

Identifying Threshold Concepts in Learning Nanoscience by Using Concept Maps and Students' Responses to an Open-ended Interview

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Abstract: This study explores students understanding of key concepts in nanoscience with the intention of identifying a potential threshold concept in the field through the analysis of student concept maps and explanatory interviews. The analysis of students' maps indicates conceptual development and learning difficulties in learning size-dependent property change at the Nano-scale. In addition, it identifies potential threshold concepts in the study and understanding of nanoscale science from the students' perspective. It also indicates the importance of previous learning in science to integrate isolated concepts and to help students achieve a deeper understanding of key phenomena at the nanoscale.

Introduction and Rationale

Since Feynman (1960) invited us to the "room at the bottom", nanoscience and technology has not only attracted considerable interest from scientists and engineers but also from the general public. While it has grown as a new, potentially rich field in science, substantial attention has yet to be given on research about its educational perspectives. Recent studies (Stevens, S. et. al. 2007) with scientists, engineers and learning scientists, have identified a number of potential 'big ideas' or key concepts central to the understanding of nanoscale science and technology. To the end, this study is a preliminary exploration of students understanding of a number of those key concepts with the intention of identifying a potential threshold concept in the field.

Meyer and Land (2003, 2006) describe the term, *threshold concept* as a conceptual gateway representing 'a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress'. *Threshold concepts* have also been characterized as being transformative, integrative, probably irreversible, potentially troublesome, and often boundary makers (Meyer and Land, 2003). The troublesomeness of knowledge here refers to a concept being conceptually difficult, meaningless, inert, alien or implicit (Perkins, 1999 & 2006). Traditionally key concepts or big ideas in a discipline (including potential threshold concepts) have been identified through research methods aimed at developing a consensus of expert opinion (Stevens, S. et. al. 2007). Similarly, concepts which are troublesome with respect to student understanding have often been identified by experts 'through professional reflection on the nature of the subject as a conceptual entity' (Davies 2006). In so far as these methods draw upon expertise to identify problems for student understanding, such methods might be referred to as 'top-down' approaches. On the other hand, 'bottom up' approaches focus on identifying troublesome concepts through research with students, themselves. Such approaches identify both the variation in the ways in which students experience or understand a concept and the key dimensions of variation which might constitute the troublesomeness of the concept - such as the aspects of variation revealed in phenomenographic studies (Marton & Booth 1997). This study primarily focuses on the less frequently taken 'bottom up' approach, although it is done against the background of a 'top down' perspective of a faculty expert. For the purposes of this study, the experts concept map is not used here as a means of comparison with student concept-maps but rather as a way of identifying the key concepts in the specific area.

Methodology

This study focuses on the analysis of student interviews in which the students were asked to construct and explain concept maps exploring the troublesome nature characterizing their understanding of fundamental nanoscience concepts. Students were probed for their deeper understanding of the concepts and their relationship. Concept maps, consisting of nodes (concepts) and connecting lines (propositions), have been used in research and classroom practice to reveal and assess student knowledge and structure in sciences and other disciplines (Novak & Gowin, 1984). Based on Ausubel's meaningful learning and an epistemological idea that concepts and concept relationships are the building blocks of knowledge structure, concept maps reveal a learner's knowledge of facts, ideas, and how they are related to each other.

Data were collected from 7 volunteers out of 21 engineering majors taking an introductory thermodynamics of materials science course including a unit and a term project on nanoscience concepts in which a learning tool was developed to aid students to learn about property changes in nanometer range. Based on an interview with the course professor and his construction of an expert concept map, 15 key nano-concepts were selected and provided for students to construct their own concept maps. Pre- and post-concept maps

including students' responses to open-ended interview questions about the construction of their maps (understanding of concepts and reasoning for propositions) were explored in detail. In addition, to help clarify the distinctions the researchers were attempting to identify, students were provided with working definitions of three different categories of concept during the interview: (i) important, (ii) difficult, and (iii) threshold. Students were then asked to select concepts from their own maps and to identify them with respect to these categories and to provide reason for their responses.

Findings and Discussion

The comparative analysis of the change in students' pre and post maps, showed an increase in the links students made between concepts for thermodynamic behaviors at Nano-scale and surface related terms such as "surface energy/force/tension" or "surface area to volume ratio". This indicates an increase in the knowledge of concepts and their relationship with respect to size-dependent or surface-dominated property change at the Nano-scale. However, student interview responses with respect to their reasoning about the mechanism of size-dependent property change (such as melting point depression) showed a lack of understanding and misconceptions of these key phenomena. Although the expert in the field (the course instructor) suggested "surface area to volume ratio at Nano-scale" might be a threshold concept in the understanding of the cluster of concepts presented in the nano-unit of the course; as a simple ratio it was not itself regarded as a conceptually difficult concept for students to understand. Although as a critical concept for explaining property change at the nano level, it was regarded as difficult. A previous study (Cohen et al., 1999) also discussed learning difficulty in understanding the concept beyond its mathematical meaning. Students of this study reported concepts in thermodynamics related to the nature of matter - including surface energy, surface forces etc. - as threshold concepts. In addition, the difficulty of visualizing the concept of "size at Nano-levels" was mentioned as another potential threshold concept in this course. Both these concepts were regarded as prerequisite knowledge to the thermodynamics course, concepts acquired in previous science and engineering courses. This suggests the importance that previous learning in science plays in integrating isolated concepts in Nano-science and in helping students understand science at a Nano-scale. In particular, student reports of "size at Nano-levels" as a related threshold concept points to the troublesome nature of the concept of "size" at Nano-levels. The size conception within surface-dominated property change at Nano-scale could be counter-intuitive to students familiar with macro-scale in a visible range.

Identifying threshold concepts from students' concept maps will help us to better understand student learning, conceptual difficulty, and conceptual development in nanoscience education. In future, comparing the different perspectives on threshold concepts between teacher and students might also provide useful information for the preparation of nanoscience education.

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