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Abstract

The scope and versatile nature of Career and Technical Education (CTE) discipline areas provide a platform for the integration of STEM subject areas, accomplishing the goal of providing all students a STEM-geared curriculum as well as preparing them for the world of work. Today, it is commonplace to say that relationships between science, technology, engineering, and mathematics disciplines are becoming increasingly stronger, permeating the workplace and creating new demands for solving daily work-related problems. This article discusses the integration of STEM practices into the curriculum and highlights ways to think about a conceptual framework that may facilitate the teaching and integration of STEM concepts. The intent of this article is to contribute to ongoing discussions among educators, employers, parents, and all those concerned in order to seek coherence in STEM instruction.

Keywords: Constructivism; CTE; Goal orientation theory; Problem-based learning; Situated learning theory; STEM integration; Systems thinking

"In recent years, not only educators, but also political, civic and industry leaders have pushed for a greater emphasis on science, technology, engineering and mathematics (STEM) disciplines integration in our schools" (Technology Student Association, 2011). According to the National Governors Association (Toulmin & Groome, 2007), national statistics reveal that there will be a great shortage of math and science teachers in the next decade in comparison to the number of students who will actually opt for STEM-related careers in the future. Solutions to these challenges will require a new scientific workforce equipped with a skill set of new technology and interdisciplinary thinking. The challenges the world faces today call for a global society that is multidisciplinary and may "require the integration of multiple STEM concepts to solve them" (Wang, Moore, Roehrig, & Park, 2011, p. 1). Therefore, it is imperative to train and prepare a diverse STEM-literate workforce with the capability to understand and comprehend the technological world (Merchant & Khanbilvardi, 2011).

The scope and versatile nature of career and technical education (CTE) discipline areas provide a platform for the integration of STEM subject areas, accomplishing the goal of providing all students a STEM-geared curriculum as well as prepare them for the world of work (Association for Career and Technical Education [ACTE], 2009). A search for CTE and STEM education curriculums in academic databases will yield an insurmountable amount of documents and curriculums. A study by the Academic Competitiveness Council found 105 STEM education programs that experienced frequent programmatic changes with differing definitions of what constitutes STEM curriculums and programs in addition to multiple program goals (U.S. Department of Education, 2007). The National Governors Association (Toulmin & Groome, 2007) reported that there was a misalignment of STEM coursework between K–12 postsecondary skills and work expectations; between elementary, middle, and high school requirements within the K–12 system; and between state standards and assessments. This misalignment has resulted in a system in which students participate in incoherent and irrelevant coursework that does not prepare them for higher education or the workforce.

In spite of the lack of consensus related to the details of STEM integration, both national and state policymakers are pushing a STEM agenda. Most states and school districts have not yet put in place standards and curriculum frameworks that provide clear signals about the kinds of academic learning that occur when STEM disciplines are integrated into the curriculum. Additionally, states have no consensus on what key concepts students should master and whether those concepts should be included in the curriculum at a certain grade level or within a specific content area. “Likewise, state assessments of student achievement vary widely” (National Science Board, 2007, p. 5). Researchers have argued that there is a continuing need to clearly define a theoretical framework for STEM integration that may be the basis for comprehension of curricular and classroom practices (Lederman & Niess, 1998; Venville, Wallace, Rennie, & Malone, 1999). To this end, the purpose of this article is twofold: (a) to discuss STEM integration practices into the curriculum and (b) to highlight ways to think about a conceptual framework that may facilitate the teaching of STEM concepts and integration into the curriculum. It is assumed that the term STEM is used both to denote and to emphasize the connection points and overlap among science, technology, engineering, and mathematics. For this purpose, integration of STEM concepts into the curriculum should then be based upon the existence of a coherent conceptual framework that helps educators and students to make connections and to comprehend these connection points and the overlap among STEM disciplines. In this paper, I do not recommend a particular conceptual framework but rather propose how to think about a conceptual framework that may guide STEM integration into the curriculum.

