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Being Part of the Larger STEM Environment

William J. F. Hunter
Illinois State University

As you think about your teaching at the elementary, secondary, or tertiary level, I suspect that you care about the relevance of topics and skills to your students—your students' current interests and their future interests. What do you think motivates your students? Hopefully, you can tap into their intrinsic areas of motivation to solve real-world problems and to care about their family, their neighbors, their community, and their more distant neighbors across the world. We face immense challenges as a society, and we need you and your students to enthusiastically take the initiative to address them. We are closing in on 8 billion people on the planet. The United States—about 5% of the world's population—is responsible for nearly 30% of the world's annual energy consumption. China has more than 20% of the world's population and consumes less than 7% annually. Less developed countries consume even less than that. So, what would happen if those 5 billion people in less developed countries started using the amount of energy that we use? What would happen to climate change if all 8 billion people used an American amount of energy? This is a problem that you and your students can help to address. Furthermore, what are the social justice implications of those 5 billion people being prevented from using an American amount of energy? I've been struck recently by the importance of passion and critical analysis in helping to guide STEM learning and STEM teacher education. As you read the articles in this issue, I challenge you to think about how these authors are doing their part and how you can do your part to encourage students to take action on relevant topics and become agents for productive problem solving.

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Integrating Informational Text and STEM: An Innovative and Necessary Curricular Approach

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Abstract

Recent standards-based reforms call for the use of a variety of informational texts at the elementary level. Informational texts are essential for implementing integrated problem-based science, technology, engineering, and mathematics (STEM) learning in elementary classrooms. Additionally, integrated STEM projects support the use of informational texts as students conduct research, design solutions, and communicate their results, thereby providing real-world applications of informational text. Elementary teachers need encouragement and support in order to increase the use of informational texts that assist in implementing effective STEM lessons. The authors provide strategies for melding informational texts with problem- and project-based learning in STEM.

Keywords: Informational text; Integration; STEM

The educational system in the United States is undergoing significant changes with the wide-scale implementation of new standards-based reforms, the push for deeper levels of critical thinking, and the incorporation of higher frequencies of informational text use (Calkins, Ehrenworth, & Lehman, 2012; National Governors Association Center for Best Practices [NGA] & Council of Chief State School Officers [CCSSO], 2010a). Coupled with this shift in education is a contradiction in the U.S. employment ratings; even with national unemployment rates at historically high levels, large numbers of jobs are going unfilled. Most of these jobs have one thing in common: They require employees with an educational background in science, technology, engineering, and mathematics, otherwise known as STEM (Engler, 2012). When addressing Congress in 2012 on the Encouraging Innovation and Effective Teaching Act (H.R. 3990), U.S. Representative Bucshon of Indiana noted that

> "The [national] STEM workforce is exploding [or expanding rapidly] and is expected to continue to grow well into the future. From 2000 to 2012, STEM jobs grew nearly 8%, from 2010 to 2018 that increase is expected to jump to nearly 17%." (Brown, 2012, para. 1)

Echoing these findings, "a study by Georgetown University Center on Education and the Workforce shows that by 2018, 8 million jobs in the U.S. economy will require a college degree in STEM"

(Murphy, 2011, para. 3). Rep. Bucshon summarized his comments to Congress by asserting that "'STEM education is vital to the careers of the future and what better way to encourage student participation than by putting before them teachers who have a passion [for] and experience within STEM fields'" (Brown, 2012, para. 1).

Brenner (2009) noted that there is a rising effort in the United States to engage additional numbers of young students in STEM fields and in STEM-related career paths. One way to improve instruction and engage students in the interdisciplinary aspects of science, technology, engineering, and mathematics is through an integrated approach to STEM education. Instead of teaching each of the STEM disciplines as parallel subjects, they are intertwined and presented in a holistic or interdependent approach using problem-solving strategies (Lantz, 2009). Sanders (2009) suggests that the elementary classroom provides an excellent launching point for this STEM integration. Elementary teachers who use STEM lessons that introduce creativity and innovation can help students with career exploration and development (McLaughlin, 2009). Although it is becoming more common to hear the term STEM spoken in elementary schools, there is still much ground to cover before it can be said that STEM is truly a part of the elementary school curriculum. The development and expansion of greater skills in STEM is increasingly important for student achievement at all levels of education, and given the most recent changes in education in the United States, it is becoming more popular and hence more acceptable for schools to integrate the STEM disciplines.

The newest round of standards-based reforms, the most prevalent of which is the Common Core State Standards (CCSS), requires teachers to integrate literacy into all aspects of the curriculum. The International Reading Association's (2010) *Standards for Reading Professionals* require teachers to model reading and writing as lifelong skills used for authentic purposes in daily life. Further, Danielson (2007), whose work is used in many states as a teacher evaluation instrument, states that teachers should plan activities and assignments in their classrooms designed to promote deep, meaningful learning. These learning activities have three characteristics in common: They (a) emphasize thinking and problem-based learning, (b) permit choice and initiative, and (c) encourage depth rather than breadth. All of these are characteristics of informational text reading and writing as well as STEM education.

The STEM Dilemma

Despite the lucrative potential of STEM and the seemingly boundless opportunities in these fields, many young people remain reluctant to enter career fields that require a background in STEM. Murphy (2011) postulated that

> Children at birth 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: touching, tasting, building, dismantling, creating, discovering, and exploring. For kids, this isn't education. It's fun! (para. 5)

However, "by the time students reach fourth grade, a third of boys and girls have lost interest in science. By eighth grade, almost 50 percent have lost interest or deemed it irrelevant to their education or future plans" (Murphy, 2011, para. 6). This means that millions of students are turning their backs on science and on STEM when we need them most. Gomez, Oakes, and Leone (2006) noted that even those students who do not turn their backs on STEM often enter postsecondary

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programs without a clear understanding of the field, its practice, or its impact on society. Given this startling information, we assert that K–12 teachers should be responsible for helping students understand this significance. This understanding can be done through both integrated STEM and informational text.

Standards and Elementary STEM

Science and mathematics are not new to elementary classrooms. However, the introduction of technology and engineering at the elementary level has been a relatively recent phenomenon in schools, as is the increased use of informational texts in the early grades. One reason for these shifts at the elementary level is the development of the idea that in order to make the biggest impact on students, you must reach them at an early age (DeJarnette, 2012; Murphy & Mancini-Samuelson, 2012). Various sets of standards, including the CCSS (NGA & CCSSO, 2010a, 2010b), the National Research Council's *Framework for K–12 Science Education* (2012), and *Technology for All Americans* (International Technology Education Association, 1996), are calling for increased coverage of engineering and technology in elementary education. Inclusion of engineering and technology at the elementary level provides children with the opportunity to be fully engaged and think critically about the problems that society is facing, especially through use of the engineering design process—which is central to the study of technology and engineering. Informational text could be a natural vehicle through which this content is explored and a student's interest is developed and fed.

Although STEM is not directly mentioned in the CCSS, it should receive considerable attention based on the skills and competencies called for in these standards. Calkins, Ehrenworth, and Lehman (2012) note that the CCSS represent the most sweeping reform in K–12 education that this country has ever seen and suggest that they will play an influential role in American schools. The *Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects* (CCSS ELA) emphasize much higher levels of reading comprehension than previous standards, placing equal weight on reading and writing and stressing the importance of critical thinking and problem-based learning (NGA & CCSSO, 2010a). The CCSS ELA point out that cognitive and intellectual growth occurs through time, across years, and across disciplines, which will require the integration of literacy into all content areas including, but not limited to, science and technical subjects (NGA & CCSSO, 2010a). The CCSS ELA call for an increased emphasis on reading, interpreting, and understanding various types of informational texts as pivotal skills connected to STEM teaching and learning.

"STEM literacy involves the integration of [each of the] STEM disciplines and four interrelated and complementary components" of STEM literacy (Bybee, 2010, p. 31). The *National Science Education Standards* (NSES; National Research Council, 1996) laid the groundwork for combining science with mathematics and technology; however, the goals proposed by the NSES have often fallen short in practice. The *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) will put integration into practice by directly linking science content to technology and engineering practices as well as to the objectives in the *Common Core State Standards for Mathematics* (CCSSM; CCSSO & NGA, 2010b).

Mayes and Koballa (2012) align the CCSSM with the *Framework for K–12 Science Education*'s Science and Engineering Practices (SEPs). The eight mathematical practices within the CCSSM directly align with the SEPs of the framework. Further analysis reveals that several of these SEPs also align with the standards in the CCSS ELA, specifically Practice 4 ("analyzing and interpreting data"), Practice 7 ("engaging in argument from evidence"), and Practice 8 ("obtaining, evaluating, and communicating information"). This alignment is particularly strong given the assumption that the majority of the texts used when teaching STEM at the elementary level would be informational in nature.

Informational Text and STEM Learning

Duke (2003) "define[s] *informational text* as text written with the primary purpose of conveying information about the natural and social world . . . and having particular text features to accomplish this purpose" (p. 14). According to Keene (2008), there has been a growing awareness that informational literacy is the key factor in successful participation in our global society—a society in which "success in schooling, the workplace, and society depends on our ability to comprehend this information" (Duke, 2004, p. 40). Furthermore, we live in an information-based world in which most of what we read daily is informational text (National Assessment Governing Board, U.S. Department of Education, 2008). "The amount of information that we confront on a daily basis is more than most people had to contend with in an entire lifetime only a little more than 100 years ago" (Benson, 2002, p. 1). Students need to understand where and how to find information in order to survive (Duke, 2004, 2010).

In the *Reading Framework for the 2009 National Assessment of Educational Progress* (NAEP; National Assessment Governing Board, U.S. Department of Education, 2008), the Grade 4 assessment was divided equally between passages of literary and informational text, and "in K–5, the [CCSS ELA] Standards follow NAEP's lead in balancing the reading of literature with the reading of informational texts" (NGA & CCSSO, 2010a, p. 5). Calkins et al. (2012) refer to the CCSS as "an absolutely crucial wake-up call" (p. 9). A critical look at the CCSS reveals that these standards are designed to provide all students with a thinking curriculum beginning in the earliest grade, kindergarten. Taking all this into consideration, there should be little debate about whether we should include informational text in early schooling. The real question is: How should this inclusion be accomplished?

Given calls for the increased use of informational texts and the rapidly expanding interest in engaging younger students in integrated STEM education content, it seems clear that these two initiatives can be complementary. Integrated STEM education requires students to be engaged in real-world investigations that originate with their own questions and research (Mayes & Koballa, 2012). These investigations must be grounded in evidence that is recognized by the educational community. This evidence can best emerge from reading, conducting research, and creating informational texts. Informational texts will complement the integration of STEM by exposing young students to informational text structures and features such as tables, graphs, charts, and symbols that must be taught explicitly (Maloch, 2008). When students discover the connection between conducting research, gathering information directly related to a STEM problem, and ultimately solving that problem, they will be developing skills that will benefit them throughout their lives.

Informational texts have the ability to present the concepts of STEM in a new way for elementary students. It is important for teachers, librarians, and parents to choose informational texts relevant to subject areas that can spur deeper thought and curiosity about STEM content areas (Hill, 2013). Informational texts have the ability to engage and inspire the young reader

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by showing the possibilities of STEM. Van Loo (2012) was able to draw upon informational texts to connect STEM not only within literature but also within the real world. He carefully selected different informational texts that satisfied the CCSS ELA requirements but also drew upon STEM. After reading the informational text, he would engage students in discussions about the science, technology, engineering, and mathematics and challenge them to think about how things could have been different if certain engineering and technology had been developed within the setting of the plot. This method of presentation creates a segue to introduce students to design challenges and critical thinking, all the while creating a purposeful learning experience with both the informational text and the STEM subject areas. Clearly, informational texts have the capacity to advance intellectual understanding and the application of that newfound knowledge in solving engaging STEM problems. Table 1 displays select notable informational texts that may be used to set the stage for STEM learning. The recommended works all address innovation, and many have been recognized through various awards, such as the Robert F. Sibert Informational Book, Caldecott, and Newbery medals.

