THRESHOLD CONCEPTS AND CONCEPTUAL CHANGE PROCESSES

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This paper reviews the idea of threshold concepts in the context of conceptual change processes students experience at the cognitive and social dimensions of learning. Literature suggests that students' ontological views play a part in the development of their prior conceptions, which could be alternative to scientifically accepted ideas. It is proposed that students may be able to negotiate troublesome concepts in a productive way as they engage in the meaning-making process with peers. Moreover, the social negotiation of knowledge can influence the conceptual change processes students experience in a discipline. This paper will serve as a theoretical benchmark against which to evaluate the design of a study that will focus on exploring how peer to peer collaboration supports the understanding of chemistry threshold concepts in post-secondary teaching and learning.

Keywords: threshold concepts, conceptual change, collaborative learning

THRESHOLD CONCEPTS AND CONCEPTUAL CHANGE PROCESSES

Threshold concepts are key concepts fundamental to attaining mastery in a discipline. Learning for mastery was proposed by Bloom (1968) as an instructional method where students are expected to reach a particular level in learning a concept before moving on to learn the ensuing concepts. To attain mastery learning, students need to be proficient in not just the foundational lower cognitive levels such as remembering, understanding, and applying but also be able to move to higher cognitive levels, which include analyzing, evaluating, and creating (Tijaro-Rojas, Arce-Trigatti, Cupp, Pascal, & Arce, 2016), as laid out in Bloom's Revised Taxonomy (Krathwohl, 2002).

Meyer and Land (2003) described threshold concepts as key concepts that are difficult for students to comprehend. The field of threshold concepts developed from a UK national research project that was started to understand the features of teaching and learning environments that can support undergraduate education. Threshold concepts are widely known across different disciplines. Examples include infinity and limit in mathematics, gravity in physics, sampling distribution in statistics, evolution in biology and mole concept in chemistry (Land, 2012). The present paper will serve as a theoretical benchmark against which to evaluate a study that will focus on exploring how peer to peer collaboration supports the understanding of chemistry threshold concepts in post-secondary teaching and learning.

Threshold Concepts

The process of understanding threshold concepts opens up a "previously inaccessible way of thinking" and eventually leads to a "transformed way of understanding" a discipline (Land, Cousin, Meyer, & Davies, 2005, p. 53). When such "conceptual gateways or portals… or thresholds have been crossed, … the world looks different" (Meyer & Land, 2006, p. 19). Threshold concepts encompass knowledge that is troublesome (Meyer & Land, 2006; Perkins,

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1999) and the process of learning a threshold concept might cause learners to experience an in-between state of liminality (Meyer & Land, 2006), where they fluctuate between their prior understanding and the new knowledge they have gained.

Once students have mastered a threshold concept, their understanding is transformed and a new conceptual space is opened. Mastery of these concepts also brings about an ontological shift in learners' understanding of a discipline (Land, 2012). Threshold concepts are transformative because they cause a significant shift in the way the subject is perceived. They are often irreversible and are therefore less likely to be forgotten, and integrative, meaning they reveal the interrelationship between concepts which was unknown before. These concepts can be bounded or have disciplinary boundaries, and are troublesome (Meyer & Land, 2006).

THRESHOLD CONCEPTS AS LEARNING BARRIERS

The troublesome nature of threshold concepts can become a learning barrier for students which, in turn, can promote the development of alternative conceptions. Alternative conceptions are formed when students hold ideas that are different from scientifically accepted views. If the learners are unable to pass through the liminal space, they start practicing mimicry or rote memorization to fulfill the short-term learning goal (Land, 2012). Moreover, when they cannot form an integrated understanding of concepts, they experience difficulties in applying these concepts to different contexts.

Threshold concepts encompass troublesome knowledge, which can exist in forms such as ritual, or knowledge that students memorize for the sake of learning but do not really understand the depth, and inert, which is knowledge that remains unused and disconnected from application. This knowledge can also exist as conceptually difficult knowledge that often leads to a combination of misunderstandings and ritual knowledge, alien knowledge that is counterintuitive and conflicts with our views, and tacit or implicit knowledge that is not examined. Another form includes knowledge due to troublesome language, where terms can be interpreted in different ways by students (Perkins, 1999). In order to understand how students approach threshold concepts, it is pertinent to explore literature on students' conceptual change processes. The next section expands on how the development of conceptions occurs and on the idea that students' conceptions can be viewed as developmental and dynamic structures.