STEM Integration in the CTE Curriculum

In a culture that increasingly embraces STEM concepts in the workplace, literacy in these disciplines and how they relate to each other is imperative. “Hevesi (1999, 2007) reports on a research study conducted by the Comptrollers Office in the City of New York that identified three major skill and knowledge indicators of workforce success after high school: (1) mathematics competency, (2) science competency, and (3) technological competency” (Clark & Ernst, 2008, p. 22). To this effect, “states are implementing programs to foster student preparedness in … [STEM discipline areas] and to better prepare students with the technical skills needed for the emerging workforce. These initiatives blend elements of career and technical education (CTE) and STEM through shared curricula goals and professional development” (ACTE, 2008, p. 57). Thus, “STEM integration [into the curriculum] is an interdisciplinary teaching approach, which removes the barriers between the four disciplines” (Wang et al., 2011, p. 2). According to Huntley (1999), an interdisciplinary approach to teaching implies that “the teacher(s) makes connections between the disciplines only implicitly” (p. 58). In other words, instruction involves “explicit assimilation of concepts from more than one discipline” and is “typified by approximately equal attention from two (or more) disciplines” during a learning episode (Huntley, 1999, p. 58).

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STEM integration into the CTE curriculum offers students an opportunity to experience learning of different concepts in a contextual manner rather than learning bits and pieces and then assimilating them at a later time (Tsupros, Kohler, & Hallinen, 2009). CTE programs of study are aligned to the National Career Clusters framework, which organizes CTE instruction and learning experiences into 16 career themes (National Association of State Directors of Career Technical Education Consortium, 2010). Ruffing (2006) stated that the 16 career clusters sought to mirror "all aspects of industry and allowed students to purse a full range of careers with vertical and lateral mobility" (p. 5). The career clusters seek to provide students with relevant contexts for studying and learning about the world of work.

> According to Sanders and colleagues (in press), STEM integration is the intentional integration of content and processes of science or mathematics education with the content and processes of technology or engineering education along with explicit attention to technology or engineer learning outcomes and science or mathematics learning outcomes as behavioral learning objectives. (Walkington, Nathan, Wolfgram, Alibali, & Srisurichan, in press, p. 3).

> An increasing number of programs across the country describe a STEM focus. Typically, these programs fall into three categories: (a) a concentration on developing a greater depth of content knowledge in a single STEM field (*e.g.,* chemistry, mathematics, physics, electrical engineering) as preparation for a variety of employment opportunities or advanced study; (b) an emphasis on a particular STEM education discipline (*e.g.,* mathematics education, science education, technology and engineering education) and offers a mix of discipline-specific research, pedagogy, and content courses; or (c) a focus which is more cross-disciplinary, requiring participants to enroll in a set of core education and research courses and to select a mixed collection of elective courses from a list of STEM-related disciplines across campus (*e.g.,* biology, geology, mathematics). While each of these options offers participants significant advanced preparation under the umbrella of STEM, they continue to isolate science, technology, and/or mathematics into discipline-specific "silos," indeed, they lack explicit integration across the STEM disciplines. (Smith, 2009, p. 78)

Nevertheless, different models of STEM integration into curriculum and teaching practices exist. Dugger (2010) argued that

> There are a number of ways that STEM can be taught in … schools today. One way is to teach each of the four stem disciplines individually …. Another way is to teach each of the four STEM disciplines with more emphasis going to one or two of the four (which is what is happening in most U.S. schools today) . . . . A third way is to integrate one of the STEM disciplines into the other three…. For example, engineering content can be integrated into science, technology, and mathematics courses … . [And lastly,] a more comprehensive way is to infuse all four disciplines into each other and teach them as an integrated subject matter. (pp. 4–5)

Wang, Moore, Roehrig, and Park (2011) suggested that STEM integration into the curriculum can be achieved through the addition of a design activity as the culminating event to a unit where students are expected to apply acquired STEM knowledge to complete an assignment. Wang et al. further posited that this approach has produced a seamless integration of STEM content into teaching practices and was a successful learning experience for students. The second approach, according to Wang et al., was to start a unit with a design challenge. This approach can be modeled into the curriculum by using products of the designed world (e.g., wind turbines) and introducing STEM concepts to describe the process of problem solving and various levels of success of different design approaches attributed to the amalgamation of these disciplines. Sanders (2009) advocated for "'purposeful design and inquiry' (PD&I) … [pedagogy as the basis for] integrative STEM education. PD&I pedagogy purposefully combines technological design with scientific inquiry, engaging students in scientific inquiry experiences situated in the context of technological problem solving" (Sanders, 2009, p. 2).