Table 1
Recommended STEM-Related Informational Texts

Author	Title
Jennifer Berne	*On a Beam of Light: A Story of Albert Einstein*
Franklyn M. Branley	*Floating in Space*
Robert Byrd	*Electric Ben: The Amazing Life and Times of Benjamin Franklin*
Vicki Cobb	*Harry Houdini*
Elisha Cooper	*Farm*
Lois Ehlert	*Color Zoo*
Olivia Evans	*Discoveries and Inventions (Encyclopedia with Flaps)*
Bruce Goldstone	*Great Estimations*
Steve Jenkins & Robin Page	*How Many Ways Can You Catch a Fly?*
Steve Jenkins & Robin Page	*What Do You Do With a Tail Like This?*
Barbara Kerley	*A Cool Drink of Water*
David Macaulay	*Cathedral: The Story of Its Construction*
David Macaulay & Neil Ardley	*The New Way Things Work*
JoAnn Early Macken	*Flip, Float, Fly: Seeds on the Move*
Patrick O'Brien	*You Are the First Kid on Mars*
Alice & Martin Provensen	*The Glorious Flight: Across the Channel With Louis Bleriot*
Joyce Sidman	*Swirl by Swirl: Spirals in Nature*
Kathleen Thorne-Thomsen	*Frank Lloyd Wright for Kids*
Vera B. Williams	*Three Days On a River In a Red Canoe*

Using Problem-Based Learning as a Delivery Vehicle

Many elementary teachers express discomfort in the STEM disciplines and question their ability to teach STEM (Hibpshman, 2007). Lantz (2009) noted that elementary level teachers often lack adequate content knowledge in science and mathematics as well as experience in effectively integrating these subjects into a lesson or unit. Although "there have been attempts to define the results (function) of STEM education," there has been little agreement about how this should be accomplished (Lantz, 2009, p. 3). Students engaged in STEM should become "problem-solvers," "innovators," "logical thinkers," and "technologically literate" (Morrison, 2006, p. 2–3). Currently, there are neither national STEM standards nor certification requirements to teach STEM. One thing that almost all researchers seem to agree upon is that a problem-based learning (PBL) environment may be the best method for delivering STEM in the elementary classroom.

PBL has been successfully implemented and widely used in a number of disciplines including health care, architecture, engineering, economics, technology education, social studies, and science (Krajcik & Blumenfeld, 2006; Massa, Dischino, Donnelly, Hanes, & DeLaura, 2011). A study by Marx et al. (2004) confirmed that PBL has been successful at increasing students' tests scores compared to traditional instruction. The researchers found that PBL creates an atmosphere in which students feel compelled to conduct research, ask questions, and explore beyond the stated requirements of a given lesson.

Deep knowledge of each of the STEM disciplines is not required to fully engage elementary students in informational text and integrated STEM content. Rather, an understanding and application of the pedagogy of integrated STEM education is required. Integrated STEM education is best delivered through creative problem-based integrated lessons and activities in which the elementary students assume the role of problem solvers, researchers, inventors, and designers to solve problems that draw from many disciplines. These problems are typically unstructured theme-based design problems that cause the elementary students to solve engaging problems directly related to content standards. The pedagogies and heuristics unique to the fields of STEM education draw from the scientific model of inquiry and the engineering design loop (or process) to provide elementary students with a framework for addressing the research and learning needed to solve a given problem.

The *engineering design loop* (heuristic) is used as a learning tool for elementary students as they progress through a STEM problem that is referenced back to informational text (see Figure 1). Generally, the engineering design loop requires that the elementary student complete a number of steps, including clarifying the problem, conducting research on how others have solved similar problems, brainstorming potential solutions, selecting a potential solution, constructing a model or prototype, testing the chosen solution (model or prototype), evaluating the solution (model or prototype), and presenting the solution. The role of the teacher is to design robust STEM problems that extend upon informational text, deliver important standards-based content, and engage the elementary students. The teacher also provides students with the impetus for considering informational texts, gathering research, and engineering a potential solution to the STEM design problem. These strategies can be drawn directly from the CCSS ELA (i.e., "write informative/explanatory texts to examine a topic and convey ideas and information clearly"; NGA & CCSSO, 2010a, p. 20) and the International Technology Education Association's (2007) *Standards for Technological Literacy* (STL; i.e., "develop abilities to apply the design process"; p. 115).

For example, one STEM challenge calls for the elementary students to apply the engineering design process to solve a problem called the "Balancing Act" (see Figure 2). In this lesson, the students work in teams to create a mobile that displays the relationship between science (the natural world) and technology (the human-made world) through the artistic expression of the

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Figure 1. The design loop project. Preservice teachers personalized their own design loop by including pictures and elements that would aid younger students within the elementary classroom.

mobile. The students conduct background research on mobiles (the only art form to originate in the United States), gather information about the nature of science and the human-made world from informational texts such as *Alexander Calder and His Magical Mobiles* by Jean Lipman and Margeret Aspinwall (1981) or *Mobiles: Building and Experimenting with Balancing Toys* by Bernie Zubrowski and Roy Doty (1993), and then locate artifacts that can be arranged in a state of equilibrium to represent the relationship between nature and technology. This experience shows students how the individuals that they just read about in the informational text went about solving the problems that they faced. The engineering design loop has the potential to be used as a resource for students to solve a variety of problems inside and outside of the classroom. The experience of solving the activity will provide multiple ways for our students to learn and retain information as well as provide an interest for continued learning.

Kwan (2000) notes that despite the benefits to student learning, many teachers are reluctant to initiate PBL and STEM in their classrooms, citing concerns about classroom management, releasing control over learning activities, and inability to answer students' questions. By combining informational texts, integrated STEM, and the PBL methodology to establish the background organization, motivation, and structure for creating meaningful learning (Lauritzen & Jaeger, 1997), many existing teacher concerns should be eliminated. The use of STEM content, PBL teaching methods, the use of heuristics, a connection to children's literature or other informational texts, and linking to appropriate state and national standards will allow teachers to present disciplines with which they have limited backgrounds in an engaging and nonthreatening manner.

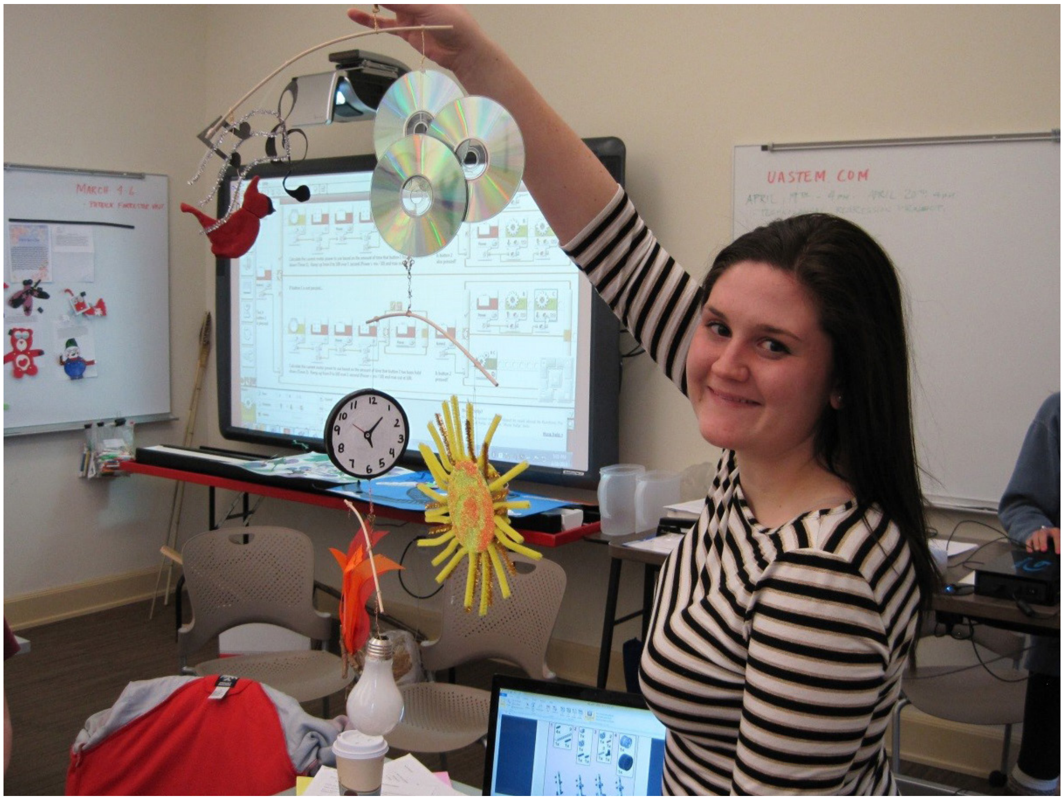

Figure 2. Balancing act. Preservice teachers create a mobile that displays the relationship between science (the natural world) and technology (the human-made world).

Application of a STEM-Based Informational Text Lesson

Most in the STEM community would agree that it is critical that young students have an early understanding of the differences between natural and human-made environments. Similarly, it is important for young students to understand that most engineers and technologists spend a great deal of time trying to create inventions, products, and systems that improve on the natural world. For example, Swiss inventor George de Mestral invented Velcro after examining the hooks on cockleburs attached to his dog upon returning from a nature hike. A basic STEM-based informational text lesson might examine the relationship between natural fibers and patterns made by spiders and the human-made products that might ensue.

Using an informational text such as *Are You a Spider?* by Tudor Humphries and Judy Allen (2003) or *Spiders* by Nic Bishop (2007)—depending upon the age of the students—as a springboard for learning could facilitate a rich STEM experience. The lesson might begin by reading the chosen text focusing on spiders and discussing the life and contributions of spiders. This could be followed by viewing videos of spiders making webs online (see http://www.youtube.com/watch?v=r5aKhnWniWU&feature=related). The students could also be asked to stand in a circle and toss a ball of yarn back and forth across the circle to form a human web. Finally, the students could be grouped into teams and asked to design a web using thread that would hold the greatest number of pennies. This STEM activity addresses standards related to geometry and measurement (CCSSM); scientific inquiry and technological design (NGSS); and engineering design, invention and innovation, and the design process (STL).

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To complete this activity, a wooden or Styrofoam frame, pushpins, coins, and fine sewing thread will be needed. First, the teams are introduced to the concepts of strength, geometric shapes and their attributes (e.g., triangles, squares, circles), measurement, spacing, weights, the design loop (how engineers make decisions), and product assessment and testing. After the teams have completed research in which they examine natural spider webs using available informational texts, they will complete brainstorming sessions to determine the best way to improve the natural design to hold the greatest number of coins. (The math content of this STEM activity could be further augmented by asking the teams to build a web that would hold the greatest amount of money using coins of different denominations.) After decisions about the design have been made, teams will use the pushpins around the perimeter of the frame and then weave a human-made web by wrapping the thread around the pushpins. After the human web has been completed, the teams will assess the quality of their design, much like engineers would, placing coins on the web to the point of failure and then revisiting the design several times in an attempt to improve upon their design (refer to Figure 3). It is also important for the teams to describe the rationale for their team design. At this point, the teacher would determine whether the students included comments about the concepts introduced at the beginning of the activity, such as geometric shapes, measurement, and spacing.

Student performance in this STEM activity could be assessed by determining the degree to which the teams utilized the engineering design loop; determining whether the students applied knowledge of geometry, measurement, shapes, and spacing; and evaluating the improvements made to the final product based on the team testing with coins. Finally, teams could be assessed on their ability to describe the process used to create their human web during the team presentation.

Figure 3. Human-made web. After examining natural spider webs, preservice teachers determine the best way to improve the natural design.

This STEM-based informational text lesson will provide young students with a measure of understanding about the intricate relationship between the natural environment and the human-made world as well as a glimpse into the roles that engineers, scientists, technologists, and mathematicians play in the development of inventions and products that we all take for granted. The lesson will also provide young students with a great introduction to PBL using informational text as a springboard for learning, the engineering design process, and the role of the all four STEM disciplines in providing solutions to human problems.

Summary and Call to Action

STEM is increasingly important to our society, and efforts need to be undertaken to engage students in the study and application of these disciplines at an early age. Although STEM programs seem to abound at the secondary school level, few integrated STEM education programs exist at elementary schools across the nation, and relatively few practicing elementary teachers seem to be prepared to deliver comprehensive STEM programs. Meanwhile, alarming numbers of students seem to be opting out of STEM programs of study at the secondary and postsecondary levels, many making the decision to avoid STEM courses and programs of study as early as fourth or fifth grade.

To change the status quo, we must prepare a new generation of teachers who have the desire and skills to engage elementary students in the STEM disciplines early and keep them engaged throughout elementary, secondary, and postsecondary education. This will require attention to standards in all four disciplines, the ability to utilize current curriculum standards to access and communicate information, an enthusiasm for finding and exploiting the connections between disciplines, an inclination to utilize differing teaching methods, a commitment to teacher professional development, and a willingness to develop and teach content that may be inching toward uncharted territory.

By providing elementary students with engaging, positive, and successful experiences with the STEM disciplines, we can create an environment in which children yearn for more information, search for solutions to human problems, regularly cross disciplinary boundaries, willingly conduct research seeking answers, and continue learning well beyond the classroom. Delivering integrated STEM education in the elementary classroom is another step toward creating a more involved and more intellectually curious society as well as an insurance policy for the future of our nation. This process begins by preparing elementary teachers who are capable, comfortable, and enthusiastic about implementing integrated STEM education in the elementary classroom.