THRESHOLD CONCEPTS AND CONCEPTUAL CHANGE

Talanquer (2015) stated that the understanding of threshold concepts by learners involves conceptual change, and he proposed the term conceptual threshold "to refer to the cognitive elements and processes that support the construction of a threshold concept" and the phrase "crossing a conceptual threshold to signify the acquisition or development of such elements" (p. 3). He suggested that crossing a conceptual threshold is very demanding for learners since, during this process, they might need to "dismantle, set aside, coalesce, or separate existing assumptions, concepts, and ideas while building new ones" (p. 4). Talanquer (2015) further referred to threshold concepts as complex cognitive constructs that are comprised of elements at the conceptual, epistemological, and ontological level.

Role of Prior Conceptions

Chi, Slotta, and De Leeuw (1994) proposed a theory of conceptual change based on epistemological, metaphysical and psychological suppositions to explain why some conceptions are easier to change and others are difficult. As per the epistemological assumption, entities in nature can be viewed by individuals as one of the three ontological categories: matter, processes, and mental states. The authors further drew our attention to the conceptions formed for the constraint-based interaction, a metaphysical sub-category of the ontological category processes, by taking the examples of concepts such as electric current, heat, force, and light. Electric current originates when a charged particle is placed in an electric field and is thus not a form of matter. It is rather a constraint-based process which does not have causal agents. However, students might conceptualize current as matter due to the presence of associated components in describing current such as wires, batteries and moving particles. Such conceptions belong to the psychological assumption that students form alternative conceptions based on their ontological views towards certain scientific concepts (Chi & Hausmann, 2003; Chi, et al., 1994).

Chi, et al. (1994) suggested an incompatibility hypothesis, according to which students' difficulty in understanding certain concepts is due to the "mismatch or incompatibility" (p. 34) between students' ontological views on a concept and the ontological category to which the concept actually belongs. When there is a mismatch between the concepts to be learnt and students' prior conceptions, their alternative conceptions are robust, stable over time and across grade levels, similar amongst students, repeated over time periods (p. 35), and "systematic in the sense of whether the misconceptions conform to a coherent theory or whether they are fragmented" (p. 36) and vice versa. These ideas suggest that the ontological categories of prior conceptions and the level of compatibility between prior conceptions and the concepts to be learned determines the nature of alternative conceptions students develop in the learning of threshold concepts.

Conceptions as Entities Beyond Deficits

Brown (2014) proposed an integrated view of students' conceptions as dynamically emergent structures, which can shift the focus from students' conceptions as deficits. There have been three varying perspectives in literature on students' conceptions: misconceptions (Schneps & Crouse, 2002), coherent systems of intuitive ideas (Vosniadou & Brewer, 1992), and intuitive fragments (Clark & Linn, 2013). Brown (2014) expressed that students' conceptions need not be considered regular things, by which he meant the things that have a static structure, are predictable, and separable. If considered a regular thing, misconceptions are "chunks of conceptual knowledge that are simply wrong" (p. 1467) and could be easily substituted with scientifically acceptable knowledge. Moreover, as regular things these three perspectives are in disagreement. When considered as dynamically emerging entities, the three viewpoints offer a unique perspective on understanding the nature of conceptions, while also becoming a part of the integrated dynamic structure that Brown proposed.

Vosniadou (2008), diSessa (1993) and Smith, diSessa, and Roschelle (1994) supported the view that misconceptions are not "unitary, faulty conceptions but a complex knowledge system consisting of presuppositions, beliefs, and mental models organized in theory-like structures that provide explanation and prediction" (Vosniadou, 2008, p. 22). DiSessa (2008) and Strike and Posner (1992) supported Brown's (2014) dynamic view of conceptual change, which, according to them, must be "more dynamic and developmental" and thus reflect the fluctuating arrangement of the interdependence amongst components of an "evolving conceptual ecology" (Strike & Posner, 1992, p. 163). Students' conceptions are formed and developed from the interactions amongst the available conceptual resources (Brown & Hammer, 2013). The emergent view on the nature of students' conceptions reduces the disparity amongst the three perspectives on conceptual change, unlike when viewed as regular things, where they are seen as interacting with each other.

The perspectives expressed in the above paragraphs shed light on the intrinsic nature of students' conceptions and how those conceptions can differ from scientifically accepted views as students approach threshold concepts. However, the conceptual change processes are not just limited to the relationship between the learner and the concept to be learned at the level of mere cognition but are also influenced by the discursive processes in which a learner participates.

CONCEPTUAL CHANGE AS A DISCURSIVE PROCESS

Research developments in the area of conceptual change have evolved in the last several decades from cognitivist, constructivist and social constructivist perspectives on learning to pluralistic frameworks (Duit & Treagust, 2003, p. 672) to understand the complexity of the conceptual change processes. These frameworks have focused on understanding the conceptual change processes in the epistemological, ontological and affective domains.