Lederman and Niess (1998) argued that "integrated curriculum approaches are typically based on problems/issues students are to solve … real world problems are not the property of one discipline as opposed to another" (p. 283) and call for the logic of an integrated approach to teaching. This argument then places problem-based learning (PBL) at the heart of STEM integration. According to Barrows and Tamblyn (1980), "Problem-based learning is the learning that results from the process of working toward the understanding or resolution of a problem" (p. 1). By working toward solving the problem the student is required to develop problem solving and diagnostic critical thinking skills, conduct research, search for cues, analyze and synthesize available data, develop hypotheses, and apply strong deductive reasoning to realizing a solution to the problem. Similarly, Savery (2006) stated that:

> PBL is an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem. Critical to the success of the approach is the selection of ill-structured problems (often interdisciplinary) and a tutor [or instructor] who guides the learning process and conducts a thorough debriefing at the conclusion of the learning experience. (p. 12)

Havice (2009), Scheurich and Huggins (2009), and Laboy-Rush (2011) have suggested project-based learning as the basis of STEM integration into curriculum. Scheurich and Huggins (2009) argued that project-based learning offered educators opportunities to develop "practical, workable, applicable, powerful classroom tools to accomplish equity and excellence" and significantly improving learning (p. vii). They further argued that math and science courses were taught abstractly; "that is, students are taught formulas or laws, and then the students are tested on those formulas or laws (p. vii). According to Scheurich and Huggins, the goal of project-based learning "is to reverse this relationship: engage students in real world projects through which they learn those math and science formulas and laws upon which our world is now increasingly built" (p. viii).

Savery (2006) argued that "project-based learning is similar to problem-based learning in that the learning activities are organized around achieving a shared goal ([such as the] project)" (p. 16). Savery further stated that project- and case-based approaches to teaching "are valid instructional strategies that promote active learning and engage the learners in higher-order thinking such as analysis and synthesis. A well-constructed case will help learners to understand the important elements of the problem/situation so that they are better prepared for similar situations in the future" (p. 15). "While cases and projects are excellent learner-centered instructional strategies, they tend to diminish the learner's role in setting the goals and outcomes for the 'problem' [under examination]. When the expected outcomes are clearly defined, then there is less need or incentive for the learner to set his/her own parameters" (p. 16). This is in contrary to the real world

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of work where “it is recognized that the ability to both define the problem and develop a solution (or range of possible solutions) is important (p. 16). Additionally, Savery differentiated inquiry-based learning and problem-based learning, he stated that “the primary difference between PBL and inquiry-based learning relates to the role of the … [instructor]. In an inquiry-based approach the … [instructor] is both a facilitator of learning … and a provider of information. In a PBL approach the … [instructor] supports the process and expects learners to make their thinking clear, but the … [instructor] does not provide information related to the problem—that is the responsibility of the learners” (p. 16).