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Cultural Responsiveness of the *Next Generation Science Standards*

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Abstract

Student enrollment statistics indicate an increase in linguistically and culturally diverse students in the United States. Along with the increase in the diversity of the preK–12 student population, one would also expect to see a parallel increase in equitable learning opportunities for all students. Equity and inquiry are the key principles of the *Framework for K–12 Science Education* (the Framework) as well as the *Next Generation Science Standards* (NGSS). Due to the growth of minority populations and the increase in the enrollment of minority students, there is an increasing need to address the underrepresentation of linguistically and culturally diverse students. In this article, we intend to bring to the forefront issues related to the education of a diverse student population, including students from different racial and ethnic groups as well as English language learners, in the Western cultural views in science classrooms. We also intend to shed light on the responsiveness of Western science education, the Framework, and the NGSS to linguistically and culturally diverse students. In addition, we introduce some of the challenges that face diverse students. Finally, we provide some recommendations to meet the needs of diverse students.

Keywords: English language learners; Equity; *Framework for K–12 Science Education*; Inquiry; Minority students; Multicultural education; *Next Generation Science Standards*

The term *diversity* is an overarching term that may extend to include different groups, which include

> the four accountability groups defined in [the] No Child Left Behind (NCLB) Act of 2001 and the reauthorized Elementary and Secondary Education Act (ESEA), Section 1111(b)(2)(C)(v):
>
> - economically disadvantaged students,
> - students from major racial and ethnic groups,
> - students with disabilities, and
> - students with limited English proficiency.
>
> Further, student diversity is extended by adding three groups:
>
> - girls,
> - students in alternative education programs, and
> - gifted and talented students. (NGSS Lead States, 2013, p. 26)

In this article, the term *diversity* is directed toward minority students from diverse racial and ethnic groups and English language learners (ELLs).

The demographics of student diversity indicate an increase in the population of diverse students in classrooms. According to the National Center for Education Statistics (NCES; KewalRamani, Gilbertson, Fox, & Provasnik, 2007), over the past 2 decades, the U.S. population has become more culturally and linguistically diverse because the population of minority groups has increased more rapidly than the White population has. Villegas and Lucas (2002) stated that "one of every three students enrolled in elementary and secondary schools is of a racial or ethnic minority background" (p. 20). "Substantial growth for minority population groups is projected to continue over the next 20 years (U.S. Department of Commerce 2004)" (KewalRamani et al., 2007, p. 6).

> Between 2010 and 2050, the U.S. population is projected to grow from 310 million to 439 million, an increase of 42 percent. The nation will also become more racially and ethnically diverse, with the aggregate minority population projected to become the majority in 2042. (Vincent & Velkoff, 2010, p. 1)

According to the NCES (KewalRamani et al., 2007), "by the year 2020, minorities are predicted to represent 39 percent of the total population" (p. 7).

> In 2005, minorities made up 33 percent of the U.S. population. Hispanics were the largest minority group, representing 14 percent of the population. They were followed by Blacks (12 percent), Asians/Pacific Islanders (4 percent), and American Indians/Alaska Natives (1 percent). (KewalRamani et al., 2007, p. 7)

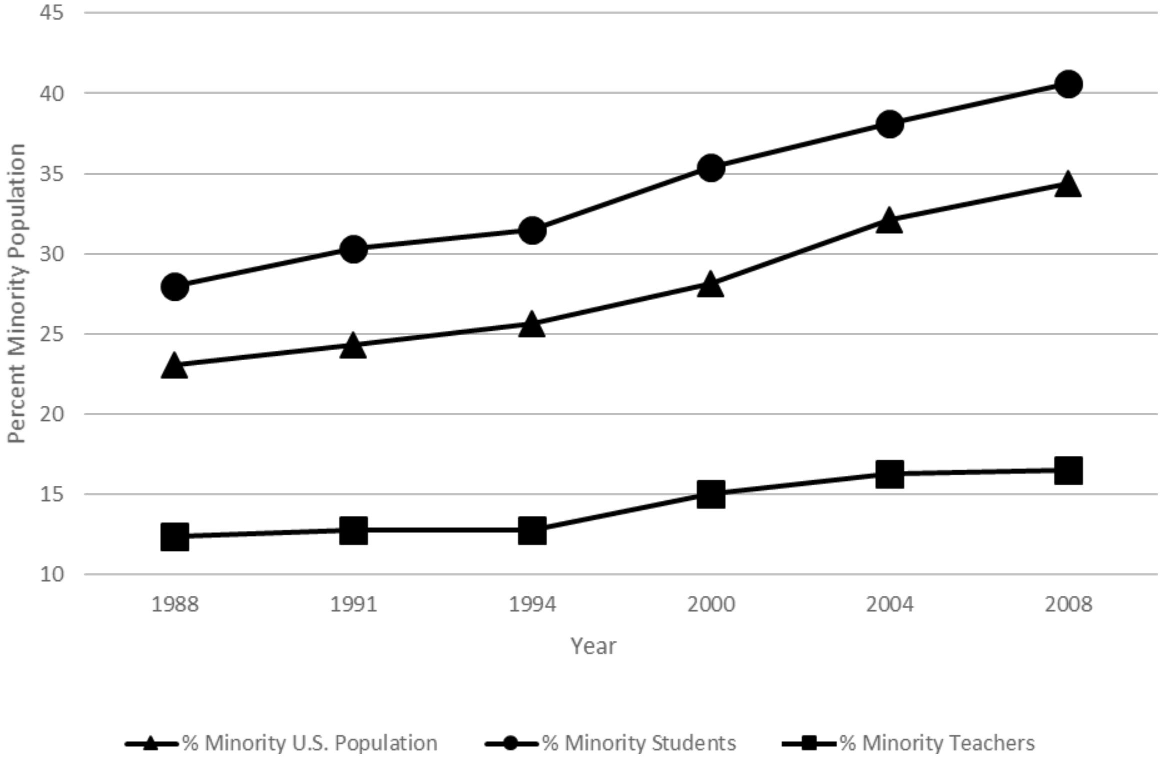

Figure 1. Percentages of U.S. minority population from 1988–2008. The data included in this graph are taken from Table 3 (p. 19) in Ingersoll and May (2011).

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Besides the underrepresentation of minority students in science education, there is a disproportionate representation rate of minority teachers in which "only 14% of all teachers are from minority cultures. The proportions are even lower by science subject area" (Rodriguez, 1997, pp. 24–25).

In their report about the shortage of minority teachers in the United States, Ingersoll and May (2011) show the increasing disparity between the percentage of minority students and the percentage of minority teachers. In the 2007–2008 school year, minorities made up 34.4% of the U.S. population, minority students made up 40.6 % of the population, and 16.5% of teachers were minorities (Ingersoll & May, 2011, p. 19). Figure 1 shows a graphical representation of the data found in Ingersoll and May (2011) showing the increasingly disproportionate percentage of minority students in comparison to minority teachers over 20 years. In order to reduce this disparity, schools must make efforts to recruit more science teachers from minority cultures. Seeing teachers from their ethnic backgrounds as leaders in schools and in science fields would empower minority students and would enable minority students to increase their achievement scores.

Challenges of Culturally Diverse Students

Linguistically and culturally diverse students are faced with challenges that persist despite the science education research regarding students' cultural background that has been done. Krugly-Smolska (1995) stated that

> A cultural context for science education did not appear to be recognized by science educators until the late 1970s in response to the crisis in science education . . . . Even then, the issue of culture was seldom met head-on and dealt with explicitly, but was treated in terms of 'science and society' and 'scientific literacy' in statements on goals, aims and objectives of science education. As a result, cultural implications for science education often must be inferred. (p. 48)

Some of the challenges that linguistically diverse students and students from nondominant groups face include inadequate instructional practices in science and inequitable learning opportunities, among other challenges, and "students from nondominant groups perform lower on standardized measures of science achievement than their peers" (Bell, Lewenstein, Shouse, & Feder, 2009, p. 209). Banks et al. (2007) stated that

> Being born into a racial majority group with high levels of economic and social resources—or into a group that has historically been marginalized with low levels of economic and social resources—results in very different lived experiences that include unequal learning opportunities, challenges, and potential risks to learning and development. (p. 15)

"Arguably, the most pressing challenge facing U.S. education is to provide all students with a fair opportunity to learn [(Moss et al., 2008; Porter, 1993; National Research Council, 1996)]" (National Research Council [NRC], 2012, p. 281). Although desegregation began in the 1950s, some schools have continued to bar minority students from achieving equitable educational opportunities, segregating students, including African American students, by assigning their academic schedules through special education programs in which they are overrepresented relative to their White peers (Young, 1990). This is just one practice that reflects the disproportionate representation of minority students in special education programs in comparison to their White counterparts. Hosp and Reschly (2004) stated that "the disproportionate representation of minority students in special education has been a constant and consistent concern for nearly 4 decades" (p. 186). This placement into special education programs stigmatizes and may discourage African American students and other minority students from pursuing educational degrees, including majoring in science disciplines. Although minority students are underrepresented in some areas of education, specifically in science education, at the same time, they are overrepresented in special education programs.

Minority students are indispensable in the educational system because of the different views, experiences, and ways of knowing that they bring to the learning environment. Diversity should be celebrated because it enriches our schools through continually broadening teachers' and students' perspectives. According to the National Research Council (NRC; 2012),

> There is increasing recognition that the diverse customs and orientations that members of different cultural communities bring both to formal and to informal science learning contexts are assets on which to build—both for the benefit of the student and ultimately of science itself. (p. 28)

As the student population in the nation's schools becomes more linguistically and culturally diverse, it is essential to establish a knowledge base to promote academic achievement and equitable learning environments for students with diverse languages and cultures (Garcia, 1999; KewalRamani et al., 2007; Lee, 2003; NRC, 2012).

"Science for all" is a phrase that has been utilized and emphasized by many educators. In response to the barriers and challenges that are faced by students from diverse groups, the *Next Generation Science Standards* (NGSS) were created in a culturally responsive manner to address challenges and issues that are inherent to the increasing diversity in classrooms. This could be done through providing accessible and equitable learning opportunities to all students in which they are able to engage in scientific practices in formal and informal settings (e.g., museums, nature centers, zoos, after school programs; Bell et al., 2009; NGSS Lead States, 2013).

The developers of the *Framework for K–12 Science Education* (the Framework) developed and articulated a broad set of expectations

> to ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC, 2012, p. 1)

The repetition of "all students" throughout this framework highlights the need to provide equitable opportunities for all students to have access to and succeed in science. Rodriguez (1998) stated, "The basic premise of multiculturalism is that all learners at any grade level must be provided with equitable opportunities for success" (p. 591). Equity is central to the advancement of science education and scientific discovery, which is the predominant purpose of science (Atwater, 1996; NRC, 2012; Rodriguez, 1998). According to the NRC (2012),

> Equity as an expression of social justice is manifested in calls to remedy the injustices visited on entire groups of American society that in the past have been underserved by their schools and have thereby suffered severely limited prospects of high-prestige careers in science and engineering. (p. 278)

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Atwater (1996) emphasized the importance of "providing equitable opportunities for *all* students to learn *quality* science (Atwater, 1993; Atwater & Riley, 1993)" (p. 822). The NRC (2012) stated that

> Equity in science education requires that all students are provided with equitable opportunities to learn science and become engaged in science and engineering practices; with access to quality space, equipment, and teachers to support and motivate that learning and engagement; and adequate time spent on science. (p. 28)

In pursuit of science for all, equity was a focal point that was emphasized in hopes that it would "motivate and inspire a greater number of people—and a better representation of the broad diversity of the American population—to follow these paths than is the case today" (NRC, 2012, pp. 9–10).

From a science educator's point of view, establishing and achieving equity should be a noble end goal of education. Achieving educational equity requires "rigorous standards that apply to all students" (NRC, 2012, p. 29). "The research demonstrates the importance of embracing diversity as a means of enhancing learning about science and the world, especially as society in the United States becomes progressively more diverse with respect to language, ethnicity, and race" (p. 29). "Clearly, a science education system must be responsive to a variety of influences—some that emanate from the top down, some from the bottom up, and some laterally from outside formal channels" (p. 244). "Science education aims to nurture equitable opportunities for success for *all* students (United Nations Educational, Scientific, and Cultural Organization, 1994)" (Aikenhead & Jegede, 1999, p. 273).

> *Status and Trends in the Education of Racial and Ethnic Minorities* examines the educational progress and challenges of students in the United States by race/ethnicity. This report shows that over time, the numbers of students of each race/ethnicity who have completed high school and continued their education in college have increased. Despite these gains, the rate of progress has varied, and differences persist among Whites, Blacks, Hispanics, Asians, Native Hawaiians or Other Pacific Islanders, American Indians/Alaska Natives and students of two or more races in their performance on key indicators of educational performance. (Aud, Fox, & KewalRamani, 2010, p. iii)

Differences among students can be related to students' culture, class, gender, religion, economic status, and other factors.

