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Why Teach Science with an Interdisciplinary Approach: History, Trends, and Conceptual Frameworks

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Abstract

This study aims to describe the history of interdisciplinary education and the current trends and to elucidate the conceptual framework and values that support interdisciplinary science teaching. Many science educators have perceived the necessity for a crucial paradigm shift towards interdisciplinary learning as shown in science standards. Interdisciplinary learning in science is characterized as a perspective that integrates two or more disciplines into coherent connections to enable students to make relevant connections and generate meaningful associations. There is no question that the complexity of the natural system and its corresponding scientific problems necessitate interdisciplinary understanding informed by multiple disciplinary backgrounds. The best way to learn and perceive natural phenomena of the real world in science should be based on an effective interdisciplinary teaching. To support the underlying rationale for interdisciplinary teaching, the present study proposes theoretical approaches on how integrated knowledge of teachers affects their interdisciplinary teaching practices and student learning. This research further emphasizes a need for appropriate professional development programs that can foster the interdisciplinary understanding across various science disciplines.

Keywords: integrated science curriculum, interdisciplinary science teaching, interdisciplinary understanding, professional development

1. Introduction

Today the term "interdisciplinary teaching" is widely used in all K-12 educational fields due to a growing awareness of the inherent value and benefits of interdisciplinary teaching. Many contemporary science educators have also begun to become aware of the necessity of interdisciplinary learning and teaching in K-12 science education (e.g., Cone et al., 1998; Johnston, Riordain, & Walshe, 2014; Knapp, Desjardins, & Pleva, 2003; McComas & Wang, 1998; Munier & Merle, 2009; Nagle, 2013; Rice & Neureither, 2006). Cone et al. (1998) described interdisciplinary teaching as an approach that integrates two or more subject areas into a meaningful association to enhance and enrich learning within each subject area. There is no question that the complexity of the natural system or its corresponding scientific problems necessitate interdisciplinary understanding informed by multiple disciplinary backgrounds that a singular discipline is unable to provide or is possibly incapable of providing. In science, the best way to learn and perceive complex phenomena of the real world should be based on an interdisciplinary approach. Science disciplines are not isolated from one another, and separation creates an artificial way to teach science, one that is not a reflection of its true nature.

Over the past few years, several U.S. science standard documents at the national level have shown evidence in support of interdisciplinary learning and teaching. The National Science Education Standards (NSES) (National Research Council [NRC], 1996) stated this approach to interdisciplinary curricular and instruction: "Curricula often will integrate topics from different subject-matter areas—such as life and physical sciences—[and] from different content standards—such as life sciences and science in personal and social perspectives" (p. 23), and "Schools must restructure schedules so that teachers can use interdisciplinary strategies" (p. 44). "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" (NRC, 2012; hereafter referred to as "the framework") and the Next Generation Science Standards ([NGSS]; Lead States, 2013) presented a more holistic view and meaningful association across various specific subjects of science. Specifically, the two national documents emphasized a conceptual shift for American science education-crosscutting concepts (CCCs) as "unifying themes" that establish meaningful connections across multiple scientific contexts. The CCCs show core ideas in science and how students make connections between ideas from different disciplines.

Interest in interdisciplinary learning and teaching practices in K-12 school systems has been growing in several Asian countries. A number of programs for interdisciplinary learning and teaching have been planned and carried out in several countries such as China and Korea. The State Council of China (SCC, 2001) completed a curriculum reform in elementary and middle schools nationwide. The new curriculum strengthened the links between different subjects and the connection between course content and students' real-life experiences. The Korean government has launched a reformed curriculum in which the government heavily promoted the integration of school science with other disciplines through Science, Technology, Engineering, Arts, and Mathematics (STEAM) education (Jho, Hong, & Song, 2016). Although the swing of the educational pendulum moves in a direction that is more favorable to interdisciplinary education, most science educators have realized that science lessons today focus on learning in discipline-based structures, which allows students to have limited and fragmented knowledge (Singh, Granville, & Dika, 2002; Smith, Deemer, Thoman, & Zazworsky, 2014).

