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Editorial Team

Contact Information

Mailing Address

Journal for STEM Teacher Education
c/o Center for Mathematics, Science, and Technology
Campus Box 5960
Illinois State University
Normal, Illinois, USA 61790-5960

Principal Contact

William Hunter, Editor
CeMaST, Campus Box 5960
Illinois State University
Normal, Illinois, USA 61790-5960
Phone: (309) 438-3089
Fax: (309) 439-3592
Email: whunter@ilstu.edu

Support Contact

Kate Edler
Email: kledler@ilstu.edu

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Welcome Back to the *Journal of STEM Teacher Education*

William J. F. Hunter
Illinois State University

As the new editor, I would like to welcome you back to the *Journal of STEM Teacher Education*. After a brief hiatus, we are pleased to present the 49th volume of the journal. In this first issue, you will find five articles that describe research and ideas in integrated STEM education. Each article offers a unique insight that we hope will stimulate your thoughts and help generate further research and enhanced teaching.

The scope of the *Journal of STEM Teacher Education* is limited to manuscripts relating to science, technology, engineering, and mathematics teacher education issues from early childhood through the university level. All manuscripts accepted for publication in this journal address the integration of at least two STEM disciplines, but may focus on issues about which STEM teachers at any K–20 level should know or upon issues of how to better educate integrated STEM teachers. Manuscripts that are well written and support the dissemination of substantive research, theory, or innovative teaching perspectives will be considered for publication. We welcome STEM education manuscripts that report meaningful research, present research methodology, develop theory, and explore new perspectives. However, we also encourage the submission of manuscripts that primarily describe lesson plans, activities, teaching strategies, courses, or programs relating to STEM education. *Journal of STEM Teacher Education* is an open-access journal with a vigorous peer-review process and high standards for publication. All manuscripts which report data or participation by human subjects must include appropriate oversight by Institutional Review Boards.

As editor of the journal and director of the Center for Mathematics, Science, and Technology (CeMaST) at Illinois State University, I believe that as a society we face a number of problems that share particular characteristics:

- The problems of and solutions for our current and future world are primarily interdisciplinary.
- These problems will be solved by collaboration—locally, regionally, nationally, and internationally.
- These problems will be solved by teams of scientists, technicians, engineers, and mathematicians working collaboratively and innovatively to improve the lives of people everywhere.
- The next generation of STEM professionals must be taught in such a manner as to enable them to work collaboratively with other professionals from diverse fields.
- Future work should be grounded in research that established successful methods for achieving goals.

These characteristics have led to the development of the **CeMaST Stance**:

- Although we will support individual projects, our focus will be to encourage and pursue projects and ideas that bring together professionals from **multiple disciplines**.
- We will focus on problems that affect the day-to-day lives of people around the world and encourage STEM students and professionals to tackle them. We may support basic research, but we will preferentially support **applied and integrated solutions to current problems**.
- We will preferentially promote projects that have an **interdisciplinary research and/or outreach** component.
- We will work on projects that have both **local interest and national significance**.

As we move forward I hope that you will find these articles stimulating and informative. Please feel free to share this issue and these articles with your colleagues. Open access is available at jstemed.org.

As always, we welcome your contributions. Any comments or suggestions may be directed to me via the website or at whunter@ilstu.edu.

Respectfully,

William J. F. Hunter

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A Conceptual Framework for STEM Integration Into Curriculum Through Career and Technical Education

Paul A. Asunda
Southern Illinois University

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).

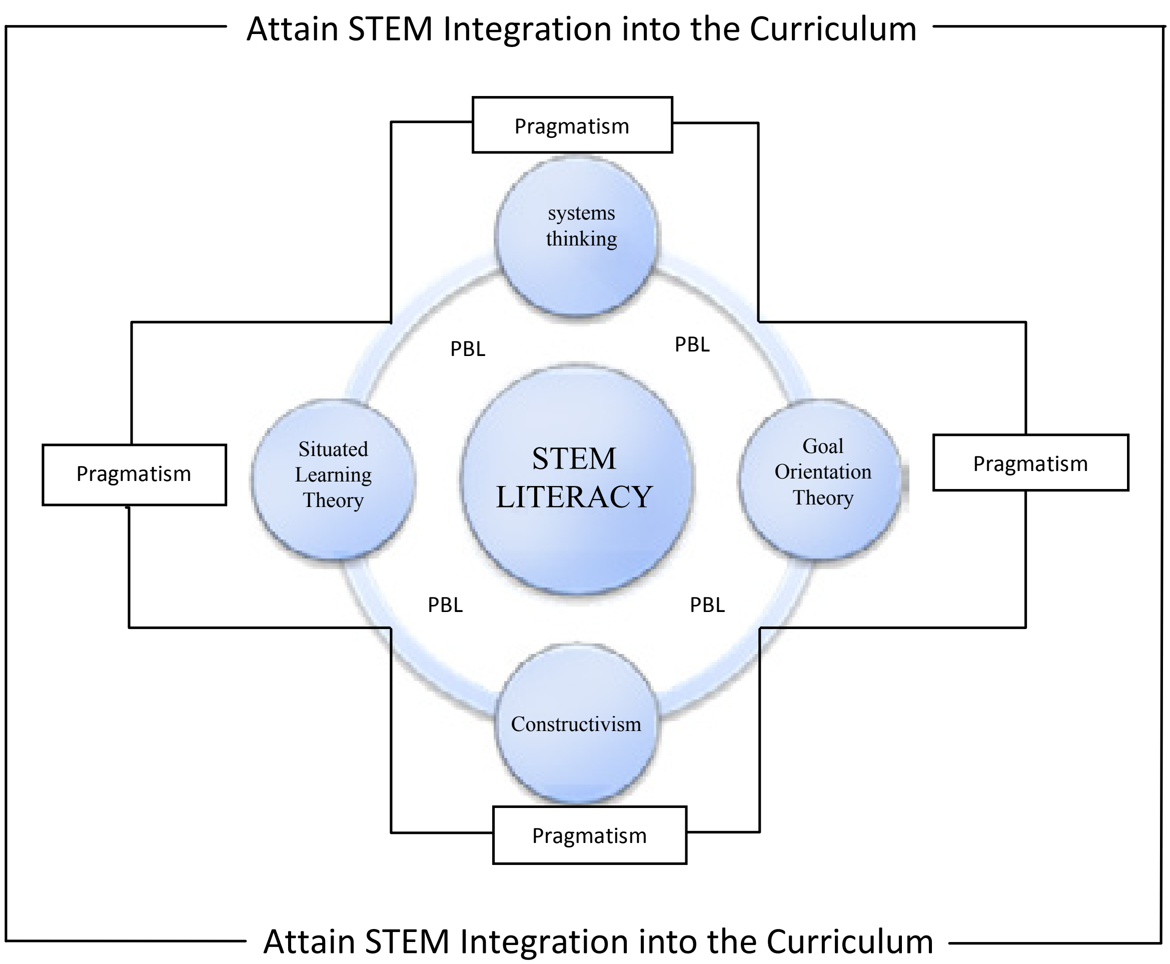

Figure 1. A conceptual framework for STEM integration into the curriculum.

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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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Author

Paul A. Asunda
Assistant Professor
Southern Illinois University, Carbondale
Department of Workforce Education and Development
Email: pasun07@siu.edu

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Bridging STEM With Mathematical Practices

Cory A. Bennett and Wendy Ruchti
Idaho State University

Abstract

Science, technology, engineering, and mathematics (STEM) is often defined as a meta-discipline wherein content from all fields is integrated. However, many teachers are not content experts within each of these disciplines and bridging these individual fields can be a challenge. Yet, content integration need not be the only means by which STEM integration occurs; common practices that focus on thinking and reasoning can and should also exist within classrooms. Even though each STEM field has their own distinct ways of thinking, there are common practices that can link learning to increase students' readiness for the 21st century. This paper highlights how the *Common Core State Standards for Mathematics*' Standards for Mathematical Practice can serve as a common framework around which educators across grade levels can integrate STEM thinking into their own classrooms.

Keywords: Integration; Mathematics; Mathematical Practices

Much attention has been placed on developing student interest and competencies in science, technology, engineering, and mathematics (STEM), and rightfully so. The demand for STEM professionals in the United States outpaces supply and proficiency in mathematics and science is declining (Jobs for the Future, 2007; National Assessment of Educational Progress, 2007). The need to increase and develop K–12 students' mathematical and scientific literacies in STEM education is ever growing and urgent. In the United States alone it is projected that eight million jobs in science, technology, engineering, and mathematics related fields will be needed in the next ten years (United States Department of Commerce, 2011). Furthermore, literacy in STEM has several benefits including the ability to understand and participate in societal and economic matters relevant to an individual's environment, situation, and context (Zollman, 2012) and students who excel in STEM content areas often have several attributes that are valued in higher education and the workforce (Teaching Institute for Excellence in STEM [TIES], 2006). The National Research Council (National Research Council [NRC], 2011) states that even students who do not pursue careers in STEM related fields will need and benefit from being appropriately literate in science and mathematics. Therefore, excellence in STEM education is relevant and necessary to all students.

Traditionally, secondary schools operate within a departmentalized framework that often inhibits the integration of content areas, emphasizing knowledge in silos; this approach may be easiest, but does not meet the needs of students. Teachers with specific content expertise also often struggle in making the connection between disciplines, especially when involving mathematics (Russo, Hecht, Burghardt, Hacker, & Saxman, 2011). The same dilemma exists within many preservice teacher development programs. Preservice teachers complete specific content and methods courses but rarely learn how to blend or infuse content. While elementary schools offer ideal learning situations with flexible periods of time for integrated learning, many elementary teachers lack the content knowledge to effectively create such situations in STEM (Russo et al., 2011).

Furthermore, mathematics has been, and will continue to be, one of the main content areas at the forefront of standardized testing. Historically, testing of this nature has focused on procedural content knowledge and does little to help students learn mathematical problem solving or reasoning. Nor does this discrete measure of isolated facts help students learn to reason across STEM disciplines or other related 21st-century skills. In order to address the STEM career and college readiness needs, greater attention needs to be on developing STEM thinkers and problem solvers who can effectively communicate and collaborate with others. In essence, educators need to find ways to bridge STEM disciplines by supporting student thinking and reasoning regardless of the STEM content.

One of the more recent initiatives for improving student performance in mathematics came from the development and implementation of the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices [NGA Center] & Council of Chief State School Officers [CCSSO], 2010). These standards seek to increase students' mathematical performance and understanding through the development of conceptual and relational understanding; the knowing of what to do, how to do it, and why particular mathematical methods are appropriate and effective for problem solving. For quite some time now there has been substantial attention on high-stakes testing to raise test scores and measure student learning (Popham, 2008). In doing so, an over-emphasis is placed on developing students' computational skills and not on reasoning and thinking skills; skills applicable beyond just mathematics. Part of the *Common Core State Standards for Mathematics* includes the Standards for Mathematical Practice (SMP), the behaviors and habits of mind used by proficient and creative mathematical thinkers. While other content areas, both within and beyond STEM disciplines, might have practices that support and develop the necessary behaviors within their discipline, mathematics is the cornerstone for all STEM disciplines. It is the language by which the sciences, technology, and engineering verify, validate, or construct their work and understandings. The focus of this paper is on using the mathematical practices to bridge STEM-related practices; practices that have their roots in a shared structure, mathematics. In doing so, K–16 educators will have a common framework from which to support relevant and contextually-based and integrated student learning experiences across STEM disciplines.

Rethinking Integration

Integrated content represents an ideal situation for learning; content is often inherently linked in practical or real-world situations and thus it should be linked in learning experiences, too. However, content integration need not be the only means by which STEM reasoning can be promoted and developed. In fact, content integration need not even be the first means by which STEM reasoning is developed.

Since reasoning skills are at the root of all STEM disciplines (TIES, 2006), a logical first step would be to focus on common habits of mind that link scientific and mathematical practices, engineering design processes, and technology foundations. The CCSS SMP (NGA Center &

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CCSSO, 2010) provide an ideal framework by which educators in all core STEM disciplines can infuse essential practices that promote reasoning, communication, problem solving, and using appropriate tools to support and justify thinking. Specifically, the eight SMP are:

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning. (NGA Center & CCSSO, 2010, p. 10)

While originally framed around the Process Standards from the National Council of Teachers of Mathematics' *Principles and Standards for School Mathematics* (2000) and the National Research Council's (2001) report, *Adding It Up*, the SMP fundamentally extends beyond mathematics and bridge the STEM disciplines. When learning science and engineering, students engage in practices that parallel the thinking practices of scientists and engineers; they learn to understand how science is done. As in mathematics, "doing science" or "doing engineering" is not an algorithmic procedure, sometimes not even experimental, but a reasoning process that is open to exploration and discovery.

In the science classroom, students are encouraged to plan and carry out investigations and use skills necessary as they "make sense of problems and persevere in solving them" (NGA Center & CCSSO, 2010, p. 10). Engineering investigations, in particular, are designed to solve problems given constraints. *A Framework for K–12 Science Education* (NRC, 2012) defines engineering "in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems" (p. 3), problem solving aspects also found within the SMP and scientific design.

In using the SMP as a guiding framework around which teachers can support STEM thinking skills, the need to have extensive content knowledge in numerous and specific STEM areas is diminished; helping students learn to think is what matters (Roberts & Billings, 2009). Each SMP begins with the language "mathematically proficient students" (NGA Center & CCSSO, 2010, p. 6–8), but by replacing the word *mathematically* with the word *STEM*, a different picture and conceptual framework for infusing STEM skills begins to take shape. It is through this STEM focused SMP lens that the integration of STEM thinking in the classroom can be promoted and developed.