Race and gender are some of the factors that directly influence a student's experiences, which in turn influence and shape their mental models and intellectual orientation and understanding (Krugly-Smolska, 1995; McDowell, 1990). Other factors include class, personal experiences, culture, language, and religion (Krugly-Smolska, 1995; Lee, 2003). This raises the question of how to integrate the science disciplines with students' languages and cultures? There is no single answer to this question. Regarding culture, which can be defined as sets of beliefs, values, norms, and behaviors of a group, Lee (2003) emphasized the importance of using linguistic and cultural resources that diverse students bring into science classrooms, even though such resources may not be easily recognized by the mainstream. Thus, drawing in some examples and bringing in resources from cultures other than the dominant one ensures equity for diverse student populations in education. Doing so enriches the learning process and maximizes the opportunities of diverse students not only to be engaged in meaningful learning but also to share their experiences with students from other cultures.

Students from diverse cultures who may speak different languages come to schools with previously constructed knowledge that is shaped and influenced by their culture and through their personal experiences. Providing culturally diverse students with equitable learning opportunities helps them to "capitalize on their linguistic and cultural experiences as intellectual resources for the new scientific knowledge" (Udokwu, 2009, p. 62; see also Lee, 2003). However, challenging issues may arise, especially when culturally diverse students' experiences are not in harmony with the dominant culture or with the science discipline in Western culture. Like "students in developing countries . . . [who feel] that school science is like a foreign culture to them (Maddock, 1981)" that clashes with the system of their native cultural beliefs, history, and values, "many students in industrialized countries [like the United States] share this feeling of foreignness as well (Aikenhead, 1996; Costa, 1995)" (Aikenhead & Jegede, 1999, p. 269; see also Maddock, 1981; NRC, 2012).

> Cultural clashes between students' life-worlds and the world of Western science challenge science educators who embrace science for all, and the clashes define an emerging priority for the 21st century: to develop culturally sensitive curricula and teaching methods that reduce the foreignness felt by students. (Aikenhead & Jegede, 1999, p. 269)

Diverse students also face additional challenges when they are engaged in scientific inquiry. Scientific inquiry is the focus that the NRC promotes in its Framework, and it is also a focus of the NGSS. Scientific inquiry is also at the heart of science education and is necessary for meaningful science learning to occur. Brown and Abell (2007) indicated that scientific "inquiry-based instruction [can] help bridge cultural backgrounds and foster science learning success" (p. 60). The process of inquiry requires engaging students in discussion, raising questions, designing investigations, analyzing data, and presenting data. Inquiry is a valuable teaching methodology that can draw in more voices and bring in experiences and examples from across cultures. It "may help all students develop authentic science interactions and learn science in a context that is meaningful and relevant to their lives" (Brown & Abell, 2007, p. 60). In addition, because the practice of inquiry in science engages students in scientific discourses in social interactions for constructing scientific knowledge, "science and engineering practices can actually serve as productive entry points for students from diverse communities—including students from different social and linguistic traditions, particularly second-language learners" (NRC, 2012, p. 283).

In general, all students struggle with scientific inquiry. More specifically, however, culturally different students often struggle more because their cultural norms prioritize respect for teachers and other adults as authoritative sources of knowledge rather than developing theories and debating based on evidence and reasoning (Brown & Abell, 2007; Lee, 2003). Although diverse students come to science classrooms with styles of interactions that may differ from what teachers expect or differ from what is considered appropriate, teachers can help all students to learn science by allowing diverse approaches to scientific reasoning in their classrooms (Brown & Abell, 2007; Krugly-Smolska, 1995).

Both the Framework and the NGSS articulated the concepts of equity, inquiry, and diversity and made the standards as applicable to all students as possible. However, in the Framework, these concepts were utilized in general terms and specific situations that are exclusive to mainstream students as opposed to inclusive to all students, including both majority and diverse minority students. "Increased classroom diversity has brought equity issues to the forefront of the education reform agenda" (National Center for Education Statistics, 1999, p. 48). In light of the growing rate of population of culturally diverse students, diversity as well as equity should be more visible in the Framework. That is, the pursuit of these two integral parts of the Framework requires that more attention be given to students from diverse groups and that they be effectively included in textbooks through vignettes or examples that provide a broader variety of cultural examples that do not focus exclusively or are not dominated by the interests of one gender, race, or culture. An example that was captured and critiqued by Rodriguez (1997) is found in the *National Science Education Standards* (NSES). The author's critique of the examples found in the NSES is that the individuals in these examples "have been robbed of ethnic identity" (p. 21). The teachers themselves are "faceless" individuals with an invisible ethnic background, and they are teaching in "ethnically and culturally neutral classrooms" (p. 21). However, this example could also provide an opportunity for science teachers to attend to the diversity that is not addressed in the NSES by identifying the "faceless" or "deidentified" teacher with a Latino name, for example, that reflects the diversity in science education in the United States.

Recommendations

The United States "is not a melting pot wherein human diversity fuses into a uniform America. On the contrary, ours is a mosaic of vibrant, diverse colors in which a cultural medley forms a variegated whole called the American culture" (Chisholm, 1994, p. 43). Chisholm (1994) also stated that "this multicultural mosaic unequivocally pervades our American schools" (p. 43). However, the underrepresentation of minority students in education, particularly in the STEM disciplines, requires educators' attention to provide students from all cultural backgrounds with appropriate opportunities to learn. "A growing evidence base demonstrates that students across economic, social, and other demographic groupings can and do learn science when provided with appropriate opportunities" (NRC, 2012, p. 298). Considering the needs of diverse students may enhance their learning. Lee (2003) indicated that learning can be enhanced when it occurs in contexts that are linguistically and culturally meaningful and relevant to students' lives.

The differences in student achievement between minority and majority students, especially at the high school level because of the disproportionately high dropout rate, as well as the overrepresentation of minority students in special education programs have all been well documented in recent decades; therefore, instead of researchers simply continuing to document patterns of academic achievement relative to population demographics, their focus should be shifted "toward taking action and developing solutions" (Hosp & Reschly, 2004). Educators should be moving toward education that is multicultural for increasingly diverse classrooms. Chisholm (1994) suggested that preparing quality teachers and raising awareness about increasingly diverse classrooms starts with multicultural teacher preparation programs in which preservice teachers learn to see themselves as active participants in and facilitators of students' academic success. According to the NCES (1999)

> Addressing the needs of students with limited English proficiency or from culturally diverse backgrounds has recently become a central concern mainly because of growing student populations with these backgrounds. Therefore, teacher training to meet these needs might be particularly important to schools with large minority student populations. (p. 22)

Increasing the number of professional development programs that address the needs of students from diverse cultural backgrounds is crucial because teachers are likely to have participated in professional development programs that focus on educational reform, curriculum and performance standards, implementing new teaching methods, or assessment techniques; however, they are unlikely to have participated in professional development programs addressing the needs of diverse students (National Center for Education Statistics, 1999).

This could be applied to science education through embracing appropriate epistemologies. Science education can be a means to face the increasing diversity of student populations in a social context in which minority students are part of the larger community. With its emphasis on engineering, the NGSS will enable all students to be engaged in learning opportunities. Engineering can be inclusive of students from different cultures by recognizing the contributions of their cultures (NGSS Lead States, 2013). In the NGSS, the science and engineering practices support science learning for all, including ELLs. This helps with redefining the epistemology of science, which in turn defines school science curriculum (NGSS Lead States, 2013). An appropriate epistemology that integrates students from different backgrounds is constructivism, particularly social constructivism, which is grounded in the work developed by Vygotsky (1978). This epistemology helps educators to learn how knowledge is constructed by individuals in a multicultural science educational environment given that social constructivism emphasizes the influence of context and culture in shaping "the unique experience of each of us" (Crotty, 1998, p. 58). Atwater (1996) stated that "multicultural science education research continues to be influenced by class, culture, disability, ethnicity, gender, and different lifestyles" (p. 821). Infusing multicultural education "creates awareness, understanding, and respect for the various cultural groups in [a pluralistic] society" (Reed, 1991, p. 122). To effectively integrate multicultural science education, social constructivism is best suited for a multicultural science education in which all students, including minority students, are given opportunities to participate and examples from their cultural backgrounds are provided.

> The essence of social constructivism and its implications for multicultural science education research includes an understanding of whatever realities might be constructed by individuals from various cultural groups and how these realities can be reconstituted, if necessary, to include a scientific reality. (Atwater, 1996, p. 821)

According to Banks (2007),

> The multicultural education movement, which emerged out of the civil rights movement of the 1960s and 1970s, seeks to reform schools, colleges, and universities so that students from diverse racial, ethnic, language, and social-class group will experience educational equality. (p. 54)

Embracing multicultural or cross-cultural science education is one of the priorities of educational practitioners in the 21st century, a time in which we have seen a dramatic change in the nation's student population. According to Banks (2007), it is imperative to integrate multicultural education because it "help[s] students and teachers to reenvision, rethink, and reconceptualize America" (p. 81). Despite the complexity of the multicultural environment, embracing multicultural science education in a multicultural environment "is one of the most important ideas in this century because it emphasizes both the ways that we are each unique and the ways that we share parts of our identity with others" (Connerley & Pedersen, 2005, pp. 22–23). "Complexity is our friend and not our enemy because it protects us from accepting easy answers to hard questions," and this is apparent in accepting or rejecting scientific theories (Connerley & Pedersen, 2005, p. 28). If one views "science as a set of practices that define a singular 'culture of science' that would-be scientists must acquire . . . . [, that] culture of science does not reflect the cultural values that people bring to science" (Bell et al., 2009, p. 212).

Ignorance of other cultures, due to dependence upon one dominant culture, has been demonstrated to be dangerous (Connerley & Pedersen, 2005). "To effectively conceptualize and implement multicultural education curricula, programs, and practices, it is necessary not only to define the concept in general terms but to describe it programmatically" (Banks, 2007, p. 83). In regard to balancing the current curriculum in a diverse and multicultural school environment, Rodriguez (1997) recommended "teaching science in more inclusive and multicultural ways" (p. 32), especially with the growing population of students from different cultures.

Another action may take the form of "improving teacher training in working with students from culturally and linguistically diverse backgrounds" in hope of reducing the disproportionate representation of minority students in special education (Hosp & Reschly, 2004, p. 186). Preservice teachers should be placed in appropriate field experiences and with teacher supervisors who incorporate a multicultural focus (Chisholm, 1994). Preservice teachers should observe diversity in the classroom and how effective classroom teachers apply multicultural teaching practices in classrooms with diverse students.

Ford (1991) suggested a model for developing teachers with a multicultural perspective in multicultural classrooms. This model encompasses four stages: (1) "developing awareness . . . of one's own [culture] and other cultures" (p. 135); (2) "building knowledge and skills" through multicultural education and coursework that include "activities, research, development of thematic interdisciplinary units, case studies[,] and a foundation for multicultural exploration" (p. 135); (3) "providing experiences" that offer students direct "exposure and active involvement with multicultural populations in non-threatening situations" (p. 136); and (4) "providing resources and support" through graduate programs in education, "parents, care-givers, churches, and community agencies" (p. 137).

Developing "culturally sensitive curricula" (Aikenhead & Jegede, 1999, p. 269) is a necessity; therefore, already existing science curricula must be restructured into culturally sensitive curricula. Multicultural science education for all students espoused with new teaching delivery mechanisms help students from diverse cultures to receive meaningful learning by bringing in their linguistic and cultural experiences as valuable resources in science classrooms and enables them to be more engaged in science practices and, subsequently, show academic achievement gains (Aikenhead & Jegede, 1999; Krugly-Smolska, 1995; Lee, 2003; McDowell, 1990). In addition, developing culturally sensitive curricula aims "to reduce the [feeling of] foreignness felt by [linguistically and culturally diverse] students in education and in science classrooms," a "feeling [that] stems from fundamental differences between the culture of Western science and their indigenous [or native] cultures (Aikenhead, 1997; Jegede, 1995)" (Aikenhead & Jegede, 1999, p. 269). This feeling of foreignness toward science can be alleviated "when the culture of science [and science instructional delivery methods] harmonizes with a students' [cultural beliefs or] life-world culture"; this process is called *enculturation* (Aikenhead & Jegede, 1999, p. 274).

Traditional classroom practices may serve students whose discourse practices at home resemble those at school; however, such practices may also serve as a gatekeeper that bars students not in the dominant group from engaging in science discourse (Aikenhead & Jegede, 1999). To address this concern, effective science teaching methods should be applied to help linguistically and culturally diverse students make a smooth transition into a culture that differs from their native culture and to provide them with opportunities for the expansion and enrichment of their culture (Aikenhead & Jegede, 1999; Lee, 2003; Maddock, 1981; NRC, 2012). Such initiatives call for science teachers to make a necessary shift in their science instructional methods in order to prepare all students for college and future careers (NGSS Lead States, 2013).

