A broader threshold: including skills as well as concepts in computing education

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Abstract
We propose “threshold skills” as a complement to threshold concepts. The definition of threshold concepts assumes that theoretical knowledge is paramount: gaining the understanding of particular concepts irreversibly transforms the learners.

Mastering computing, like many disciplines, requires, however, learning a combination of concepts and skills. Mathematicians learn to do proofs, musicians learn to play their instruments, and martial artists learn to make moves by doing these activities, not just intellectually understanding them. We propose some characteristics for threshold skills and outline implications for teaching and for future work.

Keywords: Threshold concepts, Threshold skills, Professional education, Practice

1. Introduction

The theory of threshold concepts has been applied to computing by a number of authors: Zander et al. [2008], Shinners-Kennedy [2008], Sorva [2010] for example (see Rountree and Rountree [2009] or Flanagan [2012] for more). These have identified a number of potential threshold concepts, many having to do with learning to program.

One of the features of programming is that it requires skill as well as conceptual understanding. Things like writing recursive functions, object-oriented modeling, and debugging improve with practice, even after students have learned them. Moreover, when we interviewed students about learning concepts, they often discussed skill acquisition as an important (and difficult) aspect of their learning.

With this in mind, we re-analyzed a collection of interviews (about threshold concepts in computing) in the light of skills instead of concepts. What this analysis suggests is that skills as well as concepts can be “thresholds” for our students. One of our interviewees pointed the way:

There’s just some aspects to [programming] that just seem to remain kind of mysterious to me at the programming level. Not the concept level, not the theory level, not the technology level, but at the kind of code nuts and bolts level ... I sense from our conversations that you [as a teacher] feel you have more problem in getting the concepts across …

This student was explicitly telling us that we were looking for concepts, but that for her the concepts were not the problem, the “doing” was. Thus, we argue that in computing, and possibly other disciplines, skills as well as concepts need to be considered as thresholds.

Section 2 of this paper examines theories of knowledge. In section 3 we report on how the threshold concept characteristics are manifested in the context of skills, and discuss similarities and differences between threshold concepts and threshold skills. This section further shows parallels from other disciplines. Section 4 discusses implications for learning and curriculum of threshold skills.
2. Knowledge: Concepts and Skills

Philosophers and educators have long noted that knowledge comes in different forms. In discussing student learning, Entwistle [2003, p. 3] writes:

In the student learning literature, there has been an emphasis on conceptual understanding to represent high quality learning, but this had to be broadened to cover additional skills and ways of thinking, both academic and professional.

Dewey argued that theory should be the foundation of professional education [Shulman 1998], but also pointed to the need for “intelligent practice.” [Dewey 1910, p. 125] He rejected theory without deep understanding as well as practice learned as procedures removed from their meaning. This is in line with what is generally accepted in computing: a successful professional needs to master both theory and practice, and both aspects can be difficult to learn. [du Boulay 1988]

Ryle [1945] and Norman [1990, pp. 57-58] discuss notions of “knowing what” and “knowing how.” Ryle discusses this from a philosopher’s standpoint:

When a person knows how to do things of a certain sort (e.g., make good jokes, conduct battles or behave at funerals), his knowledge is actualized or exercised in what he does… When a person knows how to do things of a certain sort (e.g., cook omelettes, design dresses or persuade juries), his performance is in some way governed by principles, rules, canons, standards or criteria… But his observance of rules, principles, etc., must, if it is there at all, be realized in his performance of his tasks. [Ryle, 1945, p. 8]

Norman discusses similar concepts in the context of engineering design where he writes that “knowledge of”, declarative knowledge, is easy to write down and to teach while “knowledge how”, procedural knowledge, is “difficult or impossible to write down and difficult to teach. It is best taught by demonstration and best learned through practice.” For both of these authors, procedural knowledge is reflected in actions.

In research on professional education, the terms “theory”, “conceptual”, and “knowing what” are at one end of a spectrum; and the terms “practice”, “procedural”, and “knowing how” are at the other, with the understanding that a professional needs to master the whole spectrum.

We will refer to these two sides of knowledge as “concepts” and “skills” while being aware that these may not be the most nuanced terms and also recognizing that skills and concepts, to varying degrees, depend on each other.

3. Characteristics of Threshold Skills

We propose the following characteristics for threshold skills, derived from threshold concepts but manifested somewhat differently and one new one, the importance of practicing. This discussion is based on an empirical analysis of student interview data, described in detail in [Sanders et al. 2012]. Threshold skills:

**Are transformative** Mastering a threshold skill transforms what students can do -- and their vision of what they can do. It is empowering and, as a result, often accompanied by an increase in confidence. Contrast this with threshold concepts, where mastery transforms how students see their discipline.

**Are integrative** Once a threshold skill is attained by applying it to one task, students see other potential applications. Rather than unifying different concepts (as threshold concepts can do), a
threshold skill broadens the list of tasks students can perform or enables them to perform them in a new way.

**Are troublesome** Skills can be complex, demanding, and time-consuming to learn and maintain. They may seem alien at first (like the linear, step by step thinking required to debug a program). They may even be counter-intuitive.