Infusing the Standards for Mathematical Practice

This section highlights the cross-cutting capabilities of each of the SMP. Language from the CCSS SMP is provided as a reference, although some of the specific wording dealing with mathematical tasks or examples has been removed to provide a more STEM-focused context.

Student-centered learning experiences are presented with discussions on how teachers from various STEM disciplines might infuse each SMP to promote a cohesive approach to developing STEM reasoning. It should be noted that while the SMPs are listed separately, they are often interrelated and can support each other. This means that while they are presented as separate components, they can and should be integrated themselves.

SMP 1: Make Sense of Problems and Persevere in Solving Them

> *[STEM] proficient students start by explaining to themselves the meaning of a problem and looking for entry points to its solution. They analyze givens, constraints, relationships, and goals. They make conjectures about the form and meaning of the solution and plan a solution pathway rather than simply jumping into a solution attempt. They consider analogous problems, and try special cases and simpler forms of the original problem in order to gain insight into its solution. They monitor and evaluate their progress and change course if necessary. (NGA Center & CCSSO, 2010, p. 6)*

This SMP focuses on students understanding problems so that they know how to begin to develop a solution strategy to solve the problem. This requires that they analyze information provided within the problem and make a logical plan based on previous experiences instead of just "jumping into" solving the problem. At times, this may mean that students will need to make changes to their plan and ask if their plan, along with supporting work or evidence, makes sense. Additionally, students will be able to explain all elements of their plan including any work or relationships through other representations such as graphs, pictures, or words. Finally, STEM proficient students will recognize that complex problems have multiple correct plans and will be able to identify similarities in other plans.

In the *Next Generation Science Standards* (Achieve, 2012), students will be expected to learn about the three phases of problem solving: "defining and delimiting an engineering problem," "developing possible solutions," and "optimizing the design solution" (NRC, 2012, p. 203) These three phases can each be connected back to the CCSS SMPs. For example, students should be "defining and delimiting" engineering problems which follow a similar process within the CCSS SMP, designing plans to generate a solution to engineering-based problems. Students will need to generate a number of possible solutions, evaluate potential solutions to see which ones best meet the criteria and constraints of the problem, and then test and revise their designs. Lastly, students need to "optimize" their design plan, which involves a process of tradeoffs; the final design is improved by trading less important features for those that are more important. This process may require a number of iterations before arriving at the best possible design.

For example, an activity that teaches engineering design and problem solving, as well as forces, motion, and buoyancy, challenges students to design a system wherein helium balloons float at a specified altitude (National Aeronautics and Space Administration, 2012). To be successful, students must use criteria and constraints, along with understanding some of the relationships and goals. In essence, proficient students develop a plan, based on current understandings and past experiences, before leaping into a solution. Specifically, they must analyze the problem (helium balloons typically will float to the ceiling), identify criteria and constraints, develop several possible plans, select a design, build a model or prototype, test their plans, and refine the design; all of which require perseverance.

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SMP 2: Reason Abstractly and Quantitatively

> *[STEM] proficient students make sense of quantities and their relationships in problem situations. They bring two complementary abilities to bear on problems involving quantitative relationships: the ability to decontextualize—to abstract a given situation and represent it symbolically and manipulate the representing symbols as if they have a life of their own, without necessarily attending to their referents—and the ability to contextualize, to pause as needed during the manipulation process in order to probe into the referents for the symbols involved. (NGA Center & CCSSO, 2010, p. 6)*

This SMP deals with reasoning skills. Specifically, the need for students to view problem solving in two ways: within the context and removed from the context. In doing so, students can break down a problem into separate, and possibly abstract, parts; investigate these parts; and reason how they relate to each other. All the while, students must still be able to reflect on their reasoning as it relates to the whole problem. In essence, proficient students examine details and yet keep the original context in mind, questioning their findings along the way. Both methods involve creating meaningful representations of information and understanding the *how* and *why* involved in the solution path.

Scientists and engineers also develop explanations and solutions and need to view problems from a decontextualized and contextualized framework. They draw from theories and models and propose extensions to theory or create new models. For instance, a concept in multiple grade levels that students have many misconceptions about is the properties of matter. Students in upper grade levels learn to represent matter symbolically (e.g., CHO_2) and manipulate those symbols to balance equations and make predictions based on the structure of the chemical composition. In such situations, students must decompose a problem into parts, investigate these parts, and reason about how they relate to each other. Yet, they still must be able to reflect on their reasoning as it relates to the whole problem. Students must consider the details of manipulating the chemical symbols while keeping the original context in mind (e.g., the properties of the matter they are working with) in order to draw conclusions and make predictions about the effect of combining or manipulating the matter as it relates to the original problem.

SMP 3: Construct Viable Arguments and Critique the Reasoning of Others

> *[STEM] proficient students understand and use stated assumptions, definitions, and previously established results in constructing arguments. They make conjectures and build a logical progression of statements to explore the truth of their conjectures. They are able to analyze situations by breaking them into cases, and can recognize and use counterexamples. They justify their conclusions, communicate them to others, and respond to the arguments of others. They reason inductively about data, making plausible arguments that take into account the context from which the data arose…[STEM] proficient students are also able to compare the effectiveness of two plausible arguments, distinguish correct logic or reasoning from that which is flawed, and—if there is a flaw in an argument—explain what it is. (NGA Center & CCSSO, 2010, p. 6–7)*

At its heart, this SMP focuses on engaging in meaningful discourse. When students engage in discourse they need to use learned definitions, assumptions, and results when they defend or justify their ideas and conclusions to others. They also need to use these skills when critiquing the arguments of others. In order to effectively engage in this level of discourse students will need to listen to or read their peer's arguments, determine if it makes logical sense, compare arguments for effectiveness, and identify flaws in reasoning as necessary. Furthermore, students will need to ask questions of each other in order to improve arguments, be it their own or their classmates.

Scientists and engineers often engage in an iterative process or evaluation wherein they develop and refine ideas. Argumentation and critique are central activities in this process; they "attempt to establish or prove a conclusion on the basis of reasons" (Norris, Philips, & Osborne, 2007, p. 90). Activities that teach argumentation and reasoning in science encourage students to evaluate alternative perspectives and the acceptability, relevance, and sufficiency of the reasons used to support different perspectives (Osborne, Erduran, & Simon, 2004). For example, students can be asked to develop a tentative explanation or claim for a natural phenomenon such as the phases of the moon. Students then extend their explanation and reasons into a succinct argument using evidence, such as a lunar calendar or direct observations, and models, such as globes and foam shapes, then present their justifications to their peers who can then ask questions, refute statements, or otherwise engage in a discursive interaction based on the original argument. From this discourse and sharing of ideas, students can determine which models offer the best representation or solution path based on logic and evidence just as they do in mathematics.

SMP 4: Model With Mathematics

> *[STEM] proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace…. They are able to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas. They can analyze those relationships mathematically to draw conclusions. They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose. (NGA Center & CCSSO, 2010, p. 7)*

This SMP is rather direct. Students will need to use their knowledge of mathematics to solve real problems without previously having encountered a specific problem or scenario. During this process, students may use a variety of representations to show the relationship between the elements of the problem, as this will help them generate conclusions on the relationships. Students will also be able to interpret, reflect upon, simplify, and make assumptions based on their mathematical knowledge to help them solve real-world problems.

Students might use this SMP when exploring and investigating the water quality of a stream or river. Several variables must be considered when examining the health of a water system, many of which must be modeled mathematically in order to see patterns or draw conclusions, including, but not limited to, the levels of dissolved oxygen, nitrogen, pH, chlorine, and sediments. Measuring dissolved oxygen, for example, requires students to measure the amount of molecular oxygen (O_2) not associated with H_2O in water, the oxygen available for animals that live in water to breath. It is one of many measures of the health of an ecosystem, as dissolved oxygen changes based on temperature, atmospheric pressure, salinity, and the absence or presence of plants or animals that live in the water. Dissolved oxygen is typically measured with an electronic probe, and students often begin to understand the relationships between dissolved oxygen and temperature, pressure, and salinity as they represent their data mathematically using graphs, tables, and for-

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mulas. Modeling with mathematics allows students to identify and analyze relationships between variables in the context of water quality and infer conclusions about the health of the system.

SMP 5: Use Appropriate Tools Strategically

> *[STEM] proficient students consider the available tools when solving a…problem…. Proficient students are sufficiently familiar with tools appropriate for their grade or course to make sound decisions about when each of these tools might be helpful, recognizing both the insight to be gained and their limitations. (NGA Center & CCSSO, 2010, p. 7)*

A diverse toolkit is essential in the sciences. Students need to know how and why specific tools are necessary in solving a problem as well as the constraints of those tools. This SMP states that students need to know when and how to use available tools to solve problems, be it with paper and pencil, calculators, computers, or other data collection tools. Regardless of students' grade level or the course, they should have sufficient knowledge to determine when and which tools will be of benefit to their needs; this also includes knowing when certain tools may not be useful.

Scientists use a variety of tools to obtain information, reveal patterns, and determine relationships about objects that are too large or too small using only human senses. As part of planning and carrying out any investigation, scientists need to utilize appropriate tools (e.g., rulers, beakers, graduated cylinders, telescopes, and microscopes) for evidence collection to substantiate claims. For example, when learning to understand weather phenomena, students utilize thermometers to measure temperature, barometers to measure air pressure, anemometers to measure wind speed, and hygrometers to measure the amount of moisture in the air. However, as stated in the SMP, it is useful to not only know the information that can be gained from a specific tool (e.g., that a barometer is a tool to measure atmospheric pressure) but to know and recognize the limitations of a given tool (e.g., often barometers have elevation limitations) and take that into account when using the data from a tool to justify claims.

SMP 6: Attend to Precision

> *[STEM] proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context. (NGA Center & CCSSO, 2010, p. 7)*

Precision matters greatly in STEM (Achieve, 2012); without it little matters. This SMP highlights the need for students to use precision in written and oral language; models and representations, symbolic or otherwise; measurements and their units; and calculations and their referent solutions. Precision, which is the degree to which something can be replicated, has a different meaning than accuracy, which is how closely something is measured; however, both are important. Within STEM contexts, this means that the focus is on students being able to validate arguments, replicate procedures, and express findings based on logical and systematic thinking. Historically, and from a mathematical perspective, precision may have been thought of as just referring to calculations. But, the National Council of Teachers of Mathematics (2000) has long framed precision in a larger context of problem solving, reasoning, and communication; this is a trait of effective STEM professionals across disciplines. Although some teachers of mathematics may not attend to precision when dealing with some computations, such as when calculating the area of a 3 cm by 2 cm quadrilateral (writing it as $3 \times 2 = 6 \text{ cm}^2$ instead of $3\text{cm} \times 2 \text{ cm} = 6 \text{ cm}^2$), ultimately the student's work and explanation must attend to precision. When the famed mathematician G. H. Hardy stated, "there is no permanent place in this world for ugly mathematics" (1940/2005, p. 14) he was, in a sense, referring to precision. All STEM disciplines must attend to precision, in that the practical, technical work as well as the communication of this work needs to be stated simply and efficiently.

Students should have numerous opportunities, both formally and informally, to practice attending to precision. Precision has several facets in STEM, which include but are not limited to using appropriate and accurate vocabulary, expressing ideas in written and spoken form, and conducting investigations. Similar to the use of precision in mathematics, scientists use mathematics to communicate meaning related to their observations. Meaning in science often involves measurements, but measurements have limited precision. For example, in an activity dealing with force and motion, students release a small car at the top of a ramp to determine if the height of the ramp affects the distance the car travels. One of the tasks in this activity requires students to measure elapsed time with a stopwatch from when the car is released to when the car comes to rest. Afterwards, students compare and discuss their results with the rest of the students in the class, using specific language and details from their exploration. They discover that there are differences in their elapsed time due to the limitations in precision of their tool.

SMP 7: Look for and Make Use of Structure

> *[STEM] proficient students look closely to discern a pattern or structure…. They also can step back for an overview and shift perspective. They can see complicated things … as single objects or as being composed of several objects. (NGA Center & CCSSO, 2010, p. 8)*

Students need to be able to look for patterns and structures as they work in all STEM related disciplines in order to gain deeper insight into the topic under study. This means not only being able to identify a pattern or structure but also having the ability to reflect on their investigations, evaluate the effectiveness of their work in producing the desired results, and possibly take a new approach if their efforts seem not to be working as planned. Furthermore, students who are able to look for and make use of structure can break down complex problems into either several objects or single objects. In essence, they can see the proverbial forest and the trees simultaneously, allowing them to make adjustments to their thinking or methods to more effectively arrive at a solution.

This SMP is evident in the importance of understanding systems, "groups of related parts that make a whole and carry out functions that individual parts cannot" (NRC, 2011, p.107), as a crosscutting science and engineering concept taught at different grade levels. For example, in an upper elementary study of matter and energy in ecosystems, students would construct models to explain the relationships of each of the individual parts (plants, animals, fungi) as it relates to the ecosystem as a whole. The model would describe the interactions of systems within the larger ecosystem in terms of the flow of energy and the cycling of matter. Since complicated systems are composed of multiple parts, students learn to view the whole system as single objects comprised of related subparts with a clear structure, as described in this SMP.

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SMP 8: Look for and Express Regularity in Repeated Reasoning

> *[STEM] proficient students notice if calculations [or ideas] are repeated, and look both for general methods and for shortcuts…. As they work to solve a problem … [STEM] proficient students maintain oversight of the process, while attending to the details. They continually evaluate the reasonableness of their intermediate results. (NGA Center & CCSSO, 2010, p. 8)*

This SMP focuses on students being able to identify and explain processes and structures of thinking based on repeated reasoning. This means that students will examine and consider strategies from a macroscopic and microscopic perspective, keeping the overall goal in mind while paying attention to details. Students may take shortcuts during their investigations, or when solving a problem, and make logical adjustments based on their findings, continually evaluating results for accurateness and reasonableness.