Interdisciplinary education could be achieved through a considerable amount of help and guidance from teachers. For high-quality interdisciplinary teaching, teachers need to develop an interdisciplinary understanding of a specific concept and notice a meaningful pattern of information. One of the roles of science teachers in regard to interdisciplinary instruction is to help students deal with natural phenomena and associated real-world problems, which are not easily comprehensible or resolvable from a single disciplinary framework. Teaching science that is focused on interdisciplinary science topics and problems rather than on an isolated discipline has a potential for a variety of learning benefits. For example, interdisciplinary teaching facilitates higher-order thinking by students (Newell, 1998, 2002), which include freedom of inquiry, critical thinking, deductive reasoning, reasoning by analogy, and synthetic thinking through integrated education. Horton (1981) argued that interdisciplinary teaching leads students to a more meaningful learning experience, which enables them to reach higher levels of academic achievement. The benefits of interdisciplinary teaching provide a rationale for the necessity of interdisciplinary teaching. Students understand the big picture of a given concept or problem with knowledge from multiple science disciplines.

This paper aims to explore the historical and current trends in interdisciplinary learning and teaching in science education and to review the key literature to comprehend interdisciplinary teaching in an empirical context. This study also provides an opportunity to explore interdisciplinary understanding regarding K-12 science education. This study is divided into several sections. The first section describes the historical background on the differentiation of natural science disciplines. The second section explains the history of the interdisciplinary science curriculum and shows that the movement toward curriculum integration in the late twentieth century intended to deny the full-fledged boundary of science disciplines and bring a paradigm shift toward interdisciplinary-based science education. The third section describes the importance of interdisciplinary learning and teaching as shown in the national standards for K-12 science education. The fourth section discusses learning theories and the conceptual frameworks that support the rationale and justifications for interdisciplinary teaching such as "expert-novice theory" and "knowledge integration". The last section summarizes the literature in terms of interdisciplinary learning and teaching in the areas of science.

2. History of Science Discipline Differentiation

Tracing the history of the emergence of science disciplines and the transformation to their present-day forms provides a basis for a discussion of interdisciplinary-oriented education. The differentiation of the natural science disciplines into physics, chemistry, biology, and geoscience has a relatively short history of three hundred years (Stichweh, 2003; Weingart, 2010). Until the Renaissance, the current classification system of disciplines did not exist, and a variety of knowledge was integrated under an umbrella called natural philosophy. From the eighteenth century on, the growing specialization and professionalization in science gave rise to new academic disciplines (Nye, 1993). For example, the term biology was first coined by Gottfried Reinhold Treviranus in 1802 and since then has developed as a separate science discipline (Coleman, 1971). It is true that this differentiation process of science disciplines has provided a powerful way to organize knowledge due to the excessive amount of scientific knowledge present throughout every discipline. Humans' cognitive limitations make it easier for them to handle knowledge separated into specific disciplines (Stichweh, 2003). The growing specialization of science had been further accelerated by the dominance of reductionism up to the first half of the twentieth century. Reductionism is a belief that a larger system can be explained by breaking it down into smaller constituent elements. Thus, reductionists analyze a phenomenon or human behavior by breaking it down into pieces (Van Regenmortel, 2004).

Although science has been developing for centuries with a dominant discipline-based structure, there has always been the need to overcome the closed boundaries of varying science disciplines (Klein, 1990). At the beginning of the 1930s, the “unity of science movement” was initiated by natural scientists and philosophers of science who argued that knowledge has more varied and multifaceted perspectives than the rigorous classification and compartmentalization of specified disciplines. This movement led to the assertion that a discipline-bound approach is no longer the crucial framework for the delineation of knowledge (Hurd, 1991). The following section explains the history of the interdisciplinary science curriculum and shows that the movement toward curriculum integration in the late twentieth century intended to deny the discrete nature of the sciences and to bring a paradigm shift toward interdisciplinary-based science education.

3. History of Interdisciplinary Curriculum

The term “interdisciplinary” appeared in the 1920s in curricular contexts (Klein, 1990) and has been widely advocated (Vars, 1991). Tyler (1959) saw integration as the horizontal connections necessary for a coherent curriculum, and Bloom (1958) also advocated for an inquiry-oriented, integrated curriculum. With the growing recognition of the importance of interdisciplinary learning and teaching, the term “interdisciplinary learning” is widely used throughout educational fields today, which pertain to grade levels K-12 and college due to a growing recognition of the inherent value and benefit of it (Boix Mansilla & Duraisingh, 2007; Boix Mansilla, Miller, & Gardner, 2000; Clarke & Agne, 1997; Golding, 2009; Jacobs, 1989; Klein, 2002).