In light of this view, the common question that is still asked by teachers and administrators is: How do we integrate STEM into the curriculum? There is not just one clear answer to this question. Nevertheless, the U.S. Department of Defense Education Activity, Domestic Dependent Elementary and Secondary School (2008) stated that “students generally learn better in a standards-based environment because everybody’s working towards the same goal” (Standards-based systems increase student achievement”, para. 1). As a consequence, Asunda (2012) argued for STEM literacy standards utilizing technology literacy standards as a common approach to the integration of STEM into the curriculum. The *Standards for Technological Literacy* (International Technology Education Association [ITEA], 2000) are a defined set of 20 technological literacy standards grouped into five general categories: (a) the nature of technology, (b) *technology and society*, (c) *design*, (d) *abilities for a technological world*, and (e) *the designed world*. These “standards prescribe what the outcomes of the study of technology in grades K–12 should be” and describe “what students should know and be able to do in order to be technologically literate” (ITEA, 2000, p. 12). Asunda (2012) further stated that the integration of STEM disciplines into the curriculum should be structured “around shared themes based on existing national standards” (p. 50). National standards such as the National Council of Teachers of Mathematics’ *Principles and Standards for School Mathematics* (2000), the National Research Council’s *National Science Education Standards* (1996), the *Standards for Technological Literacy (*2000), the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology’s *Engineering Criteria 2000* (1997), and the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) could provide a standards framework for what students need to be able to do in order to be STEM literate (Asunda, 2012).

Nonetheless, as many educators already realize, design briefs in the form of assignments that mirror aspects of project-based learning are a vehicle by which integration of STEM disciplines into the curriculum can be realized. Such an approach stimulates student curiosity by providing rich context in which students can use science, technology, engineering, and mathematics concepts in meaningful ways. Could project-based design briefs utilizing a PBL approach be the focal point of STEM integration into the curriculum?

A Conceptual Framework for STEM Integration Into Curriculum Through CTE

Design refers to the process of devising something according to a plan. It is a “creative, iterative, and often open-ended process of conceiving and developing components, systems, and processes” (Asunda, 2007, p. 26). Friesen, Taylor, and Britton (2005) described design as “the creative, open-ended, and experiential components that characterize problem-solving” (p. 287). Integration of STEM disciplines into CTE curricula creates a complex learning environment.

The quality of thinking and creative action needed to learn and perform tasks and to comprehend learning outcomes and related concepts must match the complexity and interdependent nature of the disciplines and the learning environment. Such an environment involves new levels of communication, shared vision, collective intelligence, and direct coherent action by students as well educators calling for an integrated systems thinking approach to learning. Brand (2008) suggested that systems thinking is a concept that explores the interdependencies among the elements of a system, looking for patterns rather than memorizing isolated facts as students learn standard scientific methods as a strategy for problem solving. In other words, it is the process of synthesizing all the relevant information we have about an object so that we have a sense of it as a whole. STEM integration into CTE curricula may offer educators and students the opportunity to study how each of the STEM disciplines interrelate and contribute to aspects of real-world CTE learning. Such an approach to instruction "focuses on characteristics and functionality of the entire system and the interrelating subsystems" with design at the heart of problem solving (Kelley & Kellam, 2009, p. 45).

An examination of education programs reveals a diversity of theoretical constructs about learning and teaching, human development, career development, administration and leadership, change and the process of change, and other related topics to designing, conducting, and assessing educational activity (Miller, 1996). Miller further stated that disparate theories abound to guide education practice through philosophy. A philosophic position provides the lens through which the vision of a program may be viewed and becomes the conceptual framework for designing new programs. Miller (1994) argued that pragmatism was the most effective philosophy for education and work. He stated that career and technical educators have been successful in terms of practice and keeping current and relevant by using principles of pragmatism as a frame of reference and basis for workplace education. Pragmatism, building on a constructivist approach, places emphasis on learning by doing, which is the theoretical foundation upon which most career and technical programs are designed and taught. Constructivists view learning as the result of mental construction; that is, students learn by fitting new information together with what they already know.

According to Baxter Magolda (2004), "knowledge is complex and socially constructed; self is central to knowledge construction; and authority and expertise are shared in mutual knowledge construction among peers" (p. 41). Knowles, Holton, and Swanson (1998) stated that "Constructivism stresses that all knowledge is context bound, and that individuals make personal meaning of their learning experiences" (p. 142). "Knowledge is not an object and memory is not a location. Instead, knowing, learning, and cognition are social constructions, expressed in actions of people interacting within communities. Through these actions, cognition is enacted or unfolded or constructed; without the action, there is no knowing, no cognition" (Wilson & Myers, 2000, p. 59). Knowles, Holton, and Swanson (1998) further pointed out that learning is contextual, situational, and cumulative in nature, thus new information must be related to previous experiences for learners to retain and use it.