Finding and analyzing regularity is also an important scientific and engineering practice. Revealing the repeated reasoning or regularity in the natural world can lead to inferences about cause and effect relationships, which can then be used to extrapolate information and make predictions. Engineers commonly analyze and diagnose design failures based on repeated regularity, thereby helping design a more effective solution. When using a systematic process for evaluating solutions under similar conditions and tests, the regularity and repeated reasoning found in these comparisons reveal the optimal solutions to a problem. For example, a common engineering activity that might be found within a secondary classroom involves comparing the power utput of different turbine blade designs. Systematically, students can investigate the effects of blade length, number of blades, pitch, shape, and materials used to explore patterns in power output and decide on the best design. Their findings then become generalizations around which shortcuts can be developed. For example, not every length of blade must be tested as regularity in the design and testing stages will dictate the optimal size for a blade. The regularity within the patterns and the repeated reasoning during the design–redesign process also become the basis for evaluating the reasonableness of results.

Conclusions

Helping students develop as proficient STEM thinkers does not have to be restricted to content integration. By infusing the Standards for Mathematical Practice from a broader STEM perspective into the curricula, students can learn to think like mathematicians, scientists, and engineers. Although the described framework represents one way in which teachers can accomplish this goal, it is by no means the only way. Under ideal circumstances, both content and practices would be integrated, though as described earlier, not all teachers possess sufficient pedagogical, content, and process knowledge to do so effectively (Russo et al., 2011). Similarly, the Scientific and Engineering Practices proposed by *A Framework for K–12 Science Education* (NRC, 2012) could be used as a means of integrating STEM, but the connection to mathematical thinking may not be as clear to mathematics teachers. Regardless, the integration of STEM is vital to meeting the goals and challenges currently facing schools in helping students become STEM literate within the 21st century (Zollman, 2012); therefore, action needs to be taken.

The implications for teaching and learning are promising if such a model were adopted and implemented in schools. Cuoco, Goldenberg, and Mark (2012) conceptualized the learning of mathematics around *mathematical habits of mind*—the methods, procedures, and process mathematicians use when problem solving—and found that curriculum became more coherent and that the methods teachers needed to use to make connections between vastly different mathematics curricula was substantially reduced. Ultimately, learning for students became more accessible and focused. Similarly, a unified vision and framework of STEM habits of mind based on the CCSS SMP holds the same promise, fewer and more coherent methods to support student learning across curricula. Adopting and implementing such a framework directly addresses the call to understand how standards for science and mathematics (Ferrini-Mundy, 1998) and technology/engineering and science (Brown, Brown, & Merrill, 2011) mutually support each other. The suggested STEM practices provide educators from across STEM disciplines the opportunity to begin or further their conversations, at the classroom level, on methods that they can use to support student learning. The suggested practices should also provide another area for research, the examination of an interim step in moving from the traditional "silo" view of STEM to the integration of STEM habits of mind, by first integrating common practices.

Although the classroom scenarios described above are but a snapshot of the potential ways in which the CCSS SMP could be integrated, it is quite reasonable for teachers outside of the traditional core of STEM classes to support the development of STEM thinking based on the SMP. Regardless, building creative and innovative thinkers that can apply content knowledge and reasoning, within and between any STEM discipline to facilitate a deeper understanding of these interconnected and mutually supportive disciplines is long overdue. It is time to bridge STEM.

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Authors

Cory A. Bennett is an Assistant Professor of Mathematics Education in the Department of Educational Foundations at Idaho State University and a National Board Certified Teacher in Mathematics—Early Adolescents. His research interests include mathematical discourse, integrated STEM education for preservice and in-service educators, and middle level education.
Email: benncor3@isu.edu

Wendy Ruchti is an Assistant Professor of Science Education in the Department of Educational Foundations at Idaho State University. Her research interests include integrating engineering concepts with other science fields and understanding teachers' attitudes and beliefs in teaching science, technology, and engineering.
Email: ruchwend@isu.edu

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Second-Career Mathematics Teachers' Knowledge of Mathematical Connections

Brian Bowen
West Chester University

Abstract

This study investigated the ways in which second-career mathematics teachers exhibit and discuss their knowledge of mathematical connections. Results indicated that the second-career teachers were most likely to exhibit knowledge of mathematical connections when creating a mathematics problem from a given topic and when making a mathematical connection to a context outside of mathematics. The data analysis indicated that those second-career teachers that exhibited knowledge of mathematical connections were hesitant to use this knowledge in their teaching for reasons including their own perception of students' ability. The implications of these findings inform future preparation and recruitment of second-career mathematics teachers.

Keywords: Teacher education; Mathematics education

For quite some time, second-career teachers have been recruited into the education system due to shortages of teachers in particular geographic areas (e.g., urban schools) and within particular content areas (e.g., science and mathematics; Cornett, 1986; McCree, 1993; Stoddart & Floden, 1995). Now, "between 33 percent and 48 percent of those entering teaching today come from another line of work rather than straight from college (Johnson & The Project on the Next Generation of Teachers, 2004)" (Johnson & Kardos, 2005, p. 11). The United States is presently undergoing an economic crisis; industries that were once abundantly profitable are now near extinction. The resulting reduction in workforce is evident in both white-collar and blue-collar positions. At the same time, there has been an increase in the number of preparation programs designed to recruit and train second-career teachers (Haselkorn & Hammerness, 2008), and the federal government has joined in this effort by funding programs such as $E = MC^2$ and other Transition to Teaching grant programs. The result is a perfect storm of mid-career professionals with technical experience, lacking real-world industrial employment opportunities, with streamlined routes to teacher certification.

One argument made in support of the movement of second-career professionals into teaching is that, since they have degrees in the subjects in which they teach (e.g., engineering degree to teach mathematics or biology degree to teach science), they have the requisite content knowledge. Other arguments suggest that second-career teachers, as a product of their experiences from their initial career, may bring a knowledge of technology to teaching that can be applied to classroom learning (Marinell, 2008; Mayotte, 2003), an ability to engage in real-world mathematical problems that are often ill-defined (Chambers, 2002; Gainsburg, 2007; Marinell, 2008; Mayotte, 2003), and a knowledge of connections between different mathematical areas (e.g., algebra and geometry) with contexts outside of mathematics (e.g., connections between math and science; Chambers, 2002; Marinell, 2008).

The assumption being made from these latter arguments is that adults who interact in their initial career with specific content develop particular knowledge and skills with respect to that content, which they can then draw upon in effective ways as teachers. Whether second-career teachers develop particular knowledge with respect to specific content and whether and how they might draw upon that knowledge in the context of teaching remains under-examined in the field. Building a knowledge base that can begin to address this void is not limited to any single content area, but growth in understanding may be best achieved through studies that are content specific. This study specifically addressed the following research questions:

1. In what ways do second-career mathematics teachers exhibit knowledge of mathematical connections?
2. For those second-career mathematics teachers who exhibit evidence of knowledge of mathematical connections, in what ways do they speak about the sources of their knowledge?
3. For those second-career mathematics teachers who exhibit evidence of knowledge of mathematical connections, in what ways do they speak about the use of their knowledge in their instruction?

Methods

Participants for this study were purposely chosen based on their teaching, academic, and professional experiences. Procedures to select participants and method of data collection were approved by the appropriate university institutional review board. In order to participate in the study, subjects had to be currently teaching or have recently taught mathematics in any grade from 7 to 12. Participants were also chosen based on the degree to which their academic and initial career experiences involved mathematics. By choosing second-career mathematics teachers with academic and professional experiences with mathematics, there was an increased opportunity to see knowledge of mathematical connections in the responses to the tasks and to see potential relationships between participants' initial career experiences and this knowledge. The goal was to find the participants that seemed most likely to have knowledge of mathematical connections.

To determine the extent to which participants' prior academic and career experiences were *mathematically oriented*, I developed definitions to guide my interpretation. For participants' undergraduate degrees, a *mathematically-oriented degree* was defined as requiring at least two courses in calculus and one other mathematics content course at the 300 level or above. The guidelines for a *mathematically-oriented initial career* focused on how often (e.g., daily, monthly) participants reported using mathematics, how they stated that mathematics was used in the context of their career, and what level of mathematical knowledge (e.g., high school, college, graduate level) was required of them. These guidelines were transformed into questions that were given to potential participants in the recruitment form.

Phase One Data Collection

Selection of participants for phase one data collection. Before the recruitment form could be sent to second-career mathematics teachers, potential participants needed to be identified.

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Identification of participants began by contacting teacher preparation programs that specialize in preparing second-career mathematics teachers (e.g., programs similar to Transition to Teaching and Troops to Teachers), and by contacting current and former mathematics specialists who were in contact with a large number of mathematics teachers in the area. Potential participants were sent a recruitment form that collected data on participants' educational and employment experiences, generated from the guidelines previously discussed. The recruitment form asked participants to identify their undergraduate degree and to note whether they would describe it as mathematically oriented (that is, requiring courses such as calculus and differential equations). The participants were also asked to provide examples of how they used mathematics in their previous careers to ascertain the level of mathematical knowledge required for their job (e.g., high school or college level equivalent) and to identify how often they used mathematics in those jobs. Participants who held an undergraduate degree in a mathematically-oriented field, had at least four years of work experience in a mathematically-oriented profession, and used mathematics on a regular basis (e.g., at least weekly) in their initial career were asked to participate.

Table 1
Participants Educational, Initial-Career, and Teaching Experience

Participant	Gender	Degree	Initial Career	Years in Initial Career	Years Teaching
Eric	Male	BA Mathematics	Engineer	4	2
Jane	Female	BS Economics	Computer Programmer Analyst	15	9
Lori	Female	BS Mathematics	Information Specialist	23	1
Meghan	Female	BS Civil Engineering	Engineer	4	9
Mike	Male	BA Mathematics	Actuary	11	4
Reba	Female	BS Computer Science	Computer Programmer	18	5
Rick	Male	BS Engineering	Engineer	14	9
Ronald	Male	BS Engineering	Military & Telecom-munications	33	3
Sam	Male	BS Computer Science	Web Development	15	6
Tara	Female	BS Engineering / Mathematics	Aerospace Engineer	10	4
Ted	Male	BS Chemistry	Chemist	20	5
Terry	Female	BS Biology	Chemist	7	4

Out of the 26 qualified participants sent the questionnaire, 12 returned the completed questionnaire and were paid $10 for their time. The 12 participants for this study were all second-career high school mathematics teachers (one of the participants was teaching physics for the current semester and one had just begun a Ph.D. program) with at least four years of full-time initial career experience in a mathematically-oriented field. Participants' initial fields of employment included engineering (n = 4), actuarial science (n = 1), chemistry (n = 2), and computer programming

(n = 5). The participants all held undergraduate degrees in mathematically-oriented fields, including mathematics (n = 4), engineering (n = 4), computer science (n = 1), chemistry/biology (n = 2), and economics (n = 1). To assure that these degrees fit the guideline for mathematically oriented, course taking requirements for each major were checked at a local university. All of the degrees met or exceeded the guideline requirement. Table 1 displays information about participants' undergraduate degrees, initial career experience, and teaching experience.[1]

Phase one data collection: Questionnaire. The first phase of data collection consisted of a questionnaire with two sections: (a) tasks to elicit second-career teachers' knowledge of mathematical connections situated in the context of evaluating and creating mathematical problems and (b) an open response section asking participants to provide examples of how they draw on their knowledge of mathematical connections to inform their teaching.

The eight tasks that represent the first section of the questionnaire are divided into four subsections. These subsections represent the two types of knowledge of mathematical connections being examined in this study and two situational opportunities (see Table 2). The two situational opportunities that addressed participants' ability to exhibit knowledge of mathematical connections among mathematical ideas were (a) the examination of and (b) the creation of mathematical problems. The *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 2000) argues that teachers can help students seek and make use of knowledge of mathematical connections through problem selection. "Problem selection [by teachers] is especially important because students are unlikely to learn to make mathematical connections unless they are working on problems or situations that have the potential for suggesting such linkages" (p. 359). It follows that teachers themselves need to hold knowledge of mathematical connections to inform their problem selection.

The first situational opportunity asked the participants to examine potential mathematical connections in provided mathematics problems; the second situational opportunity asked the participants to create a mathematics problem. In Table 2, the rows list the types of mathematical connections and the columns list the situations in which those mathematical connections may be drawn upon.

Table 2
Problem Types: Mathematical Connections Across Situational Opportunities

Situational opportunity	**Examining mathematical problems**	**Creating mathematical problems**
Demonstrate knowledge of connections among mathematical ideas.	Two tasks	Two tasks
Demonstrate knowledge of connections of mathematics with contexts outside of mathematics.	Two tasks	Two tasks

Connections among mathematical ideas. One type of knowledge of mathematical connection that these questionnaire tasks examined was participants' ability to make connections

1 Pseudonyms are used for participants throughout the text to protect their anonymity.

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among mathematical ideas. In an effort to create tasks that could best elicit participants' knowledge of connections among mathematical ideas, special attention was paid to whether the mathematics problems themselves would elicit knowledge of mathematical connections. Mathematics problems are constructed and used for several purposes, including for practice with and assessment of specific procedural skills. For example, the following problem can be found in many traditional algebra textbooks—Evaluate: -(8 + 5). This problem provides procedural practice, but the lack of context within the problem may make it more difficult to identify and connect relevant mathematical ideas. However, there are mathematics problems purposely constructed to access knowledge beyond a procedural level; subgroups of these problems are designed specifically to support the use of knowledge of mathematical connections. The following problem is from *High School Mathematics at Work* (Mathematical Sciences Education Board [MSEB] & National Research Council [NRC], 1998), whose authors constructed problems for this text based on tasks solicited from leaders of high school curriculum and assessment projects, mathematicians, and policy leaders.