During the seventeenth century, Jean Rousseau applied the interdisciplinary concept to child-centered education to improve the unity of knowledge of children (Henson, 2003). The Herbartian movement, which began in the late 1800s, showed actual curriculum integration for interdisciplinary learning (Drake & Burns, 2004). To integrate segmented and isolated subjects, Tuiskon Ziller, a follower of Herbart, supported the idea of “integration of studies” around particular themes (Klein, 2002). In 1985, the followers of Herbart organized the National Herbart Society for the Scientific Study of Education and proposed a comprehensive approach to curriculum integration (Kliebard, 2004). Since then, Herbart’s key idea concerning the integration of a variety of school disciplines has become the basis for the concept of interdisciplinary curriculum and has helped students gain a coherent understanding of the world within modern day American education (Wraga, 1996).

Additionally, during the first half of the twentieth century, the underlying concepts of interdisciplinary learning can be seen in the history of the progressive education movement in the United States. This movement has been divided into two competing groups: administrative progressivism and pedagogical progressivism. Administrative progressives focused on the scientific and differentiated curriculum and acknowledged the existence of developmental differences in children of the same age groups (Labaree, 2005). The administrative progressives emphasized that the curriculum outcomes and the roles of children should only meet the needs of society (Labaree, 2005). Interdisciplinary learning today is much closer to pedagogical progressivism than administrative progressivism. Basically, the pedagogical progressive philosophy highlights the idea that the needs and interests of the children should be established in the curriculum and instruction. This can be achieved by integrating disciplines that correlate with socially relevant themes (Labaree, 2005). Two important components in pedagogical progressivism are developmentalism and holistic learning (Hirsch, 1996). If learning is natural, then teaching needs to acclimate to the learner, which means that a careful selection of subject topics and skill levels has to be coordinated to steadily follow a student’s pace of development. “Developmentally appropriate” practices and curricula are fundamental in pedagogical philosophy. The second component of pedagogical progressivism states that authentic natural learning only occurs in a holistic manner, where several realms of skill and knowledge are integrated into units, topics, and projects rather than taught as separate subjects. Several prominent figures spearheaded and represented pedagogical progressivism, including John Dewey, G. Stanley Hall, William Kilpatrick, and Harold Rugg. Out of all of them, Dewey was a pioneer who led the pedagogical progressivism educational movement and provided insights into major implications for current interdisciplinary learning. Dewey (1938) advocated a child-centered learning environment, where the educational experiences of children involved the principles of “continuity” and “interaction”. He believed curriculum based on personal experiences led to natural connections between prior knowledge and the learning of new material. In contrast, intentionally separated subjects may prevent children from finding and establishing the relationships among the relevant subjects. Although the movement of curriculum integration faded away after the launch of Sputnik (1957), educators have tried to find a balance between specialization and integration since the 1990s. Additionally, they have designed interdisciplinary curricula and conducted research projects associated with interdisciplinary learning and teaching based on the nature of interdisciplinary theories and methods (Klein, 1990).

A historical perspective on the root of interdisciplinary learning allows us to realize that the most critical aspect of the interdisciplinary curriculum is the notion that the curriculum has to be child-centered in the pedagogical progressive philosophy. In an interdisciplinary curriculum, students can acquire related concepts found in several relevant disciplines, which helps them make sense of the multitude of issues and problems in a real-life context. Many reformers and researchers today attempt to imbue ideas of interdisciplinary learning and teaching into the current education system.

4. Interdisciplinary Learning and Teaching in National Standards for Science Education

Various U.S. national standards have proposed the need for interdisciplinary learning and teaching in science education. After the back-to-basics movement in education in the late 1980s, ideas for integrating science disciplines became widespread again. The California Science Framework stated, "in order for science to be a philosophical discipline and not merely a collection of facts, there must be thematic connection and integration" (California Department of Education, 1990, p. 2). The teaching standards for grades K-12 published by the National Science Teachers Association (NSTA, 1998) revealed the influence of integrated curriculum instruction and provided a framework called "crosscutting ideas". College Board Standards for College Success (College Board, 2009) also proposed a similar term of "unifying concepts" in science. The NGSS (Lead States, 2013), and the framework (NRC, 2012) showed the same conceptual shift, emphasizing meaningful connections across multiple scientific contexts and providing CCCs. The CCCs encompass the nature of intertwined aspects of knowledge and an interdisciplinary understanding of science, which could be defined as the themes that bridge physical, life, Earth/space sciences, and engineering. According to the NGSS (2013), the CCCs allow students to build organizational schemas to interrelate knowledge from various science fields and aid in the development of interdisciplinary understanding in a comprehensive way.