However, science culture and "science instruction . . . can disrupt the student's worldview by trying to force that student to abandon or marginalize his or her life-world concepts and reconstruct in their place new (scientific) ways of conceptualizing" (Aikenhead & Jegede, 1999, p. 274). This process of *assimilation* can disrupt students' cultural beliefs and cause them to marginalize their own culture to replace it with Western ways of conceptualizing science (Aikenhead & Jegede, 1999; see also Maddock, 1981). "Alternatively, attempts at assimilation can alienate students from science," keeping them from "learning the content in a . . . [meaningful] way" (Aikenhead & Jegede, 1999, p. 274). The process of assimilation often makes this transition into a "hazardous border crossing" for minority students because of the discontinuity between the Western culture of science and the cultures of students from culturally different groups (Aikenhead & Jegede, 1999). Thus, the process of assimilation can result in lower achievement for minority students and the overrepresentation of minority students in special education programs. Students from cultures that do not encourage students to ask questions or engage in logical argumentation in scientific discussion based on scientific evidence, even when they have scientific understanding, might be perceived as lacking the intellectual ability or the scientific understanding to be in the science disciplines (Lee, 2003).

Even though the Framework and the NGSS clearly affirm science for all, multicultural groups are still invisible and are not recognized in the Framework. This is consistent with what Krugly-Smolska (1995) found in his study of multicultural science classrooms in Canada in which "multiculturalism did not pervade the science curriculum, and indeed there was no recognition of the multicultural context in the science classroom" (p. 51). Additionally, "there was little indication of recognition of individual cognitive or learning style differences" (p. 53). Because it is hard to pinpoint the exact cultural influences on students' academic achievement, similar findings can be predicted for the lack of representation of minority students in science classrooms in the United States. To enlighten science teachers about the differences in learning styles of diverse students, the NGSS present case studies "that are not intended to prescribe science instruction, but to illustrate an example or prototype for implementation of effective classroom strategies with diverse student groups" (NGSS Lead States, 2013, pp. 25–26). They also present "learning opportunities and challenges to all students, particularly non-dominant student groups" (p. 26). For example, the NGSS emphasize the role of language as ELLs engage in science instruction. This draws teachers' attention to the critical role of instructional practices as well as helping educators to understand "the critical role that language plays in the CCSS and the NGSS" as well as in instruction and "that the new standards cannot be achieved without providing specific particular attention to the language demands inherent to each subject area" (p. 27). In dealing with assimilation, the NGSS emphasize applying effective teaching strategies that help teachers to "understand how disconnections may vary among different student groups, as well as how to capitalize on connections" (p. 30).

The NGSS (NGSS Lead States, 2013) provide some effective teaching strategies that serve nondominant groups and help them create and establish connections to school science.

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> Effective strategies for students from major racial and ethnic groups fall into the following categories: (1) culturally relevant pedagogy, (2) community involvement and social activism, (3) multiple representation and multimodal experiences, and (4) school support systems including role models and mentors of similar racial or ethnic backgrounds. (p. 31)

> The research literature indicates five areas where teachers can support both science and language learning for English language learners: (1) literacy strategies for all students, (2) language support strategies with ELLs, (3) discourse strategies with ELLs, (4) home language support, and (5) home culture connections. (p. 31)

Taking one or all of the previously mentioned initiatives helps science teachers with achieving some of the NGSS practices and crosscutting concepts related to the understanding of the nature of science, which are presented in "the Nature of Science (NOS) Matrix":

> The basic understandings about the nature of science are:
> - Scientific Investigations Use a Variety of Methods
> - Scientific Knowledge Is Based on Empirical Evidence
> - Scientific Knowledge Is Open to Revision in Light of New Evidence
> - Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
> - Science Is a Way of Knowing
> - Scientific Knowledge Assumes an Order and Consistency in Natural Systems
> - Science Is a Human Endeavor
> - Science Addresses Questions About the Natural and Material World. (NGSS Lead States, 2013, p. 97)

The concept "Science Is a Human Endeavor" is a theme that is directly related to diversity. This theme illustrates that scientists and engineers come from diverse cultural backgrounds and have contributed to the advancement of science and engineering.

Conclusion

The intent of this article is to present a call to action for the U.S. educational system to meet the needs of the increasingly diverse student population. According to the NRC (Bell et al., 2009),

> Science is a sociocultural activity; its practices and epistemological assumptions reflect the culture, cultural practices, and cultural values of its scientists. Diversity in the pool of scientists and science educators is critical. It will benefit science by providing new perspectives in research, and it will benefit science education by providing a better understanding of science. Informal environments for science learning are themselves embedded in cultural assumptions. People from nondominant cultural groups may tend to see these institutions as being owned and operated by the dominant cultural group. Furthermore, science may be broadly construed as an enterprise of the elite. (p. 236)

However, after reviewing the Framework, the NGSS, and other related articles, it seems that in developing a culturally responsive science framework, math and science education have not yet received the attention of those concerned with the widening achievement gap and lack of proportional representation of minority students. Statistics show that linguistically and culturally diverse students and teachers are still underrepresented in secondary education, specifically in science education. The underrepresentation of minority students in secondary education leads to their underrepresentation in higher education. Rethinking science education is a necessity in light of the growing population of diverse students from different cultural backgrounds. Culturally diverse students come to school with alternative ways of knowing science that should be recognized as valuable assets for science learning (Lee, 2003). “Infusing diversity components” into science teacher education is a promising practice that requires rethinking already existing science curricula to meet the needs of every unique culture (Lim & Able-Boone, 2005, p. 225). Teachers should integrate their knowledge of students’ language and culture with knowledge of science if they are to make meaningful science learning accessible to all students (Lee, 2003). In fact, preservice teachers can be influenced through teacher preparation educational programs, which are developed to help with the development “of teachers’ thorough understanding and knowledge of the diverse needs and characteristics of families, children, and their communities in order to successfully create meaningful and quality teaching and environments for all children” (Lim & Able-Boone, 2005, p. 227), including culturally and linguistically diverse students. The above mentioned recommendations are developed in hope of making up for the lack of material resources and instructional support to provide exemplary science education for all students, including linguistically and culturally diverse students, in addition to the development of the students’ identities as competent and motivated learners. “Learning science depends not only on the accumulation of facts and concepts but also on the development of an identity as a competent learner of science with motivation and interest to learn more” (NRC, 2012, p. 286).

> It is critical to consider diversity issues and the science learning of nondominant groups for several reasons: to ensure equitable treatment of all individuals; to continue to develop a well-trained workforce; to develop a well-informed, scientifically literate citizenry; and to increase diversity in the pool of scientists and science educators who can bring new perspectives to science and the understanding of science” (Bell et al., 2009, p. 210).

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Explicating the Characteristics of STEM Teaching and Learning: A Metasynthesis

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Abstract

This metasynthesis focused on STEM teaching and learning practices in middle and high school classrooms and in informal settings. Research artifacts between 2005 and 2012 were examined. Fifty-eight unique artifacts were classified into four categories: *reform-based teaching and learning*, *informal education*, *teacher factors*, and *technology use*. Promising pedagogical reform-based practices included inquiry-based learning, engineering design, project-based learning, problem-based learning, and hands-on practices. The most common intervention identified was increasing teacher content knowledge. Even though STEM informal activities attempt to recruit underrepresented or low achieving students, the reality is that access to informal STEM activities is often based on students' expressed high interest, prior academic achievement, teacher recommendation, time and travel availability and flexibility, and overall levels of ambition or motivation. Positive outcomes, due to technology, appeared to covary with other factors such as teacher content knowledge, the presence of campus support, or active engagement within a learning community.

Keywords: Informal learning; Learning; Metasynthesis; Middle and high school; Teachers; Technology

The term *STEM* was first used in the 1990s and was frequently used to label anything that involved one or more of the following four disciplines: science, technology, engineering, or mathematics (Bybee, 2010). Mathematics and science have been the focus of practical applications of STEM. The current emphasis on STEM education, the formation of a cyber-learning funding stream, and the funding emphasis on STEM at the National Science Foundation and at the Institute of Education Sciences requires a greater understanding for what is known about STEM teaching and learning (cf. Capraro, Capraro, & Morgan, 2013). Interdisciplinary STEM education creates a synergy expanding beyond the four individual subject areas toward the solving of problems that overlap the four disciplines and among the subcategories within those disciplines.

This study is based on a project funded by the Science, Technology, Engineering, and Mathematics (STEM) Center for Teacher Professional Learning Grants program at the Texas Higher Education Coordinating Board (Grant No. 11307). The STEM Center for Teacher Professional Learning Grants program is supported through state funds under the General Appropriations Act for the 2012–2013 Biennium, Texas Higher Education Coordinating Board, Strategy A.1.3.

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However, providing this high-quality education that prepares students for majors and careers in STEM fields remains challenging for educators. Over the last 8–10 years, there has been increased interest in exposing students to integrated studies in STEM areas to better prepare them to solve 21st century problems that require knowledge in multiple fields (Bicer, Boedeker, Capraro, & Capraro, 2015). New or modified teaching strategies that emulate real-world work situations may be required to successfully implement the new experiences in learning through integrated STEM programs. The purpose of this study is to determine attributes that are common to STEM programs reported in the literature.

Metasynthesis as Mode of Aggregation

The term *artifact* has been used in association with meta-analysis (Cooper, Hedges, & Valentine, 2009; Glass, 1976; Hunter & Schmidt, 2004) for decades. The rise in interest in aggregating qualitative findings into meaningful and interpretable insights has brought metasynthesis and the term *artifact* to prominence and alignment (Cutcliffe & Harder, 2009; Given, 2008; Onwuegbuzie, Leech, & Collins, 2012; Sandelowski, 2004). In fact, the term *artifact* in both meta-analysis and metasynthesis has become ubiquitous across many fields. However, one common issue with any meta-analytic technique, whether quantitative or qualitative, is the *file drawer problem*: a recognized bias in a metatechnique that favors published research (Easterbrook, Gopalan, Berlin, & Matthews, 1991; Rosenthal, 1979). To partially address this problem, researchers interested in meta-analytic research have chosen to include as broad a swath of literature as possible. There are some instances in which the scope of the work might be limited, for example, when considering experimental studies in which causal attribution is either intended or implied. However, many published studies are correlational at best, and generally speaking, qualitative studies are not intended to be generalized to some broader population. Therefore, metasynthesis has been used to aggregate studies and qualitative narrative texts to build a better understanding of research results as ideas, themes, and theories begin to emerge. The generalizability aspect of any metasynthesis is therefore limited to techniques, strategies, practices, attributes, characteristics, and methods and not to a broader population of participants. A *meta-analysis* is “the bringing together and breaking down of findings, examining them, discovering essential features, and, in some way, combining phenomena into a transformed whole” (Schreiber, Crooks, & Stern, 1997, p. 314). The broader term *metasynthesis* also involves combining and synthesizing the characteristics identified in the aggregation of findings.

Methodology

Metasynthesis is a systematic approach to reviewing and integrating findings from multiple qualitative or quantitative studies. Metasyntheses are integrations that are more than the sum of parts and offer novel interpretations of findings (Polit & Beck, 2012). The overall purpose of this metasynthesis is to generate new holistic interpretive meaning while preserving the uniqueness of the original studies to the extent possible and while aggregating methods and techniques to allow comment on practices, methods, attributes, and techniques (cf. Mays, Pope, & Popay, 2005).

The research question that framed this metasynthesis was: What are the attributes and their characteristics commonly linked in qualitative and correlational reports of STEM research regarding middle and high school STEM teaching and learning? To answer this question, a metasynthesis

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was conducted. We attempted to identify attributes from the literature linked with successful STEM teaching, learning, interest, and attitudes.

Artifact Selection Procedures

Our comprehensive search of STEM practices in teaching middle and high school was conducted using the following search terms: "STEM practice" OR teaching OR learning OR education OR "high school" OR "middle school" OR research NOT cell NOT cells.

The idea of integrated STEM first became prominently used in classrooms around the United States in 2005; as a result, the criterion for the time period surveyed was set for January 1, 2005 through the date of the search, August 28, 2013. We did not require the word *STEM* in the title because the term was not widely used in the early years of the STEM movement. We considered any artifacts (e.g., journal articles, papers, poster presentations, dissertations, reports, and book chapters) that included substantial integration of at least two of the fields to be STEM.