Schell (2001) stated that contextualized teaching and learning is the adaptation of many innovative ways to teach and learn. It involves authentic learning, self-reflection, and teaching information in real-world contexts. Real-world examples are important and offer students an opportunity to reflect and make connections. Brown, Collins, and Duguid (1989) argued that "the activity in which knowledge is developed and deployed … is not separable from … learning and cognition" (p. 32). In other words, "learning and cognition … [may be] fundamentally situated"

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in an activity (p. 32). Brown, Collins, and Duguid further postulated that activity shapes students skills and provides experiences that are important in understanding concepts. They stated that "representations arising out of activity cannot easily … be replaced by descriptions" (p. 36). It can therefore be assumed that "situations might be said to coproduce knowledge through activity" (p. 32). "Situated learning (e.g., Lave, 1988; Lave & Wenger, 1991; Greeno, Smith, & Moore, 1992) emphasizes the idea that much of what is learned is specific to the situation in which it is learned" (Anderson, Reder, & Simon, 1996).

Wilson and Myers (2000) stated that situated learning theory advocates that whatever is present during learning becomes a part of what is learned including the context, thus *authentic learning*. If the learner can be trained in such an environment, then more of the cues that are needed for transfer are present during learning, thus increasing the probability of what is learned being available for later use. This is the basis for the concept of *authentic assessment* in which real-life situations are used to evaluation student learning. This can be a motivating factor for students because they can see the connection between what they are learning and their long-range goals, which enhances their sense of achievement. "Goals are widely recognized as being central to the understanding of motivated behavior, with different research disciplines emphasizing different levels and types of goals and their consequences" (Brett & VandeWalle, 1999, p. 1). The most recent embodiment of the motives-as-goals tradition is achievement goal theory (e.g. Ames 1992, Dweck 1986, Urdan 1997, Urdan & Maehr 1995)" (Covington, 2000, p. 174).

According to Pintrich (2000), achievement "goal theory assumes that goals are cognitive representations of what individuals are trying to accomplish and their purposes or reasons for doing the task. As such, they are inherently cognitive and assumed to be accessible by the individual" (p. 96). In other words,

> The basic contention of achievement goal theory is that depending on their subjective purposes, achievement goals differentially influence school achievement [or accomplishment of a given task] via variations in the quality of cognitive self-regulation processes. Cognitive self-regulation refers to students being actively engaged in their own learning, including analyzing the demands of school assignments, planning for and mobilizing their resources to meet these demands, and monitoring their progress toward completion of assignments (Pintrich 1999, Zimmerman 1990, Zimmerman et al 1994). (Covington, 2000, p. 174)

So then, what does a conceptual framework for attaining STEM literacy through CTE look like?

> A conceptual framework is an interconnected set of ideas (theories) about how a particular phenomenon functions or is related to its parts. The framework serves as the basis for understanding the causal or correlational patterns of interconnections across events, ideas, observations, concepts, knowledge, interpretations and other components of experience. (Svinicki, 2010, p. 5)

The National Council for Accreditation of Teacher Education (2006) defined a conceptual framework as "the underlying structure of the unit that sets forth a vision of the unit and provides a theoretical and empirical foundation for the direction of programs, courses, teaching, … [and] faculty scholarship and service" (p. 8–9). In other words, a conceptual framework provides a vehicle for educators to classify instructional concepts that are imperative in the integration process, emphasizes connections between these concepts, provides the context for instruction, and aids in course design.

