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Standard-based science education and critical thinking

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ABSTRACT

This study investigated pre-service teachers' perceptions and utilization of critical thinking in standard-based science education. A convenience sample of 120 pre-service teachers participated in the study by examining the United States' National K-12 Science Education Standards, using the Critical Thinking Attribute Survey (CTAS) originally developed and validated by the authors to measure critical thinking attributes. The main results of the study identified the science standards that exhibit critical thinking from the pre-service teachers' perspectives. The process-oriented standards, i.e., the inquiry, nature of science, technology, personal and societal perspectives had higher means than the content standards, of life, physical and Earth sciences. Several specific standard objectives are presented from top and bottom attribution to critical thinking. For example, standard benchmarks that are rated the highest included: think critically and logically to establish relationships between evidence and explanations; design and conduct scientific experiments; and acquire the abilities necessary to do inquiry investigations. Examples of the least standard benchmarks included: structure and function in living systems, transfer of energy, and properties and changes of matter. Discussion is provided to connect results with the current literature review and models of critical thinking, along with recommendations and implications to teacher education and K-12 science education practice and research.

1. Introduction

In a world that is growing ever more complex and changing at an ever-increasing rate, students should be equipped with life skills that include critical thinking (CT). The importance of developing and acquiring CT for the populace, for economic, social, political and daily life uses, is apparent (Pattanapichet & Wichadee, 2015). In addition, terrorism and ill thinking, in many parts of the world, need to be combated by educating generations to value life by healthy reasoning and higher-order thinking skills. While the 1980s and '90s brought much rhetoric about the need for improving student achievement and accountability, events at the beginning of the 21st century have helped us to realize that knowledge alone will not be sufficient to improve the quality of life in a global society. The development of CT has been one of the most essential objectives of education for many years, in areas such as economics (Heijltjes, van Gog, Leppink, & Paas, 2014), literacy (Boyd, 2012), geography (Korkmaz & Karakus, 2009), mathematics (O'Keeffe & O'Donoghue, 2015), and higher education (Choy & Cheah, 2009). As reviewed in this study, science education research has widely studied CT and reasoning (Wright & Forawi, 2000; Cameron & Richmond, 2002; Dolan & Grady, 2010; McCollister & Sayler, 2010; Yuan, Liao, & Wang, 2014). Yet, some researchers (Forawi & Mitchell, 2012; Osborne, Erduran, & Simon, 2004; Scott, 2008) have voiced concerns about students' inability to think critically.

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Attention to CT goes back to the early days of education. Vieira, Tenreiro-Vieira, and Martins (2011) point to Plato and Aristotle as the founders of the critical thinking. Al-Mubaid (2014) views critical thinking as a mental process that involves a high quality and high level of thinking for problem-solving and decision-making. Terms such as higher level thinking and reflective thinking have often been used interchangeably with the term critical thinking throughout the literature (Crenshaw, Hale, & Harper, 2011; Geertsen, 2003; Ness, 2015; Wallace, Berry, & Cave, 2009). However, while there are many definitions of the term critical thinking, for the purpose of this study, Paul's and Elder's (2007) critical thinking definition is used—'the art of thinking about thinking in an intellectually disciplined manner'. According to Paul, this type of thinking involves three essential components: (1) analyzing, (2) assessing, and (3) improving. As one embarks on the process of analyzing and assessing, thinking is taken to more critical levels or thinking is made better.

Developing science education standards is a major task that requires time, effort, and money. The United States' National Science Education Standards (NSES), investigated in this study, and the newly developed Next Generation Science Standards (NGSS), all focus on improving science education regarding what students should know, achieve and be able to do (; NRC, 2012, 2000). This is one of several examples worldwide for the standard-based education that attempts to increase K-12 students' understanding of scientific content and practices. The NGSS (2013) framework hence emphasizes that:

> "...learning about science and engineering involves integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design. Thus the framework seeks to illustrate how knowledge and practice must be intertwined in designing learning experiences in K-12 science education."

The standards are intended to present both knowledge and engagement skills which subsume cognitive and physical skills. The NGSS mainly focus on science in an integrated mode, including mathematics, technology and engineering, and they highly value science performance. While this is a new direction, yet, it limits focusing only on the science subject. Therefore, the rationale of using the NSES in this study is mainly because they are based solely on science, and the focus of this study aims to investigate pre-service teacher's perceptions of the linkage between science and CT.

Quitadamo, Brahler and Crouch (2009) found that students on one of the very effective Science, Technology, Engineering, and Mathematics (STEM) undergraduate programs who were involved in peer-lead small-group dynamics showed small but significantly greater critical thinking gains. This finding encourages more research to be conducted on this topic, particularly to further investigate critical thinking skills related to science and mathematics curricula. In one of our earlier studies (Wright & Forawi, 2000), we found that process skills and integrated inquiry instruction were common science buzzwords linked to new science curricula and the development of critical thinking. Taylor, Jones, Broadwell, and Oppewal (2008) describe how scientists view working with science teachers in a manner that recognizes and develops critical thinking. Therefore, the main purpose of this study is to investigate pre-service teachers' perceptions and utilization of critical thinking of the US national science education standards.

The question is whether pre-service teachers recognize that thinking is an inherent part of the science standards and curriculum. Many of our present education majors have come through systems where the curriculum was more fact-driven, that is, taught using traditional teacher-directed methods. Indeed much of what they continue to get in higher education often focuses on learning the content in lecture-driven classrooms where there is little time for students to question and process the information. Ultimately, how pre-service teachers interpret the standards will vary because each brings a different lens through which they examine them, hence providing a rationale for this study to investigate pre-service teacher's perceptions and utilization of critical thinking of the science education standards. It is important that pre-service teachers have knowledge of CT and be able to practice assessing it, especially in the standard-based education systems.

2. Theoretical background

2.1. Critical thinking history and definitions

Traditionally, critical thinking definition involves evaluating thinking through classification. Bissell and Lemons (2006) consider Bloom's taxonomy the best way to categorize critical thinking in the classroom. This classification can be used to evaluate critical thinking using the six levels of cognitive thinking. Students can progress through the levels of the taxonomy from lowest to highest. Although critical thinking exists at every level, Paul (1992) found that the higher-order thinking skills are often experienced at the synthesis, evaluation, and design stages.

There are two theoretical perspectives that often describe the philosophical orientation of critical thinking: the philosophical tradition of CT, and the logical aspects of thinking. In this study, the authors adopt the philosophical tradition that focuses on the identification of thinking abilities, which is appropriate to the Paulian model and the perceptual scope of the present study. Such CT abilities are the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action. In this common form of CT, specific universal intellectual values are identified that transcend subject matter divisions: clarity, accuracy, precision, consistency, relevance, sound evidence, reasons, depth, breadth, and fairness (Paul & Elder, 2007). Critical thinking also involves evaluating reasoning and the factors considered in making decisions.