Threshold Concepts in Physics Education – With Focus on the Mechanics Course

Mini-Research Synthesis

2019

Stefan Bracher

Many students struggle when studying physics, especially in mechanics. They seem to simply "not get it". That this is not just a feeling of physics teachers has been shown repeatedly through the scores in the force concept inventory (FCI), a standardized test on conceptual understanding of Newtonian mechanics introduced by Hestenes et al. (Hestenes, Wells, Swackhamer, & others, 1992). The test is frequently administered at the beginning and the end of the introductory physics course in many colleges. Students not significantly improving their FCI results, as reported by Hake (Hake, 1998) is one thing, but the situation is actually worse: Lasry, Guillemette and Mazur (Lasry, Guillemette, & Mazur, 2014) found that the students that did not do well in the first FCI test, did even worse on the second.

Several theories have been proposed to explain the problems of mechanics students. A lot of research has been done on how students use the surface approach, relying on memorizing, while experts employ a deep approach, looking for the underlying connections (Chi, Feltovich,

& Glaser, 1981; Eryılmaz Toksoy & Akdeniz, 2015; Hammer, 1997; Larkin & Reif, 1979; Priest & Lindsay, 1992; M. Wilson, 2014). Often, students are blamed to simply not work hard enough. Motivational theory (Seifert, 2004) has another explanation: Students on purpose withhold effort to preserve their self-worth if they perceive failure to be likely. Much attention has been given to the “misconceptions” the students bring to the classroom and their interference with the learning process. While many teachers, as well as researchers, focus on removing them, others propose to adopt a constructivist approach and use those initial conceptions, relabelled alternative conceptions, as the base of the learning activities (Buteler & Coleoni, 2014; Lin & Singh, 2015; Smith III, Disessa, & Roschelle, 1994).

A relatively new theory that seems to be able to explain many of the observed student difficulties and behaviours in the mechanics course is the threshold concept framework proposed by Meyer, Land, and collaborators in their two books “Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge“ (Meyer & Land, 2006) and “Threshold concepts within the disciplines“ (Land, Meyer, & Smith, 2008). They define a “threshold concept” as an object of learning that acts like a portal, is transformative and enables the student to think about something in a new way. In his chapter of the first book, Perkins (Perkins, 2006) distinguishes threshold concepts from core concepts by specifying that they are transformative, irreversible, integrative, alien, conflicting with previous views, and counterintuitive. This conflict with previous thinking and intuition is exactly what has been observed in the research on misconceptions/alternative conceptions. In another chapter in the same book, Land, Cousin, Meyer, and Davies (Land, Cousin, Meyer, & Davies, 2006) compare encountering a threshold concept to hitting a wall and explain that, as a result of this impact, students may employ a wide range of strategies, including disengagement. This explanation links to Seifert's (Seifert, 2004) self-worth theory on why some students stop trying. Land et al. also speculate that advancing without truly mastering a threshold concept leads to fragmented knowledge that hinders the integration of new concepts. Could this fragmentation be at the core of the students' use of the surface approach and thus explain their choice as the result of a not properly internalised threshold concept?

Both books identify some threshold concepts in physics. Related to the mechanics course, Newton's 2nd Law of motion is mentioned. Harrison and Serbanescu (Harrison & Serbanescu, 2017) from the University of Toronto add Newton's 1st Law of motion as well as the uncertainty of measurements (error analysis). The later was already found earlier by Wilson et al. (A. Wilson et al., 2010). In another paper with the promising title "Identifying Threshold Concepts in Physics: too many to count!" (Serbanescu, 2017), Ruxandra Serbanescu includes three concepts that are usually part of the mechanics course: polar coordinates, potential energy, and angular momentum. Bar, Brosh, and Sneider (Bar, Brosh, & Sneider, 2016) consider weight, mass, and gravity to be threshold concepts. To complete, Psycharis (Psycharis, 2016) reports the following additional candidates for mechanics, as proposed by various authors: force, momentum, energy, acceleration, conservation laws, equilibrium, vectors, and frames of reference.

Those familiar with the mechanics course notice that according to that list, every single topic usually taught in the course contains at least one threshold concept. Are the physicists exaggerating? Are they confusing "threshold concept" with "core concept"? A detailed analysis using the criteria proposed by Perkins (Perkins, 2006) should be done. However, the low or negative gain on FCI scores might indeed indicate the presence of a high number of threshold concepts. Prusty and Russell (Prusty & Russell, 2011) think that there is a link between the high failure rate of up to 50% for mechanics at Australian Universities to the threshold concepts in the course.

So what should we do? Can we simply lower our expectations and let more students pass the course? If the threshold concept theory holds true, this will be difficult. A threshold does not just open up a particular concept but enables the learning of other related concepts (Carstensen & Bernhard, 2008). Incomplete understanding is likely to have long-term implications on the capacity to apply knowledge in a new context (Psycharis, 2016). Letting a student proceed without actually clearing the critical thresholds, could thus cause a problem in other courses of the program. As Meyer (Meyer, 2010) writes, threshold concepts question the traditional intended learning outcome model.

Assuming we know the thresholds, we could, as brought forward by Perkins (Perkins, 2006), focus the teaching on the area of difficulty. But what if almost everything is a threshold concept, as suspected for the mechanics course? And what if the students, as proposed by Davies (Land et al., 2006), grasp the concepts but are held back by a barrier at a deeper level of understanding?

First I think we should go back and verify that all the items that have been identified as threshold concepts are indeed threshold concepts. If mechanics contains an unusually high number of threshold concepts, can we, as Davies (Land et al., 2006) suggest, review the sequence and decongest the curriculum? Can some of the thresholds, for example, uncertainty measurements, be postponed to a later course without impacting the overall learning outcomes of the program? The current science program revision in Quebec would be an excellent opportunity to do so. On a more local level, would it be beneficial to identify the most critical thresholds and spend more time helping the students to surmount them? Davies, as well as Serbanescu (Serbanescu, 2017), write that students probably need different takes to pass a threshold. Some students might be held up at different locations. Is there a way to review how we teach mechanics, allowing for the individual amount of repetition to cross the barriers for each student? Are there any technological solutions, as discussed by Prusty and Russel (Prusty & Russell, 2011)? Or do we have to go back to the program level and see if the repetition, for example for energy conservation, could take place in another course the student is taking at the same time?

Threshold concepts are an interesting area of research that promises to give many insights on why students struggle with their mechanics courses. Unlike motivational theory, surface learning and misconceptions/alternative conceptions, threshold concepts are currently not widely discussed among physics teachers. Maybe, already becoming aware of their existence and starting to talk about them alone will have a positive impact on student success.

Self-Reflection

Having learned about threshold concepts, I feel like Alice in Wonderland that fell into a new world by peaking through a rabbit hole. The theory itself indeed seems to be a major threshold, which, once crossed, is irreversible. It is a bit unfortunate that I managed to get all the way to the integration seminar without discovering the idea of “threshold concepts”. Given the many unanswered questions and the potential impact of looking at them, I think I might have found my research topic for the Master portion of the MTP program.

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