> A lottery winner died after five of the twenty years in which he was to receive annual payments on a $5 million winning. At the time of his death, he had just received the fifth payment of $250,000. Because the man did not have a will, the judge ordered the remaining lottery proceeds to be auctioned and set the minimum bid at $1.3 million. Why was the minimum bid set so low? How much would you be willing to bid for the lottery proceeds? (p. 111)

The content of the lottery scenario has the potential to elicit or support knowledge of several mathematical connections—a necessary component of a task intended to examine participants' knowledge of connections among mathematical ideas. The structure of the problem provides the framework for students to potentially engage "in the exploration of interest rates, exponential growth, and formulating financial questions in mathematical terms" (MSEB & NRC, 1998, p. 111).

To provide the participants opportunities in which the mathematical problem itself supports identification of mathematical connections, the tasks chosen for the questionnaire most closely resemble the lottery problem discussed above. That is, problems that (a) are not straightforward exercises such as 5 + 3, (b) that include a context (e.g., word problems), and (c) that contain mathematics generally considered to be at a high school level of difficulty. To do this, I used problems with provided solutions from texts (e.g., NCTM, 2000; MSEB & NRC, 1998) that highlight the possible mathematical connections that could be made among mathematical ideas.

In creating tasks to elicit participants' knowledge of connections among mathematical ideas, one must also consider the role of participants' mathematical content knowledge. That is, participants may be more likely to exhibit their knowledge of mathematical connections about topics they are familiar with, as opposed to mathematical topics that are unfamiliar or obscure. For example, a topic such as the Maclaurin series (from intermediate analysis) may not be as well known to the participants as linear equations, area, volume, or integration (topics generally covered in high school curriculum). To address this issue, I have provided three high school level mathematics problems within Tasks 1 and 2 such that each problem represents a different mathematical content area. For example, in Task 1, the three mathematical areas represented in order of the problem presented are probability, geometry (midpoint-of-hypotenuse theorem), and algebra (exponential functions).

For Tasks 3 and 4, there is also a choice between three mathematical content areas. For example, I have used mathematical topics that generally reflect a chapter in a high school textbook (e.g., exponents) as opposed to more specific content that might be covered within that chapter (e.g., logarithms). Drawing upon high school level mathematical topics is appropriate because all of the participants are high school mathematics teachers and as such should be familiar with at least one of the content areas provided. Table 3 shows the mathematical topics for the four tasks focused on eliciting participants' knowledge of mathematical connections among mathematical ideas.

Table 3
Mathematical Topics per Task

Task	Topic choice one	Topic choice two	Topic choice three
Task 3	Writing linear equations	Quadratic equations	Exponents
Task 4	Area	Distance formula	Loci
Task 7	Writing linear equations	Quadratic equations	Powers & exponents
Task 8	Similarity	Central tendency	Trigonometric identities

Connections to contexts outside of mathematics. A second mathematical connection these questionnaires examined was participants' knowledge of mathematical connections to contexts outside of mathematics. As before, these tasks were created within two situational opportunities: participants were asked to examine mathematical problems for potential linkages to contexts outside of mathematics and were asked to create problems that contain such linkages. Again, attention was paid to the role of participants' content knowledge in the design of these tasks. For each task, the participants were given three mathematics problems reflecting three distinct content domains (Tasks 5 and 6) or were given three high school level mathematical content areas to choose from for the creation of each of their mathematics problems (Tasks 7 and 8). Grounding the tasks in high school level mathematics content increased the likelihood that the participants, all of whom are high school mathematics teachers, would be familiar with at least one of the options.

Selection of the mathematics problems intended to elicit participants' knowledge of mathematical connections to contexts outside of mathematics was again guided by the National Council of Teachers of Mathematics's (NCTM, 2000) discussion of mathematical connections. The *Principles and Standards for School Mathematics* (2000) identified two overarching contexts outside of mathematics where connections may be made: connections with another academic discipline and connections to real-world situations. The first requires making a connection with another academic discipline or subject area (e.g., science, history). For example, in Task 5, the falling object problem, one could relate the mathematical concept of writing algebraic expressions to the concept of gravity in physics.

The second context outside of mathematics where mathematical connections may be made requires making a connection with real-world situations. *Real-world situation* is a broad descriptor of mathematical problems, and there may be disagreement over what real-world problems are or need to be. For the purposes of this study, I have chosen to narrow the definition of real-world problems by developing two categories: well-defined real-world problems and ill-defined

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real-world problems. Narrowing the definition in this way potentially aligns with the types of mathematical problems experienced in the high school classroom (well-defined) and the types of mathematical problems likely experienced in the participants' initial career experiences (ill-defined).

According to Jonassen (1997), well-defined problems are "constrained problems with convergent solutions that engage the application of a limited number of rules and principles within well-defined parameters" (p. 65). For example, the Fahrenheit and Celsius scales are related by the formula F = 9/5 (C) + 32. If a child has a temperature of 100 degrees Fahrenheit, what would his temperature be in Celsius? This problem contains all the necessary elements needed to arrive at a solution, there is only one solution, and the solution process is evident in the problem by the given formula. Thus, this is considered to be a well-defined problem.

In contrast, ill-defined problems "possess multiple solutions, solution paths, fewer parameters which are less manipulable, and contain uncertainty about which concepts, rules, and principles are necessary for the solution" (Jonassen, 1997, p. 65). For example,

> In medicine, calculation of body surface area is sometimes very important. For example, severe burns are usually described as covering a percentage of the body surface area. Some chemotherapy drug dosages are based on surface area. How might body surface area be measured? What factors influence the accuracy of the estimates? (MSEB & NRC, 1998, p. 145)

The above problem provides no explicit means for solving the problem (e.g., a formula is not provided), there may be multiple answers considered correct depending on the approach used, and elements of the problem needed to find a solution are not specifically defined (e.g., relationship between a person's height and weight).

Although well-structured and ill-structured real-world problems differ in their structure, they are not separate entities. Instead, well-defined and ill-defined problems reside on a continuum that "is a function of the complexity of the problem, clarity of the goal state and the criteria addressing it, the prescriptiveness of the component domain skills, and the number of possible solutions" (Jonassen, 1997, p. 87). Participants' ability to exhibit knowledge of mathematical connections to contexts outside of mathematics may be more likely if participants were provided opportunities from more than one point on this continuum. To address this issue, Tasks 5 and 6 include both ill-defined and well-defined real-world mathematics problems.

Connection to teaching. The second section of the questionnaire provided an opportunity for the subjects to share examples of how they have used knowledge of mathematical connections among mathematical ideas and to contexts outside of mathematics in their mathematics instruction. In contrast to Tasks 1–8, the open-ended section provided fewer constraints in terms of the content and situational opportunity within which the participant was allowed to exhibit her or his knowledge. Specifically, the open-ended section of the questionnaire asked participants to respond to the following prompts:

- Provide one example of how you have used your knowledge, with respect to your ability to recognize connections among mathematical ideas, in your mathematics instruction related to evaluating mathematical problems or creating mathematical problems.

- Provide one example of how you have used your knowledge, with respect to your ability to recognize mathematics in contexts outside of mathematics, in your mathematics instruction.

This last section of the questionnaire attempted to cast a large net in hopes of gathering remaining data on how and when second-career mathematics teachers exhibit and use knowledge of mathematical connections. This data is relevant to research question one (ways in which knowledge is exhibited) and research question three (use of knowledge of mathematical connections in instruction).

Data analysis of phase one. As a means of organizing the analysis of the questionnaire, a table was created with the names of participants on the vertical axis, descriptions of tasks (including open-ended responses) on the horizontal axis, and related assigned codes. Miles and Huberman (1994) suggest that such organization may assist in drawing conclusion. Each code was assigned a specific color in the table as a way of assisting the observation of frequencies. The table was used to examine patterns (a) between Tasks 1–4 and the first open-ended response (both related to connections among mathematical ideas), (b) between Tasks 5–8 and the second open-ended response (both related to connections to contexts outside of mathematics), (c) across all participants' responses related to each type of knowledge of mathematical connections, and (d) between participants' responses across the two types of situational opportunities. The analysis of phase one data collection informed the way in which data for phase two was collected.

Phase Two Data Collection

Selection of participants for phase two data collection. One of the products of the collection and analysis of the first phase of data collection was evidence of knowledge of mathematical connections. With a sample of only 12 participants, it would be difficult to make conclusions about all second-career mathematics teachers; however, within the data collected, it is possible to discuss patterns in the way the participants exhibited evidence of knowledge of mathematical connections. This was useful in choosing candidates to participate in the second phase of data collection because the second phase was focused on the sources and use of this knowledge.

While reviewing results of the analysis of the first phase of data collection, several interesting patterns emerged. For example, some participants exhibited knowledge of one type of connection, but the data showed a lack of evidence of knowledge of the other. This occurred in both directions related to the two connections: One participant exhibited knowledge of connections among mathematical ideas but did not exhibit knowledge of connections to contexts outside of mathematics; however, another participant showed evidence of the exact opposite situation. To determine which patterns were relevant with respect to the study's research questions and for the selection of participants, I returned to the research questions to support alignment between the data to be collected and eventual conclusions to be drawn.

Although research questions two and three relate to two different aspects of second-career mathematics teachers' knowledge of mathematical connections, attainment versus use, both questions have an underlying assumption that the participants hold knowledge in this area, at least when related to the evidence of knowledge of other participants in the sample. That is, it would be difficult to describe in what ways second-career mathematics teachers discuss the use of their knowledge of mathematical connections if the evidence does not suggest they have this

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knowledge. Given the constraint provided by the research questions, I narrowed the choice of participants for the second phase of data collection to the four second-career mathematics teachers who most often exhibited knowledge of mathematical connections.

To some extent, the narrowing of the participants was relatively straightforward. For example, one of the participants, Ellen, had no responses coded as representing knowledge of mathematical connections, but in comparison Rick had 7 out of 10 responses that were coded as exhibiting knowledge of mathematical connections. I narrowed the selection of participants to those that had at least two responses coded as exhibiting knowledge of the two types of mathematical connections and that also had at least six responses of these responses in total. Five participants met this threshold: Rick, Meghan, Ronald, Tara, and Mike.

Before randomly selecting the four second-career mathematics teachers to participate in the interview, I reviewed my notes from data analysis of the questionnaire relating to these five participants. I specifically looked for data that would inform either the source of knowledge of mathematical connections (RQ2) or the use of knowledge of mathematical connections (RQ3). One response initially emerged from this review: Ronald's responses within the questionnaire explicitly discussed the way in which teaching in an urban environment influenced his use of mathematical connections in his teaching.

> I'll be very honest here. I teach in an inner city high school where there is a significant gap in basic math skills among most of my students. I spend a lot of my time reinforcing basic skills like adding and subtracting positive and negative numbers, working with fractions etc., in the context of basic instruction in Algebra 1 and 2 topics. I sometimes use examples from my previous two careers (military and the telecom business) to give students examples of how some of the concepts they are learning are used. For example, when graphing linear functions, I showed them an example of how a Cartesian plane resembles a military map grid. I also used very simplified examples of how we used linear optimization to develop pricing curves when I worked for a telecom company. But, with the exception of very few students, these examples were well beyond where my students are with their math skills. I want to be careful that I don't give the impression that I believe my students are not capable of making connections. Not so. I just have a lot of work to do before I can get them there.

Ronald's response explicitly discusses the impact of the teaching environment on his use of mathematical connections in teaching.

My next step was to go through the responses for each of the five second-career teachers that met the criteria for the interview portion of the study (Rick, Ronald, Meghan, Tara, and Mike). One other second-career teacher, Mike, also made reference to teaching in an urban environment. Mike's response focused more on the nature of the mathematical problems provided in the questionnaire. In response to the choice of mathematical problems in Task 6, Mike stated, "I wasn't crazy about the contextual potential for urban high school students in any of the questions." Mike provided a less-detailed response than Ronald related to teaching in an urban environment, but it still suggests that teaching in an urban environment impacts his use of knowledge of mathematical connections. Further analysis of the responses looking for other references to the role of teaching in urban teaching environment and evidence (exhibited) of knowledge of mathematical connections was conducted, and I found that Mike was the only other participant that also fit this type.

Why this pattern is relevant to this study emerges from research question three. As mentioned previously, one of the goals of the study is to develop a better understanding of the ways in which second-career mathematics teachers perceive their use of knowledge of mathematical connections in instruction. Mike and Ronald's discussion of the influence of urban teaching suggested that, to some extent, they were conscious of at least one factor influencing the use of their knowledge of mathematical connections.

I re-examine the responses for the remaining eligible second-career teachers (Rick, Meghan, and Tara) for data that may suggest other factors influencing their use of mathematical connections. As no other patterns emerged, I randomly chose two of the remaining three participants by assigning each a number and using a random number generator. Rick and Meghan were selected and were asked to participate in the interview process.

Second phase of data collection: Interview. The interview protocol for the second phase of data collection was divided into three sections. The first section of the protocol gathered information related to the background of the participant including the number of years they have been teaching mathematics, mathematics involved in their initial career experience, and how they perceive the relationship of those experiences to teaching. This section helped to provide a rich description of the background of the second-career teachers and to suggest relationships between their knowledge of mathematics in general and their prior experiences that were useful in refining upcoming interview questions. The second section of the protocol focused on building on the data collected from the questionnaire, specifically asking the participants how they interpreted the two types of mathematical connections included in the study, how they viewed their own knowledge of these connections, and how they account for having this knowledge (RQ2). The third section of the protocol focused on how the participants perceived their use of knowledge of mathematical connections in their teaching, particularly what variables inhibited or supported the application of this knowledge (RQ3).