Besides the United States, numerous Asian countries have proposed the need and direction for interdisciplinary learning and teaching through innovative curriculum integration. The State Council of China published an official document that encourages K-12 schools to adopt interdisciplinary teaching approaches (SSC, 2001). In similar curricular reforms, the Minister of Education in Taiwan implemented curriculum reorganization in 2001, in which K-12 school teachers were encouraged to apply interdisciplinary approaches to their teaching practices and the Ministry of Science and Technology of Korea drove the integration of school science with other disciplines through STEAM education in 2011 (Park et al., 2016). The purpose of STEAM education is to draw the interest and curiosity of students to science and technology through an interdisciplinary teaching system (Park et al., 2016). Under official curriculum policies of several Asian countries, interdisciplinary teaching has encouraged teachers and schools to conceptualize relationships between science subjects and other disciplines so students can have an interdisciplinary understanding of key complex concepts.

5. Conceptual Framework of Interdisciplinary Science Teaching

Details of the theoretical perspective of novice-expert theory and knowledge integration provide a supportive argument and theoretical foundation on how teachers develop interdisciplinary understanding (Foss & Pinchback, 1998).

5.1 Expert-Novice Theory

Within the expert-novice paradigm, numerous studies have attempted to identify the characteristics of experts in relation to novices in terms of a specific domain and problem solving (Chi & Bassok, 1989; Chi & Ceci, 1987; Chi, Glaser, & Farr, 1988; Chi, Hutchinson, & Robin, 1988; Collins & Evans, 2007; Ericsson, Charness, Feltovich, & Hoffman, 2006; Ericsson, Nandagopal, & Roring, 2009; Kuchinke, 1997). These studies have shown that experts possess more extensive and organized knowledge, which makes them more efficient in perceiving meaningful patterns, manipulating relevant information, and enabling them to perform excellently in practice compared to the novice. For example, experts solve a problem faster and more accurately and use knowledge structures that are more organized and easily accessible to them than novices do (Bransford, Brown, & Cocking, 2000; Lehrer & Schauble, 2006).

Understanding the differences in cognitive processes between experts and novices could provide a basis for recognizing the nature of interdisciplinary learning. Experts tend to find core concepts and central theoretical constructs in the cohesive framework of related concepts and then transfer them further from one domain to another to solve problems that are related to the given concept. On the other hand, novices tend to possess shallow concepts and isolate them as separate factual knowledge, which prevents them from comprehending or solving complex problems with an interdisciplinary approach. According to the schema theory suggested by Sweller, Van Merrienboer, and Paas (1998), a complex schema is constructed by incorporating a large number of interacting elements into a single element in long-term memory. Schema construction is formed through the merging of lower level schemas into one higher-level schema, which plays a critical role in reducing the working memory load in regard to learning processes. However, not all people have the same process of schema construction. Multiple knowledge structures on a lower level for one person may be perceived as a single entity for someone more knowledgeable and well informed. The main difference between an expert and a novice is that the former has a wider range of existing knowledge than the latter in terms of long-term memory. This causes differences in the cognitive construction in regard to interdisciplinary understanding. Experts are superior to novices when making inferences on how to fit new knowledge into existing knowledge clusters (Chi & Ceci, 1987). The corresponding ability allows learners to better perceive a grouped, meaningful pattern of the information and acquire more thematic knowledge. For example, the Simon and Chase (1973) study showed that expert chess players could identify isolated patterns and perceive an integrated configuration of chess piece positions. In contrast, novice players did not link interconnected constructs. Rozin (1976) proposed a "theory of access", which illustrated the difference in the ability to access a learner's knowledge structure. Even though learners have a relevant amount of knowledge in their long-term memory, there might be differences in the ability of novices and experts to access a wider range of the knowledge structure. The arguments of Simon, Chase, and Rozin have potential implications for interdisciplinary learning and teaching. Interdisciplinary learning helps students create strong relationships between a particular discipline and other disciplines, and the interconnected knowledge allows them to apply students to new situations and further allows them to learn in a more efficient manner (Ivanitskaya, Clark, Montgomery, & Primeau, 2002). This is the ultimate goal in interdisciplinary science education.

