managed to answer part **(e)** correctly. They are also the same students who got full score on the whole test. As seen from Table 1, most students failed to realize that the collar in part **(e)** exerts a couple moment on the rod *AB*, in addition to a reaction force. In addition, many of them thought that the rod on which the collar slides is part of the object in interest and have drawn a FBD for the whole system. It may be the case that those students have misunderstood our question: “Draw the free-body diagram of each object”. They may have thought that we meant the whole figure.

Meyer and Land make the strong claim that threshold concepts are troublesome to learn, *absolutely*. However, our initial results could not verify that the difficulties the students may have in drawing FBD, are due to the *concept* of FBD. Nor could we find that FBDs are *intrinsically* difficult to learn and *inherently* troublesome for *all* students. In fact, the students taking this test got a quite good result, also considering that these students might be the ones who felt the need to attend this exam brush up session. Rather, our study shows that the difficulties that some students encounter in drawing FBDs are normal didactical challenges of teaching *core concepts* as well as about the abilities of individual students to grasp these concepts. The results also show that troublesomeness in FBDs is a student-relative attribute and that students in a PBL-setting seem to have been able to reduce it. If troublesomeness can be gradually reduced by improved teaching methods, or by being taught in another type of educational setting, can it still be a major, defining characteristic of a threshold concept?

5 Discussion and conclusion

Meyer and Land (2003) mention a series of examples of threshold concepts. They claim that the concept of *limit* in mathematics is a threshold concept (p. 3). They report that mathematicians themselves were aware of the issues that surround the concept of limit, referring to them as *epistemological obstacles*. These obstacles are related to the historical development and formalization of the concept of limit. It may be in place to mention that we dealt with this same concept of limit in Abou-Hayt et al. (2019). We have used both PBL and another well-established educational theory, namely the Theory of Didactical Situations (TDS) Brousseau (2006) to tackle the epistemological obstacles of the concept of limit. This is another example of the success of PBL in taming the so-called threshold concepts. In TDS, the instructor *engages* the students by *designing* didactical situations that enable the students to overcome the epistemological obstacles (Artigue et al., 2014). If a threshold concept is identical with an epistemological obstacle, what then is the difference between a threshold concept and a core concept? Isn’t the “discovery” that the limit of a function is a threshold concept just old wine in new bottles?

Our study showed that on almost all items, the students scored very high on the test taken some time after the students had followed a PBL-based course teaching them about FBDs. Is this then evidence that PBL was the primary reason of their successful learning? Without an actual randomized experiment with control group, one cannot conclude this with any certainty, however we wish to argue that our study is existence-evidence of undergraduate students successfully learning the presumable threshold concept FBD in engineering mechanics through a PBL-based course. Furthermore, given that the test was given to the students a long time after the teaching is over, this suggests that the PBL-driven instruction in FBDs had a positive long-term effect on the students’ knowledge. The difficulty that some students have with conceptual material is familiar to all teaching practitioners and it is of course important that educators know those concepts that cause student difficulty in understanding them. The question is on what grounds we think that student difficulty is something about the concepts rather than something about the individual student ability. For, we cannot directly observe whether a student has grasped the content of a concept, since our mental life is hidden from the public. Rather, we can only infer that the student has done so.

The limitations of our study are that our sample of students are relatively small and furthermore, future interviews with students might reveal more of their learning process and understanding of, or lack of, FBDs. Also, as stated above, a randomized experiment comparing students being taught using PBL-methods with students being taught applying other teaching methods, might yield to which extent PBL is the best/better method. However, the purpose of our research is not to find out, which is the best method of teaching FBDs, but to find out if students relatively long time after a PBL-inspired course, should a level of understanding of drawing FBDs that makes it reasonable to assume that the drawing of FBDs is not a threshold concept; at least to the extent that it warrants further study.

In conclusion, we could not verify that drawing FBDs is a threshold concept. And as Salwén (2019) rightly points out, “proponents of threshold concepts have neither provided a clear definition of ‘threshold concept’, nor presented any clear idea of what explanatory role threshold concepts are supposed to play” (p. 47). Therefore, our study also points to the need for further clarification of the concept of threshold concepts. Moreover, the study also suggests that PBL is appropriate to help the students in learning threshold/core concepts such as FBDs in engineering mechanics. We believe that the success of PBL is not unique to drawing FBDs but can be generalized to the whole course, as shown in Abou-Hayt et al. (2020). Finally, the test revealed that the students’ *lived knowledge* of FBDs is still consistent with what the first author initially intended the students to learn.

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