Data analysis of phase two. All interviews were conducted by telephone, recorded, and later transcribed. The analysis of the interviews began by reviewing notes made during the interviews and by reading each of the transcripts. I then began to group the participant responses into three categories. This analysis was consistent with the comparative approach and as such, upon the initial open-coding, resulted in broad categories (Glaser & Strauss, 1967). The three categories loosely aligned with the three research questions for this study. The first category (RQ1) included responses related to mathematical knowledge; initially this included any mathematical knowledge including the two types of connections discussed in this study. This category captured a range of responses, from responses describing knowledge of specific mathematics content to responses in which participants described their perceived lack of expertise of mathematical knowledge. For example, Mike's suggestion that he felt he had a particularly strong understanding of probability and statistics and multi-variable calculus, and Rick's statement, "I wouldn't say that my math |expertise increased during either one of those careers," were initially categorized in this way.

The second category (RQ2) included responses related to teaching; this included references to the use of mathematics in teaching as well as any reference to school related issues or reference to one's students. This category was also purposely broad, designed to capture any data related to teaching. Responses in this category ranged from participants' descriptions of the number of years they have been teaching and under what conditions to the potential influence of teaching on their use of knowledge of mathematical connections. For example, Meghan's discussion of just

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finishing her tenth year of teaching fit this category as well the way she described how her view of using mathematical connections in teaching has changed:

> I liked that idea, but the change that I have had in my perspective on that is that we need to teach basic concepts as well and if you try to do the relational problems too early then it becomes very confusing for kids.

The third category (RQ3) included responses related to participants' initial career or other prior experiences; this included references to prior academic and personal experiences. Again, this category was kept purposely broad and was designed to capture any data related to participants' prior experiences that were not explicitly related to teaching. Responses that fell into this category included identification of and time spent in an initial career and descriptions of personal hobbies that participants discussed as relevant to their knowledge of mathematical connections. Examples of responses included in the third category included Mike describing his background, saying, "I was an actuary for about twelve years and then got into teaching after that," and Ronald's description of using mathematics in home improvement:

> Well again I kind of go back to my real life experiences. I have done some home improvements and so I had to be able to compute areas and volumes and do some work with angles to figure out how to lay in trim work and those kinds of things.

Each section of the transcripts that aligned with one of these categories was physically marked (circled) and assigned a number representing the category. Sections in the transcript that were left unmarked were reread, and if they still did not align with the three categories, they were put into a fourth category of other, which would be reanalyzed after the creation of code definitions.

The next step in the analysis was to shift to axial coding of the transcript to refine in what ways the three broad categories could be further delineated (Glaser & Strauss, 1967). Beginning with the category of mathematics knowledge, I created codes that would align with the research questions as well as capture responses that may inform the background of the second-career teachers. These codes were (Code A) responses related to connections among mathematical ideas and (Code B) connections to contexts outside of mathematics. All other references to mathematics not discussing mathematical connections were coded as Code C. For the second category, teaching, four codes were created for responses that included (Code D) connections among mathematical ideas in teaching, (Code E) connections to contexts outside of mathematics in teaching, and (Code F) variables that promote or inhibit the use of knowledge of mathematical connections in teaching. All other references to mathematics in teaching that did not include mathematical connections were coded as Code G. For the third category, prior experience, three codes were created for responses that discussed participant's initial career or other prior experiences: (Code H) use of or knowledge of connections among mathematical ideas and (Code I) use of or knowledge of connections with contexts outside of mathematics. All references to use of knowledge other than that of mathematical connections were coded as Code J.

Transcripts were then revisited and coded with these 10 codes. The coding process included circling and marking each section of the transcript with an appropriate code and keeping a separate record of where each code was used. There were instances of multiple codes applied to the same participant response. For example, during the interview with Meghan, I asked her to identify a particular or set of experiences that helped her to develop her knowledge of connections among mathematical ideas. Meghan responded,

> Well those types of things didn't occur to me until after I had been in the teaching field for maybe a couple of years or so. We started using clickers, have you heard of those? That kind of helped me make that connection and say okay that is something we really need to do is make sure that we are helping them keep current on old skills and that is also how you get kids caught up that haven't understood a concept previously is you help them revisit it and maybe revisit it in a new light.

Within this response, Meghan discussed the use of clickers in teaching (Code D) and supported her and her students' work with mathematical connections (Code A).

The last step in the analysis was to arrive at a means of organizing the coding across the transcripts. On the electronic copy of each transcript, I created a color-coding scheme for each of the 10 codes and then highlighted each section appropriately. A separate color was added to represent sections of the transcript coded with two or more codes. Then I created a separate document for each of the codes, cut and pasted each response aligning with that code or codes into the new document, and noted its source. As Miles and Huberman (1994) suggest, this type of summary supports "later and deeper analysis, while also clarifying your ideas about the meaning of your data" (p. 89).

Results

Although not all of the second-career mathematics teachers were able to exhibit knowledge of mathematical connections in every opportunity provided, results indicate that the majority of participants were able to exhibit knowledge of mathematical connections in several of the opportunities provided. When examining the results of the data analysis by participant, 11 of the 12 (92%) participants exhibited knowledge of mathematical connections on at least one occasion, and 10 of the 12 (83%) participants exhibited knowledge on at least four of the eight occasions. Moreover, five of the 12 (42%) participants exhibited knowledge of mathematical connections on five or more occasions, and five of the remaining seven participants (42%) provided two to four responses exhibiting knowledge of mathematical connections.

The next level of analysis of the questionnaires suggested at least two ways in which study participants' exhibited knowledge of mathematical connections. First, as a group, the second-career mathematics teachers were more likely to exhibit knowledge of mathematical connections to contexts outside of mathematics than knowledge of connections among mathematical ideas. More specifically, when a second-career teacher exhibited knowledge of one type of mathematical connections (usually knowledge of connections to contexts outside of mathematics), they were unlikely to exhibit the same level of knowledge of the other type of mathematical connection. Another way to frame this is that it may be that knowledge in one of the types of mathematical connections does not suggest knowledge in the other. Though the majority of second-career teachers exhibited knowledge of mathematical connections with contexts outside of mathematics more frequently, individual-level analysis also showed that three second-career teachers exhibited knowledge of connections among mathematical ideas more often.

Second, as a group, the second-career mathematics teachers were more likely to exhibit knowledge of mathematical connections when the situational opportunity was creating a mathematical

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problem (54%) than when evaluating a mathematical problem (40%). When looking across both the type of mathematical connection and situational opportunity, these second-career mathematics teachers were most likely to exhibit knowledge of mathematical connections when the connection was to contexts outside of mathematics and the situational opportunity was creating a mathematics problem (71%). This combination of situational opportunity and mathematical connection was almost twice as likely to result in a response exhibiting knowledge of a mathematical connection than the other options.

For those participants who exhibited knowledge of mathematical connections, they attributed this knowledge to sources such as teaching and the study of teaching rather than to their initial career experiences. For example Ronald stated,

> A lot of this came from, once I taught for a year or two we were in a master's program also, which is math education at Southern Connecticut State University so I was taking master's course work while I was teaching. That is where I would say some of the connections came. There is this class called teaching high school math from an advanced perspective or something like that where a lot of it was making connections and giving different representations of concepts.

Meghan, who spent four years as an engineer, voiced a very strong opinion about the way in which her initial-career experience influences her knowledge of mathematical connections to contexts outside of mathematics in instruction. She spoke about how the experiences in her initial-career did not support growth in her knowledge of mathematical connections to contexts outside of mathematics.

> Actually, my experience outside of teaching showed me how little math is really used in the real world. I don't say that lightly, I used more math in college to get my education than I did in the jobs that I was doing outside of college.

Mike, who spent 11 years as an actuary, was very cognizant of the disconnect he perceived between his initial career experiences and his knowledge of mathematical connections to contexts outside of mathematics.

Mike:	Now that I have taken PhD course work, I have a much greater appreciation for those kinds of connections [connections to contexts outside of mathematics] and I did not before. Part of it might be that that masters program was really math content heavy and we didn't do a lot of area research on math ed and I was sort of pragmatic too, you know this is what seems to be working in classrooms as far as instruction and it was mostly math content like I said so that's why I didn't think of out of classroom context for connections.
Interviewer:	You have spent twelve years in this actuarial experience...
Mike:	Right, exactly. Applications of math concepts.
Interviewer:	Right. It seems like that didn't naturally transition to the classroom thinking that way teaching wise.
Mike:	I would say that's accurate. Yes.

Interestingly, Mike's perception of his own knowledge of mathematical connections to contexts outside of mathematics did not change through the use of mathematics in the real world, but instead by graduate work studying mathematics instruction. Mike explained that one reason that his initial-career experience did not inform his knowledge of mathematical connections related to teaching is because of how he "dichotomized the two things."

The participants who did exhibit knowledge of mathematical connections also appeared to struggle to apply their knowledge in teaching due to variables such as their perceptions of student ability and a depreciated view of the role of mathematical connection in mathematics pedagogy. For example, Rick stated,

> It is going to sound cliché because it's the same old well it sounds wonderful and a lot of people are on board with trying to do things in context and making connections, but at the same time there's also a lot of pressure to take care of the latest standardized test or SATs or where everybody else is kind of more immediate driver of what goes on in the school and that kind of depends on, that comes and goes on how much that kind of gets in the way or doesn't get in the way.

This quote points to pressures inhibiting the use of his knowledge of mathematical connections in instruction, but the comments also seem to suggest that making mathematical connections in instruction are somewhat extraneous and can be cut off if other priorities arise. This idea was echoed by a second subject of the study, Ronald.

> I'll be very honest here. I teach in an inner city high school where there is a significant gap in basic math skills among most of my students. I spend a lot of my time reinforcing basic skills like adding and subtracting positive and negative numbers, working with fractions etc., in the context of basic instruction in Algebra 1 and 2 topics. I sometimes use examples from my previous two careers (military and the telecom business)… But, with the |exception of very few students, these examples were well beyond where my students are with their math skills. I want to be careful that I don't give the impression that I believe my students are not capable of making connections. Not so. I just have a lot of work to do before I can get them there.

Ronald seems to be saying that the use of mathematical connections in his teaching would require a level of mathematical knowledge his students do not yet possess.

Implications

That these second-career mathematics teachers were able to exhibit knowledge of mathematical connections but encountered difficulty integrating this knowledge into their instruction is an important finding. Particularly, this study illustrates that it may not be second career mathematics teachers' lack of knowledge that is of issue. Rather, the issues may be assisting the second-career teacher to make clearer the connection between their own career experiences and the classroom. Data from this study suggests that efforts made by university preparation programs may need to further examine to what extent they are balancing content and pedagogy. Evidence of this may be seen in the way Mike spoke about the difference experiences between his masters and PhD work.

An additional issue inhibiting the integration the use of second-career teachers' knowledge of mathematical connections may be the way in which these teachers perceive the role of developing

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students' knowledge of mathematical connections in mathematics instruction. Evidence for this can be seen in the way in which Ronald and Rick both spoke about the integration of mathematical connections and their concern over student knowledge as well as bureaucratic pressures. This is an encouraging finding, as the perceptions of second-career mathematics teachers can be challenged in their preparation program and supported during their teaching with resources from professional organizations such as the National Council of Teachers of Mathematics, the National Science Teachers Association, and the National Research Council as well as through the examination and use of curricula that develops students' knowledge of mathematical connections as an integrated component of mathematics instruction (e.g., University of Chicago School Mathematics Project).

Although the focus of this study was on second-career mathematics teachers, the results may be extended to other STEM second-career teachers. Several of the participants of this study came from professions whose experiences may also provide connections to teaching the subjects of chemistry (chemist), physics (engineer), or computer science (web development). The way in which participants in the study encountered difficulty integrating connections between their prior career experiences and teaching may be mirrored in a similar way in these subject areas.

The participants in this study represent only a subset (a substantial subset) of the teaching population; however, the results of the study may also be informative for those who prepare teachers through a more traditional route. In Ma's (1999) study of Chinese and American teachers, the Chinese teachers referred to mathematical connections among mathematical ideas as a "'knot' that ties a cluster of concepts that support the understanding of the meaning" of a mathematical topic (p. 82). This is a goal not specific to those entering teaching from mathematically oriented initial careers. The results of this study may also impact the ongoing assessment question regarding how to identify what constitutes evidence of knowledge of mathematical connections (in general and specific to various types of mathematical connections). Translating this view into a rubric to identify a response that qualifies as a mathematical connection is a complex process and the methods used in this study could continue to shed light on this issue. Given that more effective definitions of mathematical connections still need to be developed, further work aimed at expanding and refining a measurement tool is an important next step for research about teachers' knowledge of mathematical connections.

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Author

Brian Bowen
Assistant Professor
West Chester University
Mathematics Department
Email: bbowen@wcupa.edu

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Elementary STEM Education: The Future for Technology and Engineering Education?

Michael K. Daugherty, Vinson Carter, and Lindsey Swagerty
University of Arkansas

Abstract

Technology and engineering education has struggled to maintain a foothold in the secondary schools for more than twenty years. Project Lead the Way, Engineering by Design, and other engineering-related curriculum initiatives have assisted the profession in maintaining some presence in the secondary schools, but the influence of technology and engineering education curriculum at junior high and high schools across America is clearly less than it was just 20 years ago (Volk, 1997; Volk, 1993). A leadership role in the preparation of elementary STEM teachers may provide the profession with a substantial contributing position in the education of teachers.

Keywords: Teacher education; Technology and engineering education; STEM

Introduction

Technology and engineering education has struggled to maintain a foothold in the secondary schools for more than twenty years. Project Lead the Way, Engineering by Design, and other engineering-related curriculum initiatives have assisted the profession in maintaining some presence in the secondary schools, but the influence of technology and engineering education curriculum at junior high and high schools across America is clearly less than it was just 20 years ago (Volk, 1993; Volk, 1997; Akmal, Oaks, & Barker, 2002; Wright, Washer, Watkins, & Scott, 2008).