**Are semi-irreversible** Unlike threshold concepts, threshold skills degrade over time with lack of use. They do not completely go away, however. Students who have acquired a threshold skill stay transformed and know where the skill applies, but may need to review or practice.

**Must be practiced** Part of the definition of a skill is that it is attained or learnt through practice, where practice is “repeated exercise in or performance … so as to acquire or maintain proficiency.” [Oxford English Dictionary Online, 2012]

True mastery of a skill means it becomes almost automatic. One computing student noted that after he acquired a particular skill, “it’s almost like it’s a tool and you don’t even think about using it. You say I need to do this. Okay, done.” In foreign language learning, the equivalent might be the point at which you begin thinking in your new language and no longer need to translate mentally before speaking.

Learning to converse in a foreign language may be a good example of a threshold skill. Learning vocabulary lists and grammar rules are not enough; you need to practice speaking the language. Being able to converse is transformative: you can communicate with people you would not have been able to talk to before. It’s integrative: once you’ve learned one language, it’s easier to learn the next. It’s troublesome: real fluency in any language typically takes years of work to achieve. Moreover, elements of foreign languages can seem strange and counter-intuitive at first. (Children are neuter and chairs are masculine? Verbs have gender?) Finally, the skill is semi-reversible and needs to be practiced. If you learn a language and then don’t use it for several years, you’ll become rusty, but will re-learn much more quickly than if you were learning it for the first time.

In areas generally thought of as skills there are also concepts. For instance, learning martial arts includes a theoretical side, understanding how applying different forces affects the opponent’s movement. This is not enough, however; there is also a need to practice the skills of doing the proper movements so that it is possible to perform the movement automatically with speed and accuracy. While it is easy to understand the necessity of both theory and practice in martial arts, it is still a problem to teach this to novices. Many martial styles teach novices basic movements (skills) without emphasizing the concepts. As the novices progress, they are expected to learn more about the concepts behind the movement. Giving the students all the theory at once does not result in good martial arts practitioners, neither does unnecessary practice of movements – both aspects need to be learned in relation to each other. Advanced practitioners still need to practice and hone their skills, but more emphasis is put on the theoretical side. [Greger et al., 2006]

We suspect that a similar dynamic is at play in other practical disciplines, and even in those that are more traditionally academic. From mathematics education, Worsley et al. [2008] propose that the technique of substitution and solving ordinary differential equations are candidates for threshold concepts. They might, however, be examples of threshold skills. Similarly, in physics laboratories, instruction helps students connect theory to practice. [von Aufschnaiter and von Aufschnaiter, 2007]

In research on professional education, the terms “theory”, “conceptual”, and “knowing what” then, may be considered to be at one end of a spectrum; and the terms “practice”, “procedural”, and “knowing how” are at the other, with the understanding that a professional needs to master the whole spectrum.
4. Implications and future work

The idea of threshold skills has implications for both research and teaching. In computing, for example, textbooks have relatively few exercises at the end of each section (compared to, say, mathematics books). In recent years, many introductory programming classes have added what are called “closed labs”: class time during which students work on modifying and/or writing programs with supervision. Much attention has been given to how students should work with each other during these labs, but little to the actual assignments that are given. As threshold concepts have the potential to organize a curriculum, threshold skills can focus and organize the activities and assignments we give our students.

As with threshold concepts, there is a question of granularity. Is the threshold skill learning to speak a foreign language, or certain parts of that process, for example, being willing to make mistakes? Are all the martial arts moves thresholds, or are some of them stumbling blocks while others are not? These are questions for future investigation.

Another important question is the relationship between skills and concepts. For some computing concepts, the threshold might include both a concept and a skill, tightly connected together. Practicing the skill leads to deeper understanding of the concept, this in turn leads to increased skill. [Eckerdal, 2009]

Some effort has been made in computing education research to consider the dependencies between concepts akin to threshold concepts [Mead et. al, 2006, Pedroni et al., 2007]. This seemed to work relatively smoothly for algorithmic concepts like selection (and hence for procedural programming built up from them), but the authors found object-oriented problems to be much more difficult. [Mead et. al, 2006] It was not the concepts of object-oriented languages but rather the pragmatics of using those concepts that presented the problem. We believe that this illustrates that when we consider threshold skills rather than concepts we need to be more aware that students may reach mastery by following different routes through the material – we need to be more flexible in our presentation, approaching thresholds from several directions.

In Computer Science, problem solving is a highly valued activity and ability and is what the educated professional is expected to do for a living. Problem solving, however, is neither a purely procedural activity, nor conceptual. It is not about having the conceptual knowledge itself, it is the ability to put pieces of knowledge and various skills into action in a structured and creative manner. But problem solving is also known for being hard for students to master. In the light of this, perhaps textbooks and teachers are often too keen to give students (too hard) problems to solve – (too soon) before the students have acquired the skills needed (by practice). We hypothesize problem solving in programming may contain many threshold skills.

The present work has discussed how skills, and not only concepts, can be threshold in students’ learning. There is further need to investigate the role of skills that act as threshold: how do students best learn these skills? What does “intelligent practice” mean in relation to threshold skills? How do we balance threshold concepts and skills?

References