5.2 Knowledge Integration

The Knowledge Integration (KI) perspective for interdisciplinary teaching emphasizes the role of teachers because it is their responsibility to encourage students to establish a successful conceptual change by integrating prior knowledge with new ideas and practices, which inevitably results in a more coherent understanding of science and math (Linn, 2006; Liu, Lee, & Linn, 2010). As a result, KI theory provides a rationale for the guiding mechanisms, which pertain to the acquisition, connection, and redefinition of the learner's knowledge under a constructivist view of learning (Bransford et al., 2000; Linn, 2006). Linn and Eylon (2006) conceptualized four general processes that can promote KI: eliciting current ideas, adding new ideas, distinguishing among ideas, and sorting ideas.

Linn, Slotta, Terashima, Stone, and Madhok (2010) adapted the framework of the process of KI and developed five processes of KI, which are as follows:

- Eliciting ideas: The process of learning elicit students' prior ideas, backgrounds, and experiences, which enables them to create relevant connections to new ideas from already existing ideas in a learning context. For example, in a curriculum focused on the design of fuel, teaching can elicit students' existing observations and everyday ideas about energy and chemical reactions. Many studies have shown the benefits of eliciting ideas (e.g., Hewson, 1992), so students can develop a repertoire of ideas about scientific phenomena using their observations, experiences, and intellectual efforts.

- Adding new ideas: Learning environments traditionally aim to add ideas through some kind of learning activity, which allows learners to explore the relationships among all of their existing and new ideas to eventually form connections between them.

- Distinguishing ideas: After adding ideas, students are required to carefully distinguish productive ideas from unproductive ones to connect scientifically relevant and normative ideas.

- Sorting out ideas: Students need opportunities to prioritize the numerous, often contradictory, existing ideas and sort out the various connections among these ideas to develop a coherent understanding of the subject.

- Developing criteria: Students need to develop criteria for the relationships between ideas. The criteria encourage students to coordinate productive ideas of target phenomena and demonstrate a coherent and durable scientific understanding (p. 5).

Shen, Liu, and Sung (2014) considered three special processes in interdisciplinary knowledge integration: translation, transfer, and transformation. The translation process involves specialized terminologies and jargon developed within each discipline, which should be interpreted differently in other disciplines. Transfer refers to the process where students apply explanatory models and concepts learned from one disciplinary context to another. Transformation indicates the potential to apply explanatory models and concepts learned from one discipline to a new system in a different discipline. Thus, the KI process implies that a "deep transfer" of the knowledge of teachers is a crucial step in drawing on their interdisciplinary understanding rather than only focusing on adding new ideas between disciplines. The transformation process requires both integrations of relevant disciplinary knowledge and the appropriate transfer. Linn (1995) suggested a method of teaching called "scaffolded knowledge integration", which can encourage students to develop interdisciplinary understanding, especially of a complex domain, by enabling them to develop a more coherent scientific literacy. The goal of instruction is to motivate students to integrate new models with existing views and to distinguish among the models. In interdisciplinary instruction, students can have a cohesive view of a domain while identifying a process that will allow them to add more sophisticated models to their repertoire and then apply their ideas to relevant problems. Davis (2004) analyzed changes in knowledge integration for one prospective science teacher in a unit of instruction. He characterized the prospective teacher's knowledge in terms of the knowledge integration processes, found in the work of Linn and Hsi (2000), which includes adding new ideas, making links among ideas, and distinguishing between ideas. The prospective teacher had relatively well-integrated science subject matter knowledge, adding ideas to her repertoire and identifying weaknesses in her knowledge, but she did not consistently use her strong and well-integrated science content knowledge for teaching. Ma (1999) argued that teachers need robust and well-integrated knowledge that could be used in a meaningful manner. In particular, because science has an intrinsically interdisciplinary nature, Ma (1999) highlighted that science teachers have a greater need for the professional interdisciplinary understanding of content knowledge. He argued that combining several processes provides promising ways to improve science instruction. Lederman, Gess-Newsome, and Latz (1994) found that the subject matter and pedagogy knowledge structures of the pre-service science teachers showed developmental changes as they went through the professional teacher education program. Their initial knowledge structure representations showed listings of discrete science topics with a lack of coherence. However, their knowledge structures became more interconnected and complex during the teacher education program.