Two comprehensive search engines were used: Google Scholar and EBSCO. The Google Scholar search returned 1,128 hits, and the EBSCO Academic Search Complete (with medical journals eliminated) returned 7,621 hits. Studies were screened to eliminate those related to an agricultural or medical meaning of the word *STEM* (e.g., plant stems, stem cell research); elementary level, undergraduate level, or graduate level STEM education; and studies dealing only with STEM careers. References were also checked on each coded study to locate additional artifacts. All artifacts available that appeared to relate to middle or high school STEM education were collected. This resulted in a total of 509 artifacts, with 58 of these artifacts fulfilling the inclusion criteria of (a) including substantial integration of at least two of the STEM fields, (b) having been published between 2005 and 2013, and (c) being empirical studies (i.e., studies that collected and analyzed data were included, whereas theoretical studies were not). Substantial integration was defined as addressing the relevant content area standards for at least two STEM fields (Laboy-Rush, 2007). For example, the use of technology with mathematics, science, or engineering was not considered a substantial integration because the technology was assistive and not a focus of the learning. Therefore, the search for integrated STEM artifacts would not have located the numerous studies that failed to note that integration in the keywords or abstracts.

The artifact coding process was composed of three parts. For the first part, the five coders were randomly assigned articles, and each article was assigned a categorizing word or phrase that characterized the contents of the manuscript. For example, one categorizing phrase was "reform-based teaching and learning," and another was "informal STEM." These phrases were brought back to the group, and the coders compared each other's categorizing phrases and discussed their intent and meaning. Through consensus, the group arrived at four categories that characterized the contents of the manuscripts. Then, one person read each of the manuscripts contained in a category and coded it for content and effects. Finally, the group met to reconcile their codes and justify their analyses. After consensus was reached, the team realigned the initial categories to better reflect the themes of the study artifacts.

More specifically, 58 unique artifacts were classified into four categories: *reform-based teaching and learning* (see Table 1), *informal education* (see Table 2), *teacher factors* (see Table 3), and *technology use* (see Table 4). Within these tables, some artifacts were repeated because different aspects of the artifacts were examined to shed light on one of the four areas of STEM teaching and learning mentioned above. Therefore, the sum total of artifacts coded for each category was greater than the total number of artifacts because one artifact often contained information about more than one category. Finally, themes within each category were identified through an iterative process of constant comparison among the artifacts (Strauss & Corbin, 1990). Early in the analysis process, tentative linkages were developed between categories and evidence of effectiveness. As the coding progressed, themes for each category emerged. Upon saturation, the coding process shifted toward verification (Lincoln & Guba, 1985). Artifacts were revisited and reviewed again as additional themes emerged.

Background of the Categories That Emerged

Reform-based teaching and learning. Improving teaching and learning can involve practices that are student-centered and constructivist in nature (e.g., inquiry-, project-, and problem-based learning). These practices encourage students to (a) learn about the world around them, (b) engage knowledgeably in public discussion about issues of scientific and technological concern, and (c) increase their economic productivity as a result of knowledge and skill acquisition (National Research Council [NRC], 1996). Furthermore, reform-based teaching and learning practices have a history of producing positive outcomes (Anderson, 2002) such as increases in cognitive achievement, skills (Shymansky, Kyle, & Alport, 1983), scientific literacy, vocabulary knowledge, conceptual understanding, critical thinking, and positive attitudes (Haury, 1993). The results of these practices, however, are mixed. Strobel and van Barneveld (2009) conducted a metasynthesis of extant meta-analyses comparing reform-based practices to traditional classroom instruction. They found that, in general, reform-based practices promoted long-term retention of content knowledge and developed 21st century skills, whereas traditional practices were more effective for short-term retention of knowledge. However, in another metasynthesis, Clark found "that the failure to provide strong learning support for less experienced or less able students could actually produce a measurable loss of learning" (Clark, 1989; as cited in Kirschner, Sweller, & Clark, 2006, p. 81). In a different metasynthesis, he also found that "when learners are asked to select between a more or a less unguided version of the same course, less able learners who choose less guided approaches tend to like the experience even though they learn less from it" (Clark, 1982; as cited in Kirschner et al., 2006, p. 82).

Informal STEM learning opportunities. Informal STEM learning environments generally provide occasions for scientific learning without the time constraints commonly found in more formal settings (Hofstein & Rosenfeld, 1996). Informal learning settings (e.g., museums, zoos, science centers, and science camps) often have the tools, resources, and expertise to support STEM learning opportunities. The advantages of flexible time constraints in informal learning environments facilitate greater chances to augment conceptual learning, reflection time, assessment of subject matter, and informal discussions. These environments provide opportunities to facilitate student understanding and transform learning processes and concepts. Within informal settings, there are many opportunities for scaffolding student knowledge, attitudes, and STEM career options.

National and international interest has focused attention on informal learning opportunities. International comparisons have indicated that U.S. informal education opportunities may have been overlooked because there is a great deal of emphasis on formal STEM learning (Lee, 1998). However, there is a movement in the United States to examine the usefulness of STEM learning that can occur in informal learning environments. Informal STEM environments can account for

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a considerable amount of student learning (Gerber, Marek, & Cavallo, 2001). National education groups have examined the impact of informal opportunities on STEM knowledge. Informal learning can complement and scaffold STEM teaching and student learning and increase participation in STEM for the underrepresented (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007; NRC, 1996; National Science Board, 2010).

Informal science learning has gained traction as a possible contributor to student learning. Informal environments can be mechanisms for linking formal and informal efforts to improve student learning in STEM areas (Falk et al., 2012; NRC, 1996). Community resources have been useful in students' and adults' pursuit of STEM understanding (Bell, Lewenstein, Shouse, & Feder, 2009).

Teacher factors. "Many factors contribute to a student's academic performance . . . . But research suggests that, among school-related factors, teachers matter most" (RAND Education, 2012, p. 1). Some of the teacher factors that were considered in this study include attitudes, knowledge, beliefs, and practices that impact student learning and instructional practices. Examples include teachers' willingness to integrate technology (Yoon & Liu, 2010) and teachers' perceptions of students whom they would encourage to pursue engineering studies (Nathan, Tran, Atwood, Prevost, & Phelps, 2010). Teacher factors also included classroom factors fostering students' team skills through teacher designed collaborative learning activities.

Technology. Technology should be explored not only in concert with other STEM disciplines but also for its contribution to student learning. Generally, technology is one STEM component included in various combinations of interdisciplinary STEM education. Technology plays a vital role enabling students to relate science and mathematics knowledge across STEM disciplines (Sanders, 2009). In the 21st century, students need to be familiar with technological developments in order to understand changes in the world around them (Bybee, 2010). Developments in technology make our world more complex, and students need an appropriate technology rich education. In STEM education, the integration of technology with science, engineering, and mathematics enables students to relate these subject areas to the real world (Capraro et al., 2013).

Results

The four categories gave rise to the aggregated findings. Within the aggregated findings, counts of artifacts comprising each category, the generalized method, and the outcomes were identified. The findings were then reorganized for interpretation into themes that clearly illustrate the common practices and expected outcomes from the extant literature on middle and high school STEM teaching and learning.

The category of reform-based teaching and learning practices contained 25 of the 58 artifacts (see Table 1). The practices were classified as inquiry, engineering design, project-based learning (PBL), problem-based learning, the Legacy Cycle, or hands-on activities. Students were exposed to reform-based practices in a variety of settings at different grade levels, explored a variety of STEM-related subjects, and were immersed in these STEM-related learning environments for different lengths of time. In addition, different target groups of students were the focus of the studies, and some teachers received professional development (PD). Students were exposed to these reform-based strategies in both formal and informal settings. Fourteen of these studies took place in formal classrooms, and the remaining 11 took place in informal settings, including after school or weekend programs (3), summer programs (5), or combined after-school and summer programs (3). Students were in middle school (12), high school (11), or both (2). These students were involved in different subjects related to STEM integration along with writing, reading, and social studies. Students were engaged in STEM-related projects using six different reform-based practices for 1 week or less (3), 2 to 5 weeks (6), 6 weeks to one semester (6), or more than 1 year (6). Four of the studies did not describe the length of time that students were engaged. Groups of females (10) and underrepresented students (8) were samples of interest. In nine of the 25 studies, the students' teachers received PD designed to support them in the implementation of the reform-based practices. Most of these reform-based teaching and learning practices focused on: enhancing students' content knowledge (17), developing students' skills (8), increasing students' use of technology (3), promoting students' interests in STEM-related college majors and careers (8), examining students' perceptions and attitudes (12), and providing rich learning environments for students (1).

In the category of informal education, there were 22 unique artifacts (see Table 2). The venues for informal learning included after-school or evening programs and clubs (8) or summer camps (14), some including follow-up mentorships. The lengths of the activities varied: 3 hours (1), 40 hours (2), 80 hours (1), 2 days (1), 3 days (1), 4 days (1), 1 week (1), 2 weeks (5), 1 month (2), 7 weeks (1), 10 weeks (2), 18 months (1), and longitudinal (one 3-year and one 5-year activity). A total of 1,965 participants were included within 21 of the studies that provided demographics with a range from 21 to 239 participants within each study. Some of these participants were from underserved, underrepresented, low SES, and minority populations (6 studies, 576 students); some were chosen randomly or by lottery (3 studies, 390 students); and others only attended if they had a high aptitude, high STEM interest, or high scores in mathematics and science (7 studies, 550 students). Many informal activities had more than one focus with one activity using as many as seven different teaching pedagogies. These pedagogies included: inquiry, hands-on activities, PBL, small and large group activities, field trips, modules, discussions, collaborations, and projects. They also included experts such as mentors and role models. Most of these informal activities contained a combination of two or more of these pedagogical strategies. The subjects were some combination of science, mathematics, engineering, technology, music, and robotics with some containing more than two of these specific subject areas. Most of the artifacts described interventions dealing with (a) increasing student knowledge and understanding, (b) increasing the STEM pipeline by developing a wider breadth of understanding for STEM careers, and (c) improving student attitude and confidence in STEM areas.

Twelve artifacts were classified as pertaining to the influence of teacher factors on STEM learning (see Table 3). Six principle themes for teacher factors emerged: (a) enhanced teacher content knowledge, (b) deep understanding of STEM teaching practices (effective pedagogy), (c) frequent and effective integration of technology, (d) effective use of team skills and collaborative learning, (e) high teacher self-efficacy, and (f) emphasis on deliberate instructional practice. Team skills and collaborative learning were discussed in five of the 12 artifacts. Of these five, three made reference to the importance of collaboration and how collaborative teams were structured within the outreach or PD programs, but they did not measure student outcomes based on levels or degree of collaboration. One artifact, however, described in detail how they structured teams, activities, and criteria for the primary purpose of fostering multiple layers of collaboration while discouraging passive cooperation and negative competition (Nag, Katz, & Saenz-Otero, 2013).

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Table 1
Attributes of Reform-Based Teaching and Learning Strategies in Artifacts Reviewed ($n = 25$)

Reference	Reform-based strategy	CK[a]	Skill[b]	Technology use	Majors/ careers	Perceptions and attitudes	Learning environment
Brown et al. (2010)	Project		✓			✓	
Duran & Şendağ (2012)	Problem		✓				
Duran et al. (2014)	Inquiry	✓	✓	✓	✓	✓	
Heggen et al. (2012)	Inquiry	✓		✓	✓	✓	
Hudson et al. (2012)	Engineering design						✓
Hylton et al. (2012)	Inquiry	✓				✓	
Kampe & Oppliger (2011)	Project		✓	✓	✓	✓	
Kanter & Schreck (2007)	Legacy Cycle	✓					
Ketelhut (2007)	Inquiry	✓				✓	
Kim et al. (2011)	Inquiry					✓	
Klahr et al. (2007)	Engineering design	✓				✓	
Klein & Sherwood (2005)	Legacy Cycle	✓					
Little et al. (2009)	Inquiry	✓	✓		✓		
Lou, Liu, et al. (2011)	Project	✓	✓			✓	
Lou, Shih, et al. (2011)	Problem	✓	✓		✓		
Mehalik et al. (2008)	Engineering design	✓					
Menzemer et al. (2007)	Hands-on	✓				✓	
Mosina et al. (2012)	Hands-on				✓		
Olivarez (2012)	Project		✓				
Richards et al. (2007)	Engineering design	✓					
Ricks (2006)	Inquiry	✓			✓	✓	
Schnittka (2009)	Engineering design	✓				✓	
Williams et al. (2007)	Inquiry	✓	✓				
Wimpey et al. (2011)	Inquiry	✓					
Zhe et al. (2010)	Problem				✓		

Note. ✓ = present.

[a] CK = content knowledge.

[b] Skill = technology, inquiry, critical thinking, reasoning, and problem solving.