> "Miller (1996) stated that a conceptual framework contains (a) *principles* … 'that state preferred practices and serve as guidelines for program and curriculum construction, selection of instructional practices, and policy development' and (b) *philosophy* which 'makes assumptions and speculations about the nature of human activity and the nature of the world' … (p. xiii)." (Rojewski, 2002, p. 8)

In the same vein, Rojewski (2002) suggested that for a conceptual framework to be effective it should (a) establish the parameters of professional purposes of a program, (b) espouse the philosophical tenets of a field and how they relate to practice, and (c) provide for a platform to comprehend current activity and future directions of the field. Rojeswki further stated that "a conceptual framework does not necessarily solve all problems or answer all questions present in a profession, but it should provide a schema for establishing the critical issues and allowing for solutions, either conforming the problem to the framework or vice versa" (2002, p. 8). To adhere to Miller and Rojewski's suggestions, the framework I propose is offered as a graphical illustration that highlights four theoretical underpinnings with pragmatism as the key philosophical disposition that integrates learning activities situated in PBL toward realization of STEM integration into curriculum through CTE (see Figure 1).

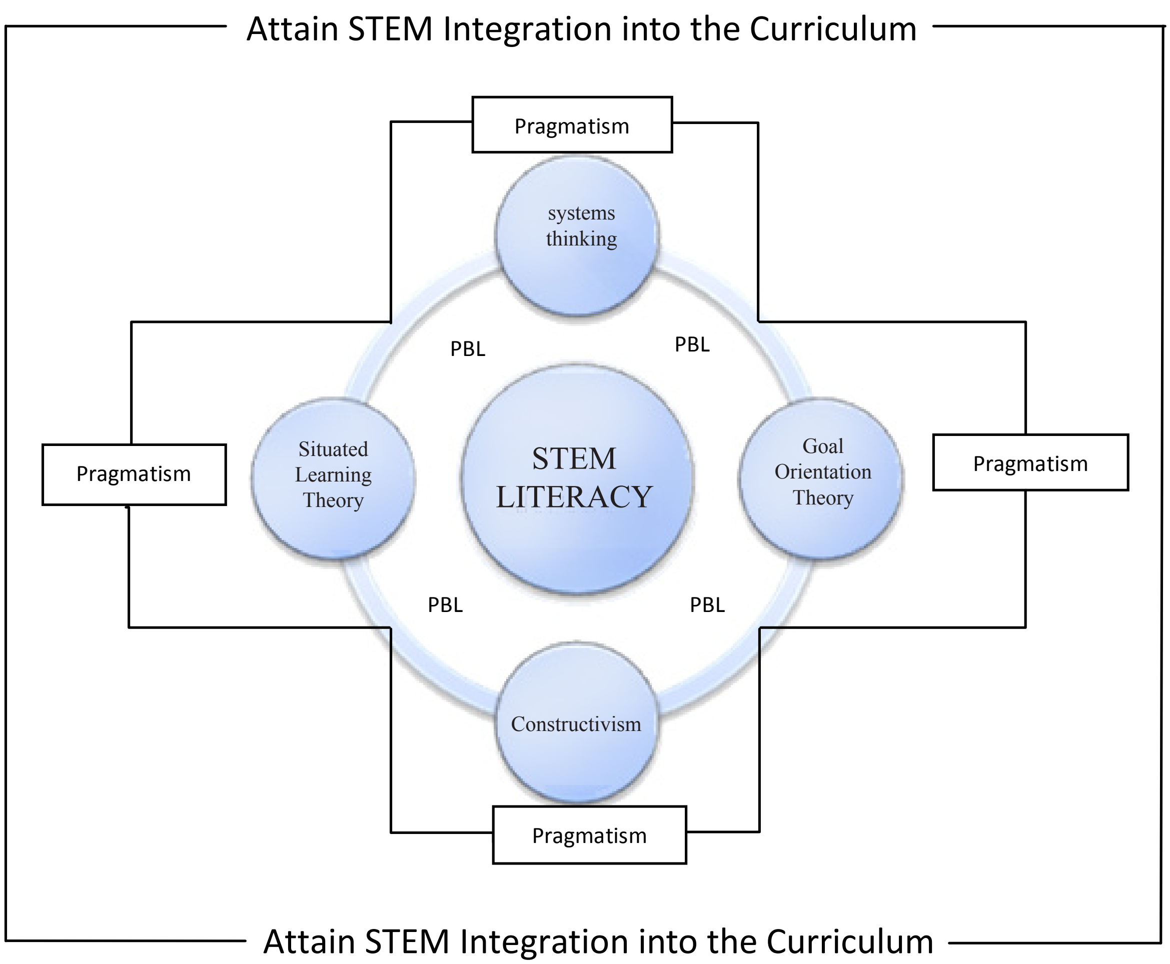

Figure 1. A conceptual framework for STEM integration into the curriculum.