It seems clear that the decrease in frequency of technology and engineering education at the secondary school level is, in large part, due to high-stakes testing and the fact the this discipline is not directly assessed on any of the high-stakes tests required of secondary public schools in the United States (Musoleno & White, 2010). In a middle school study, Musoleno and White discovered that due to No Child Left Behind and other high-stakes testing, teachers are forced to spend more time in core subject areas such as reading, writing, and mathematics. This increased focus time has dramatically altered the amount of time available to spend on other subject areas. In the age of high-stakes testing, there is little room in the secondary curriculum for subjects that do not directly impact student performance on those examinations, and it appears that many school administrators have decided that technology and engineering education is one of those subjects (Catterall, 2012). Although the National Assessment of Educational Progress (NAEP) will conduct a trial test of national technology and engineering literacy in 2014, this may come too late to convince many educational leaders.

At the same time that technology and engineering education seems to be becoming scarce in secondary schools, integrated STEM education is attracting increased attention and gaining momentum from educators, politicians, and the media across the nation. Recent attention has brought to light the low number of students pursing STEM disciplines and degree programs in the United States (Toulmin & Groome, 2007; National Science Board, 2010). There is a great need in America for talented scientists, engineers, technologists, and technicians. The National Governors Association (Toulmin & Groome, 2007) has called for a new workforce of problem solvers, innovators, and inventors who are self-reliant and able to think logically, also suggesting that creating such capacity is one of the critical foundations that drive innovative capacity in the nation. A key to developing these skills is strengthening science, technology, engineering, and mathematic (STEM) competencies in every K–12 student.

Although most inside the technology and engineering education profession would argue that this discipline is the best hope for truly integrating STEM education in the secondary school, secondary school administrators are not likely to expand a disciplinary offering in an already crowded school curriculum, even when educational leaders believe it to be important. This is particularly true when the discipline in question is not included in the myriad of high-stakes testing (Catterall, 2012).

Interestingly enough, at the same time technology and engineering education has been struggling to maintain or possibly expand a foothold in secondary schools through new STEM and engineering initiatives, elementary schools throughout the nation seem to be pleading for assistance in implementing new integrated STEM education programs (Center for Digital Education, 2010). In addition to educational and political pressure to improve overall student |performance in mathematics and science, elementary school leaders are increasingly recognizing that STEM curricula may have the greatest impact at the elementary school level. Research suggests that children's aspirations in STEM areas are largely formed by the time they are 10–14 years old and vary little after this age (Archer et al., 2012; Murphy & Beggs, 2005; Tai, Qi Liu, Maltese, & Fan, 2006). Since interest in STEM subjects and STEM careers is largely formed by the time children reach the upper elementary and middle school level, it becomes increasingly critical that children's interest in these areas be captured and encouraged during the early to middle elementary grades, long before the point at which they enroll in courses leading to eventual career paths during high school and college (Archer et al., 2012).

DeJarnette (2012) noted that

> Numerous programs abound for high school and middle school students in regard to STEM initiatives; however, fewer opportunities exist for elementary students and their teachers. Research has shown that early exposure to STEM initiatives and activities positively impacts elementary students' perceptions and dispositions (Bagiati, Yoon, Evangelou, & Ngambeki, 2010; Bybee & Fuchs, 2006). By capturing students' interest in STEM content at an earlier age, a proactive approach can ensure that students are on track through middle and high school to complete the needed coursework for adequate preparation to enter STEM degree programs at institutions of higher learning. As a result, programs focusing on STEM initiatives and content are a growing priority in elementary schools throughout the United States with aims to provide early exposure for elementary students. (p. 77)

Coupled with this, research suggests that elementary school is the most appropriate time to

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engage students in integrated STEM education and spark the interest of elementary-aged students—particularly in science, technology, engineering, and mathematics. Brotman and Moore (2008) implied that female students who engage in hands-on science projects at the elementary level are more likely to perform well in science and are more prone to engage in science fields at the collegiate level. They argued that if we are to increase girls' and boys' engagement in science, we need to work toward influencing the education that students receive in the elementary classroom (Brotman & Moore).

Technology and engineering teachers can play an important role in developing elementary students' awareness and curiosity in STEM. A study by Habashi, Graziano, Evangelou, and Ngambeki (2008) found that teachers were effective at directing elementary students' interest in STEM subjects and pursuing STEM careers. Students' personal interests in objects were shown to be a motivational influence for engaging in STEM activities. However, in this longitudinal study, the effect was strongest with third grade students when their interests were more "plastic" and diminished significantly by sixth grade. These results indicate that if more children are to enter the STEM pipeline, then teachers in early elementary grades need to be prepared to provide interesting and engaging lessons that focus on developing children's problem-solving and spatial ability while encouraging their intrinsic interest in STEM.

The need for strong and engaging STEM programs at the elementary school level also appears to be particularly important for female students. Dave et al. (2010) noted that although the number of women majoring in engineering related fields has increased in the last few decades, percentages lag behind those in other STEM disciplines. Young women often have misperceptions about the nature of engineering, and that leads to a lack of involvement and motivation. Engineering is often seen as men's work, and young women often fail to understand how engineers can have a positive impact on society or how they can help fill that need (Hersh, 2000). This problem may be exacerbated by traditional elementary teachers who have a limited background and knowledge of STEM fields. Given that many elementary teachers feel apprehensive about teaching STEM lessons (Rittmayer & Beier, 2008), a formula for changing the status quo will require the infusion of highly skilled STEM educators who can provide engaging lessons and professional development for other educators within the elementary school—something that technology and engineering educators are particularly well-suited to provide. There have been some national efforts to integrate technological literacy, engineering, and STEM into the elementary school curriculum like the Engineering is Elementary curriculum, but the overall effect is very limited.

Review of Literature

Importance of STEM Education

For several years, politicians and educational leaders have been working to strengthen STEM education in the United States (Thomasian, 2011). Thomasian described that the National Governors Association reports two immediate STEM goals that must be addressed: "increase the proficiency of all students in STEM and grow the number of students who pursue STEM careers" (p. 5). The reasons are clear and compelling: "STEM occupations are among the highest paying, fastest growing, and most influential in driving economic growth and innovation" (p. 5). He goes on to note that "unfortunately, the United States has fallen behind in fully realizing the benefits of STEM education" (p. 5) and progress measured by the National Assessment of Educational Progress examination shows little improvement over the past decade.

Technological fields, like engineering, are in desperate need of more qualified workers, yet not enough students are pursuing studies in STEM that would prepare them for technical careers (Rockland et al., 2010). Unfortunately, many students have very limited interest in STEM careers, particularly engineering, because they are not exposed to topics in these fields during their K–12 studies. Most K–12 teachers have not been trained to integrate relevant STEM topics into their classroom teaching and curriculum materials. The National Science Board reported, "In the next decade, the Nation is going to need 2.2 million new teachers in K-12 schools and community education settings. The greatest need now and into the future is for teachers in the STEM areas" (2007, p. 3). Bybee (2010) stressed that STEM literacy involves the integration of STEM disciplines as "interrelated and complementary components" (p. 12).

While the evidence outlining the need for more STEM-prepared students is overwhelming, postsecondary education has done little to meet this demand. Thomasian (2011) noted that although STEM career opportunities are expected to grow by 17% between 2008 and 2018, many higher education institutions have not increased their output. In a recently published report, the National Governors Association stresses the need for new teacher preparation programs and professional development that "stresses a multidisciplinary approach for better preparing all students in STEM subjects and growing the number of postsecondary graduates who are prepared for STEM occupations" (Thomasian, 2011, p. 9).

The report from the National Governors Association (Toulmin & Groome, 2007) also notes that the target is to increase STEM proficiency for all students—regardless of eventual career. The report implies that "the ability to understand and use STEM facts, principles, and techniques are highly transferable skills that enhance an individual's ability to succeed in school and beyond across a wide array of disciplines," and all students should be prepared with these skills (Thomasian, 2011, p. 12). "These skills include: using critical thinking to recognize a problem; using math, science, technology, and engineering concepts to evaluate a problem; and correctly identifying the steps needed to solve a problem (even if not all the knowledge to complete all steps is present)" (p. 12). These skills clearly represent primary concepts underlying the field of technology and engineering education and items highlighted in the *Standards for Technological Literacy*.

A surprising amount of research has concluded that an interdisciplinary or integrated curriculum provides students with a relevant, comprehensive, and more stimulating experience in the classroom (Bybee, Powell, & Ellis, 1991; Furner & Kumar, 2007; LaPorte & Sanders, 1993; Loepp, 1999; Satchwell & Loepp, 2002). Recent research in curriculum development indicates that much of the newest and most valuable knowledge involves more than one subject, and Stohlman, Moore, and Roehrig (2012) endorsed an integrated approach to STEM education that can inspire students' future success and interest in STEM disciplines. Stohlman et al. also reported that "effective STEM education is vital for the future success of students. The preparation and support of teachers of integrated STEM education is essential" (p. 32). The ability to attract students into the STEM workforce is a chief component in advancing the sustainability and success of the U.S. innovation economy (Atkinson & Mayo, 2010). The implementation of STEM education into elementary schools can connect students with opportunities in STEM fields.

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Why Deliver STEM in the Elementary School?

> The combined effects of standards-based reforms and accountability demands arising from recent technological and economic changes … are requiring schools to accomplish something they have never been required to do—ensure that substantially all students achieve at a relatively high level. (Corcoran & Silander, 2009, p. 127)

Meeting that challenge will require educational leaders to reexamine the curriculum, the manner in which instruction is delivered, and the level at which core subjects are taught (Corcoran & Silander, 2009). Corcoran and Silander also note that "most high schools organize instruction by subject or discipline, thus encouraging an isolated … approach to teaching rather than one in which teachers are guided by a shared vision or goals" (p 157). Compounding the problem, most schools also start STEM instruction at the secondary school level (Means et al., 2008). Means et al. found that there were at least 315 public STEM schools in the United States as of the 2007–2008 academic year; 86% of these schools served students in Grades 9–12, while only 3% to 4% serve students in Grades 1–5.

Anthony Murphy (2011), Executive Director of the National Center for STEM Elementary Education, notes that

> We need to begin STEM education early with our children, certainly in elementary school and possibly even younger. Children … are natural scientists, engineers, and problem-solvers. They consider the world around them and try to make sense of it the best way they know how by touching, tasting, building, dismantling, creating, discovering, and exploring. For kids, this isn't education. It's fun! Yet, research documents that by the time students reach fourth grade, a third of boys and girls have lost an interest in science. By eighth grade, almost 50 percent have lost interest or deemed it irrelevant to their education or future plans … . That means that millions of students have tuned out or lack the confidence to believe they can do science [or pursue a future in STEM]. (Murphy, 2011, para. 5)

After examining a variety of elementary STEM programs across the nation, DeJarnette (2012) suggested that elementary STEM education be greatly expanded to help foster an interest in STEM subject areas for continued interest among students. She further noted that students who complete STEM programs in high school have a greater likelihood of continuing in STEM fields for college and careers, and the same likelihood would occur between the elementary school and the middle school if STEM programs were expanded during the early grades. The goal of educators now should be to look at increasing the number of students interested in STEM programs in middle school and high school; therefore these concepts should be presented at the elementary grade level (DeJarnette, 2012).

In secondary education,

> Effective teachers with content knowledge in STEM play a key role in student achievement. Almost all of these secondary STEM teachers have a degree or minor in one of the STEM disciplines, but elementary teachers are generalists and typically major in education. (Murphy, 2011, para. 7)

So, it should not be a surprise to anyone that teachers at the elementary level are somewhat apprehensive about teaching STEM—in large part, they were not prepared to teach STEM effectively (Murphy, 2011). "Research shows that many elementary teachers feel anxious about teaching STEM subjects. If they themselves lack confidence, how can they impart passion and knowledge to their elementary students? (para. 8).

It is one thing to understand the benefits of STEM programs and to start the process to implement programs within the elementary schools. However, we must also look at the qualifications of the teachers. Integrated STEM education content and methods are not included in most of the general teacher education courses required for elementary teacher licensure (Epstein & Miller, 2011). In order for STEM programs to be successful, we need teachers who understand the significance and importance of integrated STEM along with the content areas of science, mathematics, technology and engineering (Epstein & Miller, 2011).

Kelley (2010) noted that

> There are a number of examples in technology education history of multidisciplinary and interdisciplinary efforts linking technology education with other disciplines; however, there has never been a time in technology education where multidisciplinary and interdisciplinary efforts are not only promising but also may be essential for the prosperity of technology education. (p. 2)

It seems that a very important role for the technology and engineering education profession may be to provide STEM content and methodology to a new generation of elementary education teachers.

University of Arkansas STEM Education in Elementary Teacher Education

In 2012, the University of Arkansas developed and implemented a graduate certificate program with a concentration in STEM education for their 5-year Master of Arts (MAT) in Teaching Early Childhood (elementary) Program. This program was created to meet the demand for highly qualified teachers at the early childhood and elementary levels with knowledge of each STEM discipline and how these subjects can be effectively integrated in the classroom to maximize learning and interest. The graduate certificate program is comprised of five courses, two of which are parts of the MAT program. The remaining courses may be taken as students are completing their undergraduate degree or taken concurrently with the MAT as electives.