Vosniadou (2008) suggested that conceptual change is not just an internal cognitive process specific to an individual but also an activity integral to the socio-cultural world. Moreover, conceptual change need not be identified as an "exchange of pre-instructional conceptions" but rather as learning pathways that involve the restructuring of the "pre-instructional conceptual structures of learners" in order for the learners to acquire the "understanding of the intended knowledge" (Duit & Treagust, 2003, p. 673). The sections below elaborate the role of collaborative learning in supporting the progression of conceptual change amongst learners as they approach threshold concepts.

Collaborative Learning

Dillenbourg (1999) has defined collaboration in very broad terms as "a situation in which two or more people learn or attempt to learn something together" (p. 1). According to Roschelle and Teasley (1995), collaboration is "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (p. 70). Collaborative interactions are comprised of three prime criteria: "interactivity, synchronicity, and negotiability" (Dillenbourg, 1999, p. 8).

Dillenbourg (1999) stated that interactivity does not necessarily imply the frequency of interactions but refers to the meaningfulness of those interactions and how they affect participants' reasoning. Synchronicity is another criterion that features collaborative learning as the fundamental meaning-making process. Other processes include clarification, disagreement, elaboration, and agreement amongst others, which can be established only while the participants are involved in discussions at the same time. Dillenbourg (1999) further expressed that as participants engage in negotiation, they can learn meta-communication, or how to interact, and how to create a space for negotiation in the middle of a disagreement.

Mutually shared cognition.

Olivera and Strauss (2004) recognized that collaboration can be approached by understanding the process from cognitive and social perspectives: on the one hand, cognitive perspective looks at the individual cognitive effects of group work; social perspective, on the other hand, focuses on evaluating the interpersonal characteristics of effective group work. There is a third perspective that looks at the development of mutually shared cognition by drawing our attention to the sociocognitive processes that operate within the group (Barron, 2003).

Mutually shared cognition involves the interaction between cognitive and social processes as participants develop a shared conception of the goal (Wong, 2003). Negotiation of knowledge is considered key to the construction of mutually shared cognition (Baker, 1995; Dillenbourg & Baker, 1996). Construction of mutually shared cognition in a group appears similar to achieving convergence or a common ground in relation to the assigned problem. Since this process involves negotiation of meaning, there could be a divergence in participants' perspectives, which might demand elaboration of the varied views.

Teasley (1995) suggested that during collaboration, the focus is to be understood by others, which drives us to explain a concept in a coherent manner, thus resulting in the elaboration of knowledge. Based on Vygotsky's (1986) idea of scaffolding, it was suggested that learning is enhanced when students give elaborated help to each other (Webb, 1991). "Elaborated help stimulates reorganization, awareness of knowledge gaps and inconsistent reasoning, and results in more elaborated concepts because students create new relations by giving examples, using analogies, reformulating or referring to school or everyday experiences" (van Boxtell, van der Linden, & Kanselaar, 2000, p. 313). Mutually shared cognitions can be established if this process of argumentation and clarification eventually results in the convergence of meaning (Bossche, Segers, & Kirschner, 2006).

A constructive learning space is created when participants achieve mutually shared cognition where they learn to be open to others' opinions by testing their varying perspectives (Engestrom, Engestrom, & Karkkainen, 1995); there are opportunities for exploiting the cognitive capacities of the team not as separate individuals but as a group (Orasanu, 1990); and the argumentation process is deeper and richer in quality. Such a learning space can facilitate the effective learning of threshold concepts by learners as they negotiate the conceptual troublesomeness with peers and learn to integrate concepts through the dialogic process. Discourses amongst peers can create possibilities for transformation of students' ontological and epistemological views on the concepts they engage in. These ideas suggest that the development of mutually shared cognition in the social negotiation processes amongst learners in the learning of threshold concepts can create opportunities for them where knowledge is co-created, mediated, negotiated, elaborated, and clarified.

CONCLUSIONS

Understanding of threshold concepts involves the mechanism of conceptual change, which is a complex and gradual process in which the prior conceptions play a key role in laying a foundation for building sophisticated understandings of concepts. Conceptual change is not as simple as replacing prior conceptions with new ones in an instant, and alternative conceptions can be transitional resources in helping students gradually move along the conceptual change process. Viewing alternative conceptions as building blocks and tapping into these resources using student-centered teaching strategies, including opportunities for collaboration, can be fundamental to students' meaningful learning in a discipline in the long run.

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