Table 2
Attributes of Informal Education Artifacts Reviewed (*n* = 22)

Reference	Participants	Venue	Length	Selection	Pedagogies	Focus
Adamchuk et al. (2009)	147 MS	SC & AS	40–80 hours		R, Inquiry, PS, GIS	Attitudes, CK
Duran et al. (2014)	77 HS	Summer & AS	18 months	Special needs, F	T, Collaboration, Inquiry	CK, Careers, Perceptions, Attitudes
Cantrell et al. (2009)	130 HS	Seminar	5 years (L) 8 weeks	Interest in STEM	Seminars	Careers
Heggen et al. (2012)	21 MS	AS	10 weeks	Minority, low SES	T, Problem-based	TS, Careers
Hirsch et al. (2006)	36 T & S	Summer PD	2 weeks		Career awareness	Attitudes, CK
Hoyles et al. (2011)		AS		UK	Collaboration	Attitudes
Hubelbank et al. (2007)	129	SC	2 weeks	Lottery	PS, Role models, Hands-on	SE, Careers, Courses
Hylton et al. (2012)		SC	1 month	High STEM interest	Inquiry, PS, Enrichment	Courses, Confidence
Javidi & Sheybani (2010)	87 MS	SC & Saturdays	3 years	Low SES, Rural, Urban	R, Gaming, CP	Attitudes, Interest, Careers
Johnson et al. (2013)	133	SC	2 weeks	Talented	Research, Field trip, Scientists	Courses, Attitudes
Kim et al. (2011)	100	Summer	1 week	Underrepresented	Inquiry, Hands-on, Modules	Attitudes
Marle et al. (2012)	32	SC	4 days	Average	Real life exposure to science careers	Confidence, CK
Menzemer et al. (2007)	26 (11 LD)	Summer & AS	Varied	Special pop./LD	Hands-on, Technology	Attitudes, Careers, CK
Miller et al. (2011)	9 T & 84 S	Summer PD	2 days	Low SES, Minority		CK
Mosina et al. (2010)	239 HS	Summer & AS	10 weeks	Low SES, Minority	Projects, Mentors, Research, Exhibits	Courses
Nugent et al. (2011)	72 MS	Clubs	Episodic	M, White, Urban	R, Collaboration, PS	21st CS, CK, SE
Nugent et al. (2011)	147	SC	40 hours	Urban, Rural, Diverse	R, LEGOs, Hands-on	
Nugent et al. (2011)	141	One event	3 hours	Mixed abilities	Stations	Attitudes, Motivation
Nourbakhsh et al. (2005)	28 HS	SC	7 weeks	Application process	R, Challenge-based, Hands-on	CK, PS, CP, Collaboration
Prins et al. (2010)	48 MS	SC	3 days		Projects, Mentors, Exposure to careers	Career
Ricks (2006)	50	SC	4 weeks	High STEM interest	Hands-on, PS, Field trips, Inquiry	CK, Attitudes, Courses
Welsh (2009)	58	AS	6 weeks	Existing members	R, Competition	Attitudes

Reference	Participants	Venue	Length	Selection	Pedagogies	Focus
Williams et al. (2007)	21	SC	2 weeks	Average	Inquiry, Hands-on, Discussions	Content
Zhe et al. (2010)	33 HS	SC	10 weeks	High STEM interest	Problem-based, Collaboration, Hands-on	Confidence, Career

Note. MS = middle school; HS = high school; T = teacher; S = Student; SC = summer camp; AS = after school; PD = professional development; F = female; M = male; SES = socioeconomic status; UK = United Kingdom; STEM = science, technology, engineering, & math; LD = learning disabled; R = robotics; PS = problem solving; GIS = geographic information system; CP = computer programming; CK = content knowledge; TS = technology skills; SE = self-efficacy; 21st CS = 21st Century Skills.

Table 3

Attributes of Teacher Factor Artifacts Reviewed (*n* = 12)

Reference	Teacher CK	STEM teaching practices	Technology	Collaborative learning	Teacher self-efficacy	Deliberate instructional practice
Duran et al. (2014)			✓	✓		
Finson, Pederson, & Thomas (2006)		✓				
Hotaling et al. (2012)	✓		✓			✓
Hoyles, Reiss, & Tough (2011)		✓	✓		✓	
Lambert (2006)	✓					
Moskal et al. (2007)	✓	✓		✓		
Nag et al. (2013)		✓	✓	✓		
Nourbakhsh et al. (2005)			✓	✓		
Ragusa (2012)		✓			✓	✓
Silverstein et al. (2009)	✓	✓			✓	
Yoon & Liu (2010)	✓	✓	✓		✓	
Zhe et al. (2010)				✓		

Note. ✓ = present

[a] CK = content knowledge

Table 4

Attributes of Technology Related Artifacts Reviewed (*n* = 27)

Reference	Technology used	CK	Technology skills	Teaching strategy	Majors/ careers	Perceptions and attitudes	21st century skills
Adamchuk et al. (2009)	R, HH, CP			Inquiry ł			PS
Brown et al. (2010)	Simulations		✓	Project-based		✓	
Chapman (2012)	Simulations	S				✓	PS
Duran & Şendağ (2012)	R, CP		✓	Problem-based	✓		
Duran et al. (2014)	R, CP	S	✓	Inquiry	✓	✓	Collaboration
Heggen et al. (2012)	HH		✓	Inquiry	✓		
Hotaling et al. (2012)	HH, CP	T, S		Problem-based ł			PS
Huang, Liu, & Shiu (2008)	CAI	S		Cognitive conflict			
Javidi & Sheybani (2010)	R, CP		✓	Games	✓	✓	
Johnson-Glenberg et al. (2011)	Simulations			Problem-based ł, Games	✓		
Kampe & Oppliger (2011)	R, HH		✓	Project-based	✓	✓	PS
Kay, Zucker, & Staudt (2013)	Simulations	S					
Kim et al. (2011)	CP			Inquiry			
Klahr, Triona, & Williams (2007)	Simulations	S		Engineering design		✓	
Lawless, Brown, & Boyer (2011)	Simulations	S	✓				
Lou, Liu, et al. (2011)	Solar Trolley		✓	Project-based	✓	✓	PS
Moskal et al. (2007)	R, HH, CP	T, S	✓	Hands-on ł		✓	Collaboration
Nag et al. (2013)	R, Simulations	S					PS, Collaboration
Nourbakhsh et al. (2005)	R, CP		✓				PS, Collaboration
Nugent et al. (2011)	R, CP		✓			✓	PS, Collaboration
Stephen, Bracey, & Locke (2012)	R, HH				✓		Collaboration
Strautmann (2011)	R		✓		✓	✓	
Sumners, Handron, & Jacobson (2012)	Simulations	S	✓	Inquiry ł, Games			
Tan et al. (2013)	Simulations		✓				
Welch (2010)	R			Competition		✓	
Wyss, Heulskamp, & Siebert (2012)	Recordings				✓		
Yoon & Liu (2010)	Simulations	T					

Note. ł = The match between Table 4 (technology) and Table 1 (reform-based artifacts) may not be exact. Pedagogical practices are listed in this table only when the artifact reviewed discussed student gains in technology skills, attitudes about technology, frequency of technology use, or technology content knowledge in relation to the pedagogical practice. R = robotics; HH = handheld technology device; CP = computer programming; S = science; T = technology; ✓ = present; P&A = Perceptions and Attitudes; PS = problem solving. NELS = National Education Longitudinal Study; HS = high school; MS = middle school; PBL = Project-based Learning; Tech = technology.

Participants were grouped by level of collaboration. The degree of collaboration was linked to knowledge and skills.

There were 25 artifacts that discussed the integration of technology with mathematics, science, or engineering (see Table 4). More than half (13 of 25) of the artifacts that discussed the use of technology as part of STEM integration described robotics projects. Three of the studies addressed content knowledge, eight focused on technology skills, nine discussed STEM interest, and nine others concentrated on 21st century skills. All of the robotics projects were implemented in informal environments, summer camps, and after-school programs. Nine of the 25 artifacts described projects that used simulations of some type. Many were not well characterized; however, one specifically mentioned robotics (Nag et al., 2013), and one involved simulations in games (Sumners, Handron, & Jacobson, 2012). One project used a 5-week simulation project to address national standards for middle school students in persuasive writing and social studies as well as science. The simulation addressed water resources and solving a crisis in the availability of clean water. Seven of the nine artifacts that mentioned programming used it in connection with a robotics project.

Themes From Higher Level Abstractions

In order to make the findings more accessible and more applicable for researchers and practitioners, we examined the findings through an iterative process of recategorization and discovered a higher level of abstraction. This abstraction more closely matches important areas for research and school practice. The emergent themes were (a) student content knowledge and skills, (b) teacher content knowledge, (c) perceptions and attitudes, (d) majors and careers, and (e) technology integration.

Student content knowledge and skills. The predominant purpose was to increase student content knowledge. Findings from several studies showed positive gains on student content knowledge across various subject areas (Duran, Höft, Lawson, Medjahed, & Orady, 2014; Heggen, Omokaro, & Payton, 2012; Hylton, Otoupal-Hylton, Campbell, & Williams, 2012; Marle, Decker, Kuehler, & Khaliqi, 2012; Ricks, 2006; Williams, Ma, Prejean, Ford, & Lai, 2007; Wimpey, Wade, & Benson, 2011). The duration of the program and the direct confrontation of STEM misconceptions were related to changes in student STEM conceptions (Miller, Ward, Sienkiewicz, & Antonucci, 2011; Ricks, 2006). The duration of the intervention was related to better improved student outcomes (cf. Bicer, Navruz, et al., 2015; Capraro et al., 2016; Cetin, Corlu, Capraro, & Capraro, 2015). However, there was no evidence that engineering and technology knowledge were influenced by reform practices (e.g., Little & León del la Barra, 2009).

Engineering-design-based practices appeared to offer benefits for student development of content knowledge. Findings from several engineering-design-based studies showed increased student content knowledge (Mehalik, Doppelt, & Schuun, 2008; Richards, Hallock, & Schnittka, 2007; Schnittka, 2009). Furthermore, science content knowledge was more often influenced by engineering-design-based practices than by inquiry practices (e.g., Nite, Capraro, Capraro, Morgan, & Peterson, 2014; Han, Capraro, & Capraro, 2014; Han, Yalvac, Capraro, & Capraro, 2015). Engineering design was often associated with greater affect and academic interest for formerly low achieving African American students than for any other group of students. Virtual and nonvirtual engineering design practices were equivalent with regard to engineering content knowledge (e.g., Klahr, Triona, & Williams, 2007). Engineering-design-based practices were closely aligned with improved proficiency with technology (Duran et al., 2014; Little & León de la Barra, 2009).

There were significant positive differences between student content knowledge and procedural knowledge when students participated in PBL, and this extended to special populations (e.g., Duran & Şendağ, 2012; Klein & Sherwood, 2005; Lou, Liu, Shih, & Tseng, 2011; Menzemer, Lam, Zhao, Zhe, & Doverspike, 2007; Olivarez, 2012). In general, students with learning disabilities tended to benefit from reform techniques (e.g., Menzemer et al., 2007). Some results were broadly defined but with mixed results showing that content knowledge could be heavily moderated by other factors (e.g., Kanter & Schreck, 2007; Lou, Shih, Diez, & Tseng, 2011). Further, PBL had a positive impact on student writing and technology knowledge (Brown et al., 2010).

Teacher content knowledge. Teacher content knowledge had a substantial impact on student outcomes. Artifacts established a positive relationship between teacher content knowledge and student learning (Hotaling et al., 2012; Lambert, 2006; Moskal et al., 2007; Ragusa, 2012; Silverstein, Dubner, Miller, Glied, & Loike, 2009). The outcomes were correlational at best because it was not possible to aggregate the effect due to the lack of detail in the reporting (no means or standard deviations reported or insufficiently reported statistical tests) or reporting percent gains or gain scores alone. However, the greater the teacher subject matter knowledge reported in the articles or time given building teacher subject matter knowledge, the better the student outcomes (Hotaling et al., 2012). Most studies included prolonged and systematic PD of STEM teaching strategies (e.g., problem-based learning, inquiry, or engineering design). Students who were weaker academically tended to benefit to a greater extent from increases in teacher content knowledge (Lambert, 2006; Silverstein et al., 2009).