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How Does a Conceptual Framework for STEM Integration Support Acquisition of STEM Literacy Through CTE?

The integration of STEM disciplines into CTE seeks to serve a significant goal of preparing students to be able to critically analyze situations as well as be technically competent. CTE courses incorporate technological literacy processes by delivery of learning content through a series of open-ended, hands-on activities that seek to give students opportunities to solve authentic problems that incorporate design-related components. Such has been the practice for ages to prepare individuals for work related technical competencies. The theoretical and philosophical underpinning of the conceptual framework proposed in this article takes into account that students cannot fully comprehend STEM related concepts without engaging in problem-based learning experiences that mirror aspects of project-based learning practices that lead toward finding solutions to societal issues and the discourses by which such ideas are developed and refined in a contextual manner (National Research Council, 2012).

CTE programs incorporate aspects of situated learning principles by offering students the opportunity to see how theory is used and applied in very practical ways. Brand (2008) asserted that CTE learning activities are based on problem-based learning, providing students with relevant activities that enable students to synthesize knowledge and to individually resolve problems in a curricular context. Adhering to Savery's (2006) argument, problem-based learning mirrors the project-based approach to STEM instruction or learning by doing which is grounded in constructivist theory (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005) and has been shown to improve student learning and comprehension of cognitive tasks, such as scientific processes and mathematical problem solving (Satchwell & Loepp, 2002). Thus, math and science concepts can be embedded in CTE instruction in an integrated approach in which students can be taught to see the whole as one. For instance, a course in forensic technology allows instructors to integrate aspects of chemistry, biology, physics, algebra, anthropology, ethics, and writing. From a systems thinking point of view, learners can reflect on the learning event and see the whole picture rather than focusing on different concepts from STEM disciplines, an attempt to see the forest as well as the trees (Brand, 2008). Further, Satchwell and Loepp (2002) stated that "students learn best when encouraged and motivated to construct their own knowledge of the world around them (Colburn, 1998; Lawson, Abraham, & Renner, 1989)" (The IMaST Learning Cycle section, para. 1). In such a learning environment, students cultivate intrinsic goals and work towards completion of given tasks with a desired outcome. It can therefore be said that the integration of STEM concepts into the curriculum through problem-based activities that mirror project-based experiences in CTE simulates real life issues while encouraging students to construct solutions to authentic challenges they may face in a social context or ecosystem.

Conclusion

The purpose of this article is not to highlight one conceptual framework to guide the integration of STEM concepts into the curriculum but rather to provide a premise from which educators interested in delivery of STEM content in CTE curriculum may reflect upon as they prepare students for the 21st century workplace. At the heart of this framework are four theoretical constructs—including systems thinking, situated learning theory, constructivism, and goal orientation theory—that blend together to accentuate how students may learn STEM concepts in CTE. Barrows and Kelson (1993) stated that "the curriculum consists of carefully selected and designed problems that demand from the learner acquisition of critical knowledge, problem-solving proficiency, self-directed learning strategies, and team participation skills (p. ?). Relating these four theoretical constructs with pragmatism advocates for a curriculum that supports real-world ideas in the classroom through problem-based activities that mirror project-based experiences as a form of instruction guiding integration of STEM concepts into CTE. Such a process may lead to coherence in student learning, what is taught, and how it is taught in programs that are STEM focused. In conclusion, if we reach a consensus on a framework that connects the STEM disciplines, a standardized curriculum that supports STEM integration into CTE may be realized.

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