6. Discussion and Conclusions

Since the mid-twentieth century, the demands of the interdisciplinary aspects in educational fields have allowed the paradigm to shift from disciplinary to interdisciplinary. The history of the U.S. science curriculum proves that interdisciplinary pedagogy is not new to education but is a spontaneous process that is intrinsic to learning science. In recently released science standards, the NGSS (Lead State, 2013) highlighted that students need to integrate modes of thinking and knowledge informed by a variety of science and engineering disciplines.

Many science topics in secondary education are highly interdisciplinary with connections to chemistry, physics, geoscience, and biology because real scientific issues are rarely confined by the artificial boundaries of academic disciplines. In science, students need to deal with complex problems and natural phenomena that are not easily comprehensible or resolvable from a single disciplinary framework. However, the discipline-based teaching system in science is still the norm in middle and high school classrooms. This system prevents students from discovering and creating links between any relevant science subjects, which eventually leads to a poor interdisciplinary understanding of issues in science and poor scientific literacy.

A paradigm shift from a discipline-based science learning approach to an interdisciplinary approach provides a wide range of desirable educational benefits for students and teachers such as cognitive advancement and the improvement of affective domains (Field, Lee, & Field, 1994; Lattuca, Voigt, & Fath, 2004; Newell, 1994).

First, interdisciplinary understanding facilitates higher-order thinking (e.g., problem-solving, critical thinking, metacognitive reflection, etc.) by asking learners to notice meaningful patterns of information and ideas (Hursh, Haas, & Moore, 1983; Jacobs, 1989; Newell, 1994). According to the National Science Teachers Association (2003), high-order thinking is "the ability to engage in effective inquiry using scientifically defensible methods, which are considered a hallmark of scientific literacy" (p. 18). Some scholars proposed that the integration of disciplines helps students develop a general core of knowledge that is essential for deeper understanding and knowledge connections. Newell (1994) suggested that the outcomes of interdisciplinary learning "enhanced affective and cognitive abilities, increased understanding of multiple perspectives, greater appreciation for ambiguity, and superior capacities for critical thinking" (p. 35). Kavalovsky (1979) asserted that interdisciplinary education enables students to become equipped with the integration of knowledge and the freedom of inquiry. Newell and Green (1998) highlighted the fact that interdisciplinary learning leads to deductive reasoning, reasoning by analogy, and synthetic thinking by students. Similarly, in reference to the effectiveness of interdisciplinary learning, Lattuca et al. (2004) referred to the outcomes as:

> Assisting students in developing complex understandings in particular subject areas, promoting the development of sophisticated views of knowledge, building students' capacity to recognize, evaluate, and use differing (multiple) perspectives, engaging student interest and increasing motivation, and enacting constructivist and active learning strategies (p. 44).

Additionally, a growing body of research shows empirical evidence that interdisciplinary courses or programs benefit students by increasing critical thinking (Astin, 1993; Buchbinder et al., 2005; Nowacek, 2005), meta-cognitive reflection (Wolfe & Haynes, 2003), problem-solving, and other higher-order thinking skills (Boix Mansilla & Duraisingh, 2007; Lattuca et al., 2004; Leonard, 2007). For example, Vars (1991) and Beane (1995) reported that interdisciplinary programs improved the achievement scores of students in comparison to a separate subject curriculum. Similarly, Eggebrecht et al. (1996) reported that students participating in an integrated science program showed better performance than students in a traditional disciplinary program.

Second, integrated knowledge expands the explanatory capacity of knowledge and provides the additional richness of viewing the topic through multiple lenses (Liu, Lee, Hofstetter, & Linn, 2008). Deep interdisciplinary understanding develops in a variety of distinct contexts and taps cognitive processes, which in turn creates links between individual disciplines. For example, students can become motivated by realizing that a single way of knowing is insufficient to understand the complexity of the natural world, which allows them to actively take an interdisciplinary stance in developing their own central perspective on all sciences and to demonstrate the full range of their understanding of science.

Third, educational scholars have suggested that interdisciplinary connections may make "learning easier … more realistic and potentially more useful to the student" (Shell et al., 2009, p. 184). Isolated disciplines were criticized as being static and for not reflecting the reality of every experience (Braunger & Hart-Landsberg, 1994; Hurd, 1991; Nielsen, 1989; Tanner, 1989). Interdisciplinary teaching helps students make sense of scientific issues and problems that are presented in real-life contexts. Interdisciplinary teaching aids them in coping with the issues by using skills and knowledge associated with any of the relevant disciplines.

Teaching practices with an interdisciplinary approach can help students make sense of science in regard to abstract scientific concepts and the role and function of science in modern-day society, which can encourage them to hold a more holistic view of real-world phenomena (Fogarty, 1991).