The first course, Introduction to STEM Education, is an introductory course in integrative STEM education and focuses on the development and introduction of STEM content and pedagogy for the PK–12 classroom. The course includes an introduction to the nature of each of the STEM education disciplines followed by an exploration of the pedagogies and heuristics unique to the fields of STEM education and insights into teaching strategies that can be used to deliver instruction in an integrative fashion. Students learn to solve real-world problems by extracting the STEM content that might be used in multiple solutions to the problem and then develop grade-appropriate lessons that can be directly implemented into the elementary classroom.

The second course, Creativity and Innovation in STEM Education, is an introductory course in technology and engineering education, which focuses on the development and introduction of technology and engineering-based activities to support science and mathematics instruction in the elementary classroom. Through hands-on, project based learning challenges, students develop an understanding of the engineering design process and the integration of science, technology, engineering, and mathematics (STEM) often used to solve real-world problems. Students are exposed to the process of engineering design, invention and innovation, trouble-shooting, technical

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and procedural processes, research and development, and experimentation. They are also given the opportunity to learn about the tools, materials, and processes needed to implement project-based learning using engineering design challenges to strengthen student understanding of mathematics and science concepts.

The third course, Problem-Based Math for STEM Education, focuses on sharing, modeling and practicing strategies to support the meaningful integration of science, technology, engineering and mathematics (STEM) with an emphasis on mathematics in the elementary classroom. Students are provided opportunities to develop confidence in their mathematical abilities by integrating the STEM disciplines in a problem-based approach. Students are given the opportunity to create project-based mathematic experiences for students and analyze their previously developed lessons for missed opportunities that may be used as a springboard for greater reinforcement of mathematic content.

The fourth course, Problem-Based Science in the Elementary Grades, focuses on the importance of science in the elementary classroom and building a strong foundation of science understanding by integrating the STEM disciplines through a problem-based approach within the elementary curriculum. Students learn about the theoretical frameworks, research, resources, and methods related to appropriate and effective classroom practice. Students are provided with opportunities to apply science toward solving human and environmental problems and how the unique developmental needs of young children may be met through an integrated problem-based methodology that uses mathematics, technology, and engineering to develop scientific solutions.

The final course in the program, Curriculum Design in STEM Education, focuses on the design and adaptation of STEM curriculum for students in regular and special classrooms. Theoretical bases and curriculum models such as Backward Design (Wiggins & McTyghe, 2006) provide the grounding for the course. Students develop curriculum and implement their work into the classroom at local partnership elementary schools during practicum experiences.

During the first semester of implementation, students and faculty collaborated on two presentations at the International STEM Education Association's annual conference. They made two presentations, *Delivering Hands-on Integrative STEM Education in the Elementary Classroom* and *Preparing Teachers to Teach Integrated STEM Education*, to audiences of practicing teachers. The students led the participants by using a narrative curriculum (Lauritzen & Jaeger, 1997) approach in which children's literature was used to set-up the background for engineering design challenges. The problem-based lessons included challenges such as building a tornado-proof scale-model structure and a catapult using concepts from all of the STEM disciplines. Although the certificate program was less than a year old at the time of this writing and no outcome assessments had been completed, it should be noted that enrollment in the program has grown from 15 preservice elementary education teachers in the fall of 2012 to 41 preservice elementary education teachers in the spring of 2013. Early elementary school interest in the STEM certificate program has expanded at a similar rate with one elementary school launching an elementary STEM laboratory and another elementary school developing a plan to enroll all teachers in the certificate program in the fall of 2013.

Collaboration and Synergy

There is clearly a growing awareness of a promising elementary teacher education role for technology and engineering education, and there are a handful of programs that have been engaged in this arena for a number of years. However, a quick glance at the *Technology & Engineering Teacher Education Directory* (Rogers, 2013) reveals that the vast majority of technology and engineering teacher education programs continue to focus almost exclusively on preparing secondary technology and engineering teachers. This article and the teacher education graduate certificate outlined above are meant to suggest that the time is right for the technology and engineering teacher education field to diversify and engage more deeply in the preparation of elementary education STEM teachers. The existing political winds and the current national fixation on STEM in general, and STEM at the elementary school level in particular, provide unique opportunities for the field of technology and engineering teacher education. These opportunities include engaging in a dialog and collaborative initiatives with elementary educators and teacher educators, developing synergy between elementary and secondary teacher education program leadership, the development of programs designed to prepare STEM educators for the elementary level, and the opportunity to immerse the field more deeply in STEM curriculum development and instruction at all levels of K–12 education. By engaging more deeply in elementary STEM teacher and curriculum development and the preparation of STEM capable elementary students, technology and engineering teacher education programs may experience renewed interest from these students as they progress into secondary and postsecondary educational programs of study that are related to STEM.

Conclusion

The *Common Core State Standards for Mathematics* introduced in 2010 by the National Governors Association Center for Best Practices and the Council of Chief State School Officers place an emphasis on process standards including problem solving, reasoning and proof, communication, representation, and connections. The National Research Council (2012) has proposed that the transition toward the *Common Core State Standards for Mathematics* will allow curricula to address topics such as STEM more comprehensively, thus enabling students to develop proficiency and greater achievement in mathematics. Furthermore, the new *Framework for K–12 Science Education* (2012) and the recently adopted *Next Generation Science Standards* (2013) place a heavy emphasis on technology, engineering, and design throughout K–12 science education. In fact, the *Next Generation Science Standards* reflect many of the same content ideas and frameworks as the *Standards for Technological Literacy* (2000)—the content standards used extensively in technology and engineering education. The technology and engineering education profession must view these changes as an opportunity to expand the delivery of technological literacy to a larger audience, especially in elementary science and mathematics education where the new standards include specific and related performance objectives.

By providing integrated STEM content and pedagogy for preservice teachers, these future elementary teachers are prepared to deliver content-rich and standards-driven lessons and engaging problem-centered learning that will influence the interests and abilities of the next generation of students. These preservice elementary teachers are also able to gain confidence, experience the student enthusiasm that is built through project-based learning, and foster a deeper appreciation and willingness to deliver STEM content in the elementary classroom. Ultimately, these preservice teachers can come to the understanding that teaching integrated STEM is something that they are capable of successfully accomplishing. It is clear that elementary STEM education provides a unique teacher education and professional development opportunity for the technology and

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engineering education profession, and it is also evident that the elementary education and elementary teacher education communities could benefit greatly from such a collaborative national relationship.

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Authors

Michael K. Daugherty
Department Head, Professor of Technology & Engineering Education
Department of Curriculum and Instruction
University of Arkansas
Email: mkd03@uark.edu

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Analysis of Content and Digital Media Infusion Quality in Integrative STEM Education

Jeremy V. Ernst
Virginia Tech

Abstract

This content and digital media analysis study was conducted within a graduate level course involving experienced science, technology, engineering, and mathematics (STEM) education practitioners. Participants assessed aural/visual proposals producing an overall score, a content score, and a digital media infusion score. The scores were tabulated and analyzed for assocations within assessed clusters, specific evaluative considerations when factoring overall score, and diffenences among associative clusters. It was determined, through formulation of the Spearman's Rho correlation matrix and further analysis through the Fisher *z*-transformation output, that experienced STEM educator content score correlation coefficients were statistically higher than the experienced STEM educator digital media score correlation coefficients.

Keywords: At-risk implications; Content analysis; Digital media; STEM education

Introduction

Dynamic media application and instructional infusion in elementary and secondary settings has broad utility for a range of learners, furthering educational intensity while propelling learners within science, technolog, engineering, and mathematics (STEM) education disciplines (Ernst & Clark, 2009). Documented benefits of digital media incorporation range from content comprehension and retention (Lippincott, 2002) to emergent literacies (Hisrich & Blanchard, 2009) to impact on overall school culture (Rose & Meyer, 1994). Expansive effectiveness of the use of dynamic learning tools for at-risk and underserved learners, as well as traditional learner groups, is well documented (Tettegah & Mayo, 2005).

Digital media-based technology implementation in K–12 STEM education classrooms has pervasive presence, created by the identifiable educational value and subsequent adoption of standard sets/electronic technology accessibility (Irving & Bell, 2004). Often there is an expectation or a localized pressure to further build digital and media technology applications into STEM education courses or paths of study. Barone and Wright (2008) identify a demand or expectancy of digital and media tool use in classrooms where many K–12 educators feel unprepared for facilitation or practice. Select teacher preparation programs do provide prospective teachers with direct exposure to the implementation of digital technology learner applications (Banister & Reinhart, 2012), but these remain infrequent at the appropriate depth.

Kraidy (2002) identifies that learner modes of cognition are further formed through digital application enabled by instructional media. Digital visualization of information supports the understanding of nonrepresentational ideas while concurrently promoting conceptual abstraction. Initiatives within science education; technology, engineering, and design education; and mathematics education that build or implement digital tools for educational consumption highlight engagement and heightened learner outcomes (Sun & Metros, 2011; Busby, Ernst, & Clark, 2011; Ke, 2006; Squire, Barnett, Grant, & Higginbotham, 2004). However, quality work indicators through established assessment criteria and factors/assessment protocols that constitute a gauge of conceptual abstraction are commonly unspecified.

Digital Content Analysis

There are many aspects that can serve as "distractors" pertaining to the evaluation of digital content. For example, in a 2008 study, Eysenbach recognized that refined design features and well-composed and aesthetically pleasing static graphics had a sizeable effect on identified credibility of information. Similarly, in a study investigating the evaluation of web-based material (Rieh, 2002), structure, graphics, and organization were the most prevalently cited characteristics applied to evaluating quality. In a 2012 study, Watson and Ernst uncovered that for knowledgeable STEM education evaluators, content has a stronger association with overall evaluation than digital media infusion. While acknowledging the separation and unique differences between the experienced evaluators of the Watson and Ernst (2012) study and the novice evaluators of the Eysenbach (2008) and Rieh (2002) studies, the large separation and seemingly contradictory findings should be noted.

With undisputed advantages of the use of digital media for STEM education learners, the continual demand for dynamic means of learner interface, and the common creation of digital-based student learning artifacts, it is reasonable to seek confirmation that knowledgeable STEM education professionals are in fact able to determine the credibility of digital artifacts. Specifically, as suggested in the Watson and Ernst (2012) study, we need to answer the question: Are STEM education professionals proficient in gauging quality of content over quality of infusion of digital media in the dynamic presentation of information? In efforts to explore this issue, a study was proposed and conducted involving STEM education professional examination of dynamic media digital artifacts.

Participants

Participants in this content and digital media analysis study were enrolled in a Foundations of STEM Education course at the graduate level. The course was housed within a school of education in an Integrative STEM Education Program. Participants in the study were pursuing one of five graduate credentialing or degree options: Integrative STEM Education Graduate Certificate, Master of Arts in Education, Education Specialist, Doctorate of Education, or Doctor of Philosophy. For the purposes of this investigation, differentiation of degree option was established only for description of participant demographical makeup. Typically, the Foundations of STEM Education Course consisted of first year students, most of which had previous K–12 STEM education classroom experience or were current in-service STEM educators. Participants enrolled in Foundations of STEM Education during this study were predominately licensed educators with current or previous K–12 experience. Three participants did not have immediate or previous K–12 classroom experience and were professionals in engineering or engineering education. Table 1

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provides participant demographics pertaining to graduate degree pursued, gender, semester enrolled in the program, and indication of previous K–12 STEM education classroom experience.

Table 1
Demographics of Study Participants

Degree *n* (%)	Gender *n* (%)	Semester *n* (%)	STEM Ed. Classroom Experience *n* (%)
Cert. = 4 (13%)	Male = 13 (40%)	First = 22 (69%)	Yes = 29 (91%)
M.A.Ed. = 15 (47%)	Female = 19 (60%)	Second = 7 (22%)	No = 3 (9%)
Ed.S. = 2 (6%)		Third = 3 (9%)	
Ed.D. = 3 (9%)		Fourth = 0 (0%)	
Ph.D. = 8 (25%)			

Note. $N = 32$

Methodology

The intent of this research study was to analyze the relationships among content evaluation, digital media infusion, and overall evaluation of electronic media presentations. There was a single overarching question that guided this study:

> *Is there a distinguishable difference between association of content/overall analysis and association of digital media/overall analysis by STEM education professionals?*

The study methodology consisted of drafting and submitting a proposed research protocol to the governing Institutional Research Board. The research protocol was reviewed and administratively approved. Once official approval was received, recruitment of study participants began. Individuals that were enrolled in a course entitled Foundations of STEM Education were invited to participate in the study examining how a knowledgeable audience evaluates a proposal developed with digital media tools. The participants were informed that there were no risks involved with participating in the study and that the submitted assessments were completely anonymous. Participants were also informed that participation in the study would have no impact on their grade either in the course or on the student-generated Integrative STEM Education Strategies Aural/Visual Proposal.

Consenting participants were asked to complete a three-part assessment form in which they were to provide three different categories of evaluation scores (overall score, content score, and digital media infusion score) on the Integrative STEM Education Strategies Aural/Visual Proposals. This study was conducted during the 15th week of a 16-week semester in order to establish course content as well as permit full development of course participant aural/visual proposals. Participants were provided online access to the proposal assessment form and asked to evaluate their randomly generated group members. Each group consisted of approximately five members (in two groups there were six members) that would then evaluate one another's work. Twenty minutes were allowed for evaluation of the three aspects of the aural/visual proposals during which time participants finalized and submitted their scores.