Finally, a number of studies have been attentive to affective gains made in interdisciplinary learning contexts. Bragaw, Bragaw, and Smith (1995) confirmed the positive values of interdisciplinary teaching on the attitudes and motivation of students toward learning. Barab and Landa (1997) stated that interdisciplinary curriculum and instruction focused on problem-solving skills motivates students to learn. The affective factors provide a driving force for action, where learners initiate and direct purposeful behavior so they can evaluate their progress toward their goal and alter their behavior to ensure success at their desired level (Singh, Chang, & Dika, 2005).

Many scholars have admitted that interdisciplinary teaching is built upon the well-established content knowledge from each disciplinary science because specialization is a precursor to interdisciplinarity. The specialized content knowledge is a necessary condition and a prerequisite to acquiring knowledge bases of other disciplines and for the provision of powerful teaching (Baumert et al., 2009; Sadler et al., 2013). If science teachers have insufficient knowledge in the specific discipline topics, they will also lack the ability to integrate the concepts. This prevents their students from having a more holistic view of science, which could limit their ability to learn advanced and real-life related science. The conceptual frameworks of interdisciplinary understanding, KI, and the lateral curriculum knowledge help science teachers contemplate the nature of an integration of knowledge; thus, they have a meta-perspective on multiple scientific disciplines even though the science courses remain as separate disciplines. Additionally, an interweaving of science subject matters could develop if teachers gain insight into the conceptual framework of the expert-novice theory. Understanding the differences between expert and novice teachers based on schema theory helps teachers perceive the cognitive developmental process of interdisciplinary understanding. Expert-novice theory points out that expert teachers have a better perception of the grouped meaningful pattern of information and acquire more thematic knowledge, which may eventually lead to successful interdisciplinary teaching. As shown in the Simon and Chase (1973) study, expert chess players could identify isolated patterns and could perceive an integrated configuration of chess piece positions. In contrast, novice players could not construct these interconnected links. This development is rooted in the individual contexts of the teachers and is influenced by factors such as the characteristics of the school's culture and support for professional development. Furthermore, individual teachers sense that these factors affect their abilities to teach in different manners, which eventually causes a gap in their abilities to perceive interdisciplinary relationships of science.

This study postulates that Professional Development (PD) can provide teachers with specific input, which can contribute to the development of their interdisciplinary understanding and KI across the boundaries of science disciplines. Lederman, Gess-Newsome, and Latz (1994) argued that providing teachers with PD that supports aspects of teachers' interconnected content knowledge allowed them to contemplate several important aspects of their science teaching in an integrated manner and to enact instructional strategies in accordance with interdisciplinary learning. This study implies that a specific PD, in alignment with interdisciplinarity, is needed for the integration of the content knowledge and further professional practices of teachers. PD can provide science teachers with a focus on integrated content knowledge and on how the whole structure of knowledge interacts with instruction strategies and student achievement. Although the PD for interdisciplinary teaching may require a considerable investment of resources to develop instructional materials, the effectiveness of PD can compensate for the existing problem in modern day American school systems. Individual science teachers receive certification in a separate subject after going through a teacher preparation program that focuses on their specific majors, like chemistry and biology, during their undergraduate or graduate studies. This education system naturally allows science teachers to teach a specific discipline and makes it difficult for teachers to implement interdisciplinary instruction due to their own unpreparedness and ill-informed knowledge on integrated knowledge.

Science teachers in middle schools are less dedicated to a particular science discipline. However, most middle school general science classes tend to build separate blocks of physical, chemical, biological, and Earth sciences. What the students learn is predominantly affected by how the teachers are teaching to them. If nobody teaches students how to integrate the different disciplines, students are prevented from discovering and creating links between relevant subject matter. This could prevent interdisciplinary understanding in science and even lead to poor academic performance, which puts constant pressure on both the educators and students. It seems that we may be stuck in a vicious cycle of pedagogical challenges. To break this cycle, interdisciplinary teaching should be integrated into the mainstream of current science education.

In future studies, empirical evidence supporting the rationale for the effectiveness of interdisciplinary teaching should be developed. Teachers who have had exposure to interdisciplinary teaching practices and their impact on the quality of teaching would support the theoretical argument of such a study. It is a critical time for teachers and administrators to have a collective impact and propel science education in an interdisciplinary direction.

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