STEM Education Foundations Course

The Foundations of STEM Education course is a requirement in the Integrative STEM Education Program at Virginia Tech. The course approaches science, technology, engineering, and mathematics education content and practices from a distinct discipline-based historical and theoretical angle. As a result of the evidence-based material, students often form or re-form viewpoints and approaches concerning STEM education and its organizational structure in K–16 education. In the course, students discuss topics such as Science Education, Technological Literacy, Establishing K–12 Engineering Education, Mathematics Education Structure and Approach, Unwrapping STEM Education Standards, Curricula in STEM Disciplines, and Natural Integration for STEM Disciplines and Students At-Risk. Course requirements included Forum Responses consisting of posted questions within the learning management system that related to the previous class session's discussion. There were five Forum Responses required over the course of the semester. In addition to each individual post, participants were expected to review posts of classmates and provide feedback or questions where the individual deemed it appropriate. The Origins Report assignment required students to select from a list of instructor-generated STEM discipline topics, research that topic, generate a podcast, make the podcast accessible via the learning management system, and address the questions of peers based on the content of the work. In the required Reading Summaries assignment, participants gradually read a list of 22 research articles and submitted five Reading Summaries considering what the reading introduced, what the reading proposed, and what impact or implications the reading had on the identified STEM-based educational discipline. Participants also completed an essay-format course midterm examination and final examination where course content, readings, and discussions were used to answer essay questions. Finally, students completed and submitted an Integrative STEM Education Strategies Aural/Visual Proposal. In this study, the strategies proposals serve as the dynamic media learner artifact being evaluated by participants.

Aural/Visual Proposal

The dynamic media learner artifact that was developed and evaluated by study participants consisted of STEM education content based on directly challenging or expanding upon an approach or a model discussed or referenced during the STEM Education Foundations course. The models discussed or referenced through course presentations, discussions, and readings concern the further promotion and development of integrative STEM education. Participants were urged to consider the following guiding questions pertaining to the information anticipated in the proposal:

- What was the nature of the purposeful integration to occur and at what academic level was it focused?
- What underpinning research or evidence served as the basis for this type of integration?
- How was buy-in created from a local, state, and national level?

There were numerous digital media applications that could be used to develop the aural/visual proposal. Some commonly used applications were Camtasia, CamStudio, Screencast-O-Matic,

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and Screenflow. The applications were specifically used to convey audio content considering the proposal's guiding questions and to present visual material in support of the audio content. Each participant created a 7–10 minute dynamic and persuasive proposal using supplemental audio content, images, graphs, illustrations, and visualizations. Once completed, each participant proposal was made accessible through a course learning management system. A sample aural/visual proposal from a previous Foundation of STEM Education course (not included within this investigation) can be found at http://www.youtube.com/watch?v=BNpUZKXw1V4.

Proposal Assessment Form

The form used by participants to assess the aural/visual proposals consisted of an Informed Consent page, Part A (overall assessment), Part B (assessment of content), and Part C (assessment of digital media infusion). The Informed Consent page reiterated the request for participation, outlined the participant expectations, and addressed potential risks and benefits of the research along with a statement of anonymity and confidentiality. Part A requested researcher-provided proposal identifiers for the project being assessed to directly match with the overall project score identified. The overall scoring scale ranged from 1 (*Low/Poor*) to 10 (*High/Excellent*) followed by a free-response prompt gathering criteria or factors in assigning an overall score to the project.

Part B requested content scores on a scale also ranging from 1 (*Low/Poor*) to 10 (*High/Excellent*). Content analysis considerations were identified on the form as:

1. How well did the author directly challenge or expand upon an approach or a model discussed/referenced concerning the further promotion and development of Integrative STEM?
2. How well did the author address the nature of the purposeful integration to occur and the academic level at which it will be focused?
3. How well did the author address the underpinning research or evidence that serves as the basis for this type of integration?
4. How well did the author address the ways in which buy-in will be created from a local, state, and national level?
5. How well and how accurately did the author use the information presented during the course?

Part C requested digital media infusion scores on a scale also ranging from 1 (*Low/Poor*) to 10 (*High/Excellent*). Digital media analysis considerations were identified on the form as:

1. Is the quality of digital media used supportive of the proposal content?
2. 2) Is the quantity of digital media infusion sufficient to support the proposal content?
3. Are visuals appropriate/supportive of information cited and introduced by the audio?
4. Do audio and video transitions add interest without being distracting?
5. Do supplemental visualizations (e.g., images, animation, video) add interest while supporting information presented?

The web-based form was composed with parameters where participants were not allowed to alter Part A scores once proceeding to Part B. However, participants were permitted to toggle between Part B and Part C and alter scores as they deemed necessary. The form was structured in this way to enable accurate initial establishment of overall criteria without predisposition of the content analysis and digital media infusion recommended considerations.

Data and Findings

The STEM educational content outcome data, digital media outcome data, and overall outcome data were examined to uncover variations, correlations, and differences. A scatter plot (see Figure 1) of content scores with matched overall scores was constructed to provide a visual representation of the array of assessment results for the 125 participant ratings. The scatter plot of the data does not display a complete linear alignment but does exhibit a concentrated grouping uncovering a positive slope relationship of content score to overall score.

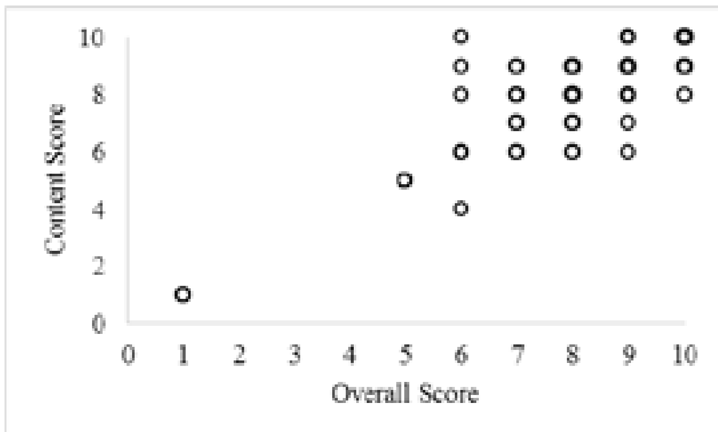

Figure 1. Scatter plot of overall score by content score (n = 125 ratings).

At the conclusion of Part A on the proposal evaluation form, participants were asked to identify specific criteria or factors used in assigning overall scores for projects. Among the 32 unique responses for this prompt, there were seven recurring criteria cited (see Table 2).

Table 2
Recurring Criteria in Assigning Overall Score

Criteria	Occurence
Overall presentation	3
Presentation flow	3
Visuals	3
Clarity	3
Depth	2
Consistency	2
Interest	2

A second scatter plot was generated (see Figure 2), providing a visual depiction of the digital media infusion outcome scores and overall outcome scores of participants. As in Figure 1, the scatter plot does not display a clear linear alignment but does present a concentrated grouping uncovering a

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positive slope relationship of digital media infusion score to overall score.

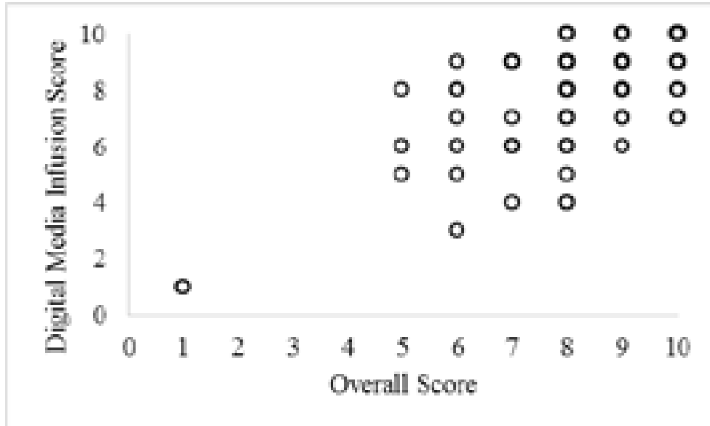

Figure 2. Scatter plot of overall score by digital media infusion score (*n* = 125 ratings)

Finally, a third scatter plot was generated (see Figure 3), providing a graphical representation of the digital media infusion outcome scores and content outcome scores of participants. As in Figure 1 and Figure 2, the scatter plot does not display a well-defined linear alignment but does depict a concentrated grouping uncovering a positive slope relationship of digital media infusion score to content score.

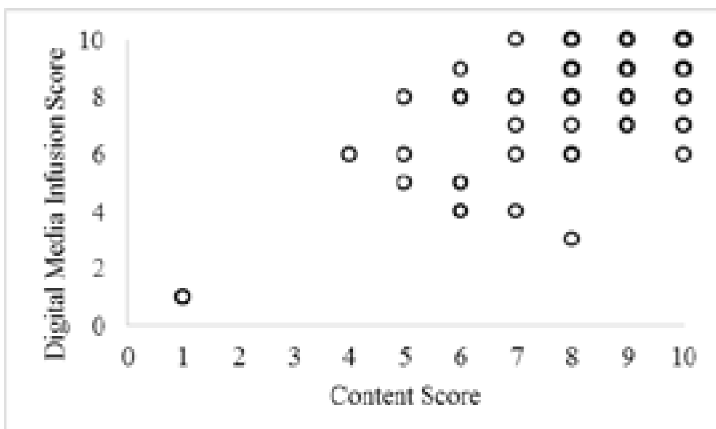

Figure 3. Scatter plot of content score by digital media infusion score (*n* = 125 ratings).

In this study, the sampling was not randomly conducted. The participants were selected for their expertise. Therefore, the distribution of the data is nonrandomized, categorically identifiable as a non-Gaussian population. Additionally, the evaluative scores in this study were ordinal variables considering meaning of different levels within the instrument classification may not be precisely the same for different individuals. Based on the nonparametric distribution and the nature of the data, Spearman's rho was selected as the analysis tool to tabulate correlation in place of Pearson, which is used for continuous variables (Sheskin, 2007). Spearman's rho measures the strength of the linear relationship between two variables when the values of each variable are rank-ordered (Weinberg & Abramowitz, 2008), and it calculates a correlation coefficient on rankings rather than on tabulation of the raw data (Muijs, 2011).

The correlation coefficients were calculated (Table 3) between each of the paired variables using Spearman's rho because the variables were ordinal in category. The Spearman's rho between content score and the overall score was 0.757, which was significant at the 0.01 level. This indicates a strong positive correlation between the two variables. As the evaluation of content increases or decrease, the overall evaluation of the proposal has a tendency to change to the same direction proportionally. There was a moderate positive correlation between digital media infusion and overall score; the Spearman's rho was 0.541 and was significant at the 0.01 level. Therefore, the overall evaluation has a tendency to increase or decrease together along with evaluation of content. A Spearman's rho of 0.498, significant at 0.01 level, was shown between digital media infusion score and content score, suggesting a moderate positive association between how the participants evaluate content and the infusion of digital media tools. The evaluation of content and the digital media infusion tend to increase or decrease together, although not in a directly proportional manner.

Table 3
Spearman's Rho Correlation Matrix

	Overall score	**Content score**	**Digital media score**
Overall score	--	0.757*	0.541*
Content score	0.757*	--	0.498*
Digital media score	0.541*	0.498*	--

*Correlation is significant at the 0.01 level (2-tailed).

The Fisher z-transformation is utilized to assess statistical differences, if any, between the content score/overall score correlation coefficient and the digital media score/overall score correlation coefficient. When a stated coefficient is greater than another stated coefficient, z will tabulate as a positive sign; alternatively, z will tabulate as a negative sign (Lowry, 2013). In the case of the content score and digital media score assessment of significance in Table 4, the z-statistic was tabulated as a positive sign while its corresponding tabled p-value was < 0.01, indicating a statistically significant difference between the two tested correlations. It was determined that the content score correlation coefficients are statistically higher than the digital media score correlation coefficients.

Table 4
Fisher Z-Transformation

Correlation difference	***n*1**	***n*2**	**Diff. Est.**	***z*-stat.**	***p*-value**
Content Score – Digital Media Score	125	125	3.53	3.0	< 0.01

Conclusions

As implementation of electronic learner artifacts in educational environments becomes more prevalent, it is important for educators to develop, maintain, or expand upon their abilities to distinguish between creatve digital media incorporation and the informative or descriptive

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nature of dynamic media-based content. In this investigation, positive slope relationships of content scores to overall scores as well as digital media infusion score to overall scores were identified. Further, significant associations were found between both content scores and overall scores in additon to digital media infusion scores and overall scores. Both content and digital media infusion are clear contributors to overall analysis outcomes for STEM education professionals. However, based on the Fisher z-transformation, a statistically significant difference between the content score correlation and the digital media score correlation was identified. This suggests that the content score was a firmly associated indicator of overall content credibility while digital media infusion was not as strongly associated based on the evaluations performed by the group of STEM education professionals. This study showed that there was a distinguishable difference between association of content/overall analysis and association of digital media/overall analysis for STEM education professionals.

Although there was a separation in circumstance and analysis technique from this study, the finding of Watson and Ernst (2012) that content possesses a stronger association with overall evaluation than digital media infusion was confirmed. Further reinforcing this conclusion is the free-response identification of overall evaluative criteria in Part A of the proposal assessment form. Based on the overall participant-identified criteria for the aural/visual proposals, content was a stronger initial consideration when evaluating the proposals given that all seven recurring factors were features central to content. Interest and visuals are partial contributors to digital media but not fully exclusive to that construct. Further investigation is needed in efforts to establish evaluation trends underneath categorizers such as specific STEM education discipline and the nature of media incorporated (e.g., static, dynamic, 2-D, 3-D, and interactive). Also, the integrative mindset and adopted practices of STEM educators working in multiple disciplines are factors that warrant further investigation in terms of evaluative quality and approach. This is information that curricula leaders, professional development providers, and preservice education programs can enact in evidence-based decision making processes when structuring inititiatives, configuring platforms, and implementing instruction. Further building digital media-based appliations into instructional practice and experiencing its vast engagment benefits, while also maintaining a strong conceptual content evaluative base to clearly and accurately document STEM learning, is the optimum outcome.

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Authors

Jeremy V. Ernst
Assistant Professor
Department of Teaching and Learning
Virginia Tech
Email: jvernst@vt.edu

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