Perceptions and attitudes. Generally, this higher order factor focused on how perceptions and attitudes changed with regard to various aspects of STEM teaching and learning. Overall, students who engaged in inquiry-based practices had positive attitudes and perceptions toward STEM. It was also found that there were positive attitudes toward learning science (Ricks, 2006), engineering careers (Hirsch, Kimmel, Rockland, & Bloom, 2006) computing (Heggen et al., 2012), and mathematics skills and self-confidence (Hoyles, Reiss, & Tough, 2011; Hylton et al., 2012; Zhe, Doverspike, Zhao, Lam, & Menzemer, 2010). When attitudes toward STEM subjects were overwhelmingly positive, these attitudes did not change during interventions (Duran et al., 2014; Heggen et al., 2012). There were no gender differences with regard to attitude or affect toward STEM (Marle et al., 2012). After a STEM intervention, males showed more positive attitudes toward science and scientists, but females remained anxious, although their views were more positive. One possible reason for this difference was that females reported that technology made science learning interesting, data gathering more accurate, and improved visualization and understanding (Kim et al., 2011). In comparison, an engineering-design-based study showed that females had a greater increase in positive attitudes toward engineering than did males (Schnittka, 2009). However, another study found that confidence level differed by gender with females having a lower confidence with regard to hands-on or virtual activities (Klahr et al., 2007). Studies focusing on PBL practices showed consistent results. Students had positive attitudes toward their summer workshop experience (Kampe & Oppliger, 2011), and STEM PBL practices had a positive influence on students' behavioral intentions, attitudes, and desire to learn (Lou, Liu, et al., 2011). However, PBL did not have an impact on students' self-efficacy toward STEM subjects (Brown et al., 2010). Both mainstream and learning disabled students were satisfied with their STEM instruction, more interested in the lessons, and had a higher self-efficacy toward STEM subjects when hands-on practices were used.

Majors and careers. One goal of many STEM reform-based practices was to increase student interest in STEM majors and future careers. Programs designed to increase student interest in STEM careers and STEM majors tended to be persuasive. First, students who were involved tended to already be somewhat positive toward STEM careers and majors. However, females tended to recognize that their embodiment of the characteristics aligned with a STEM-related career (knowledge development, affinity for STEM-related activities, and interest in STEM) through the programs (e.g., Heggen et al., 2012; Hubelbank et al., 2007; Lou, Shih, et al., 2011; Ricks, 2006). One specific difference was related to confidence, which tended to influence males and females equally (Zhe et al., 2010). Again, it is important to note that underrepresented students tended to be more heavily influenced toward STEM careers and majors. In general, informal activities focusing on STEM topics had a positive effect on students' impressions of STEM careers and were indicative of students wanting to pursue a STEM major or career (Cantrell & Ewing-Taylor, 2009; Hubelbank et al., 2007; Hylton et al., 2012; Johnson et al., 2013; Mosina, Belkharraz, & Chebanov, 2012; Ricks, 2006; Wyss, Heulskamp, & Siebert, 2012; Zhe et al., 2010).

Increased technology use. Researchers examining the implementation of STEM reform-based practices incorporated technology use as an outcome measure. Mobile phones and computers were shown to be tools valued by students in inquiry-based environments. The increased emphasis on mathematical and scientific problem solving precipitated increased technology understanding (Heggen et al., 2012). Engagement in inquiry-based learning activities increased students' use of basic technology tools, and about half of the students broadened their repertoire to include advanced STEM technologies (Duran et al., 2014; Young & Young, 2013). Students who were engaged in STEM PBL increased their use of database software; robotics and programming; modeling; computer game development; and communication technologies such as blogs, podcasting, and social networking (Kampe & Oppliger, 2011). Technology became more of an integrated tool that students learned to use to further their accomplishments in science, mathematics, and engineering.

Teacher use and integration of technology was paramount for student learning in STEM-related activities. Three factors led to classroom adoption and integration of technology: (a) sufficient time to assimilate the technology, (b) institutional support, and (c) active engagement within the learning community (Yoon & Liu, 2010). The primary challenge mitigating the impact of technology was the cognitive demands of learning about the technology placed on the teacher (Silverstein et al., 2009). This barrier ensured that students would not have the opportunity to use the technology.

Conclusions

Our conclusions are based on the prevalence and preponderance of qualitative evidence presented in the research artifacts. Almost all studies included a form of inquiry. This may not be surprising because inquiry can be found across all STEM disciplines. In many cases, the inquiry was encased within stringent curricular components that were carefully assessed and highly structured. In other studies, inquiry was semistructured with more fluid curricular components and more dynamic and spontaneous teaching episodes. Regardless of the flavor of inquiry being enacted, it was commonly associated with qualitative outcomes of increased affect toward a STEM subject or subjects, greater interest in STEM fields, and more positive feelings about learning. Inquiry was broadly defined and included problem-based learning, project-based learning, engineering design, discourse, and enactivism. Broad definitions of inquiry were used in these studies, which made identification reasonably easy, but it is troubling that there was no definition of inquiry presented in four studies (e.g., Duran et al., 2014; Heggen et al., 2012; Hylton et al., 2012; Wimpey et al., 2011). However, the description of the activities, processes, and assessments made it clear that the studies were inquiry based. For example, some studies described their model as focusing on questioning and using hands-on and minds-on activities (i.e., Little & León de La Barra, 2009), whereas others characterized their work as being student centered, active learning, requiring critical thinking, and developing problem solving skills (cf. Ricks, 2006). Only three of the studies described inquiry according to the *National Science Education Standards*' definition of scientific inquiry (e.g., Ketelhut, 2007; Kim et al., 2011; Williams et al., 2007):

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (NRC, 1996, p. 23)

Studies in which informal learning programs were used yielded interesting and unexpected sets of aggregated findings. Generally, every study that reported on informal STEM education activities (i.e., after-school clubs, camps, university visits, and on-line mentoring by STEM professionals) was aligned qualitatively with positive outcomes. Most common were self-reports of greater access, interest, and competence in STEM fields. Although most informal activities primarily indicated that students felt better connected to STEM fields, some showed students possessing greater awareness of STEM careers and increased motivation to pursue postsecondary STEM schooling. Some programs were designed specifically for women or minorities with findings indicating that this group preferred informal activities that highlighted social aspects, support structures, and building new friendships.

The single most common component for teachers who participated in STEM PD was increasing teacher content knowledge, making it one of the greatest perceived needs by researchers. This was followed by improving teachers' pedagogical practices for STEM teaching and learning. Teacher content knowledge was most effective when it was broad, covered a range of disciplines, and integrated. After teachers had acquired new content knowledge, it took additional time to translate the content knowledge to educational practices.

Many of the studies focused on students' STEM learning that followed their teachers' PD, which was focused on STEM content knowledge, reform-based STEM teaching practices, or STEM research experience for teachers. However, it was difficult to attribute student performance solely to teacher content knowledge. Although this metasynthesis included quantitative artifacts, they were correlational in nature, so no estimate of effect was warranted.

The purpose for many of the studies was to improve affect, and of those, many did not address academic performance at all. Many of the artifacts dealt with engaging students in STEM learning, experience with or comfort with various technologies, increasing interest in STEM studies and careers, and improving attitudes about STEM. In general, long-term projects produced positive results for student interest in STEM majors and careers, but these projects were most often conducted in informal environments, primarily with voluntary involvement. Projects designed to familiarize students with engineering, engineering design, and careers in engineering had an impact on the desirability of an engineering major and career. The single most common study characteristic dealing with affect was informal education, often hosted by or at a university in collaboration

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with a school or school district. Perhaps the informal settings were selected to provide additional educational support and foster collaboration between universities and K–12 schools.

Informal education experiences were fraught with equity issues. Equity issues related to "closing the gap" involve strategies for access to equal participation as well as strategies for access to equal success. Even though informal education (i.e., STEM summer camp opportunities and after-school activities) attempts to recruit underrepresented or low achieving students, the reality is that access to informal STEM activities is often based on students' expressed high interest, prior academic achievement, teacher recommendation, time, travel availability, flexibility, and ambition or motivation. Promising components within those informal programs that are recurrent and noteworthy for future study include having students identify and solve authentic problems, content-focused field trips, interactions with experts in STEM fields, experience with STEM-centric technologies, long-term projects (2-weeks or more), STEM subject integration, product-focused outcomes, and students learning to justify results and conclusions.

Implications for Educators

Teachers should capitalize on the creativity and the curiosity of students to integrate STEM into classroom activities. Teachers might ask, "How can I do that? There are already too many objectives and standards to cover." Preservice and in-service teachers need to take a closer look at the standards. Of course, just because the standards allude to integrating subjects, classroom enacted lessons do not automatically become integrated. Therefore, teachers need to be voracious consumers of PD opportunities that meet STEM integration needs from education service centers, STEM centers, STEM partners, and universities.

The STEM school development movement has gained momentum recently in K–12 classrooms as evidenced by the funds supporting the creation of a large number of new STEM-focused schools (Bicer, Navruz, Capraro, & Capraro, 2014). The theory behind this movement is that students learn less when individual subjects are taught than when subjects are integrated. What better place to start than in middle and high school to integrate STEM curriculum? In order for STEM integration not to remain just verbiage, teachers need to ask their PD providers to present strategies for making meaningful connections between disciplines. Science and mathematics teachers are prepared in teacher training programs with a single subject focus; therefore, teachers tend to impart that same perspective to their students. As a result, both science and mathematics teachers have difficulty viewing mathematics and science as an integrated whole and synergistically with engineering and technology. Teachers should not feel inadequate about their abilities to facilitate learning in the classroom. Unfortunately, most teachers do not feel comfortable integrating content. Until teachers feel confident and have time to practice this STEM integration, it will not happen. Teachers should ask their administrators and university partners to provide STEM integration training.

Imagine how much learning could take place if a team of middle school students were working on a task developing paper airplane gliders for a company (engineering)? Artifacts developed could include graphs comparing flight distances or weight vs. length of wings (mathematics and technology) and calculations of how the air pressure pushing on the wings of the glider keeps it from coming straight down (science). This integration at the middle school level can serve as a natural progression to more rigorous high school level science, technology, engineering, and mathematics coursework. These same energetic, curious, and creative students might then be more likely to choose STEM majors in college and ultimately careers in STEM fields!

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[1] Asterisks are used to indicate the studies that were used in the metasynthesis.

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Creating Teaching Opportunities for STEM Future Faculty Development

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Abstract

Graduate school is an important time for future faculty to develop teaching skills, but teaching opportunities are limited. Discipline-related course work and research do not provide the pedagogy, strategies, and skills to effectively teach and compete for higher education jobs. As future faculty, graduate students will influence the future of science, technology, engineering, and mathematics (STEM) education through their teaching. The purpose of this case study was to examine future faculty's (graduate students') perceived teaching development during a semester-long STEM teaching development course. Findings included STEM future faculty's teaching confidence and skill development in instructional design, preparation, and facilitation; greater development in skill awareness than student awareness and self-awareness; and a focus on knowledge-centered learning environments for future classroom teaching experiences.

Keywords: Doctoral students; Future faculty; Graduate students; STEM; Teaching development

> "*Teaching is not easy*."
> "*Teaching preparation takes more time than you think*."
> "*It is harder than I expected to talk and write at the same time*."
> "*I found myself elated in seeing the students using the information I taught*."
> —Excerpts from STEM future faculty's teaching reflections

Graduate school is an important time for future faculty socialization into academia, but Austin (2002) identified gaps such as the need for doctoral students to learn about faculty work and receive feedback from current faculty. According to the Association of American Colleges and Universities (Adams, 2002), graduate student professional development in teaching is important to prepare future faculty. However, graduate schools do not always provide opportunities for graduate students to train and develop as future faculty in academia. Teaching opportunities are limited, and according to Davis and Kring (2001), researchers have also expressed concern about the use of such opportunities. When graduate students have the opportunity to teach, they may experience tension between teaching and research practice (Dotger, 2011) and between teaching and epistemology (Kinchin, Hatzipanagos, & Turner, 2009).

Graduate students, including those in science, technology, engineering, and mathematics (STEM) fields, frequently aspire to higher education faculty positions requiring teaching; however, discipline-related course work and research do not provide the required pedagogy, strategies, and skills. At the same time, faculty search requirements are increasing because educational institutions are looking for individuals with teaching experience who have taken courses focused on pedagogy and teaching in higher education (Adams, 2002). Future faculty must provide teaching evidence and pedagogical knowledge to compete in today's academic job market. Boice (2000) found that when future faculty become new faculty, classroom experiences are often the difference between success and failure in academia. Specifically, novice teachers often prepare too much material, at too difficult a level, and present material too quickly. Furthermore, they frequently do not connect with students, focusing on content and excluding the process of teaching and learning.

Furthermore, STEM future faculty will influence the future of science, technology, engineering, and mathematics education. According to the National Science Foundation (2009), "future faculties will be engaged in all forms of STEM education for diverse learners, including college classrooms and laboratories, distance learning, K–12 preservice preparation, and informal education" (p. 1). Therefore, graduate school is a critical time to develop teaching to, ultimately, enhance STEM education at all levels.

In response to concerns about graduate student professional development as well as student and program requests, a large southwestern research university assessed and designed a program specific to teaching development. Rationale included advancing the university's graduate programs and students' career development as well as enhancing undergraduate education. Internal and external

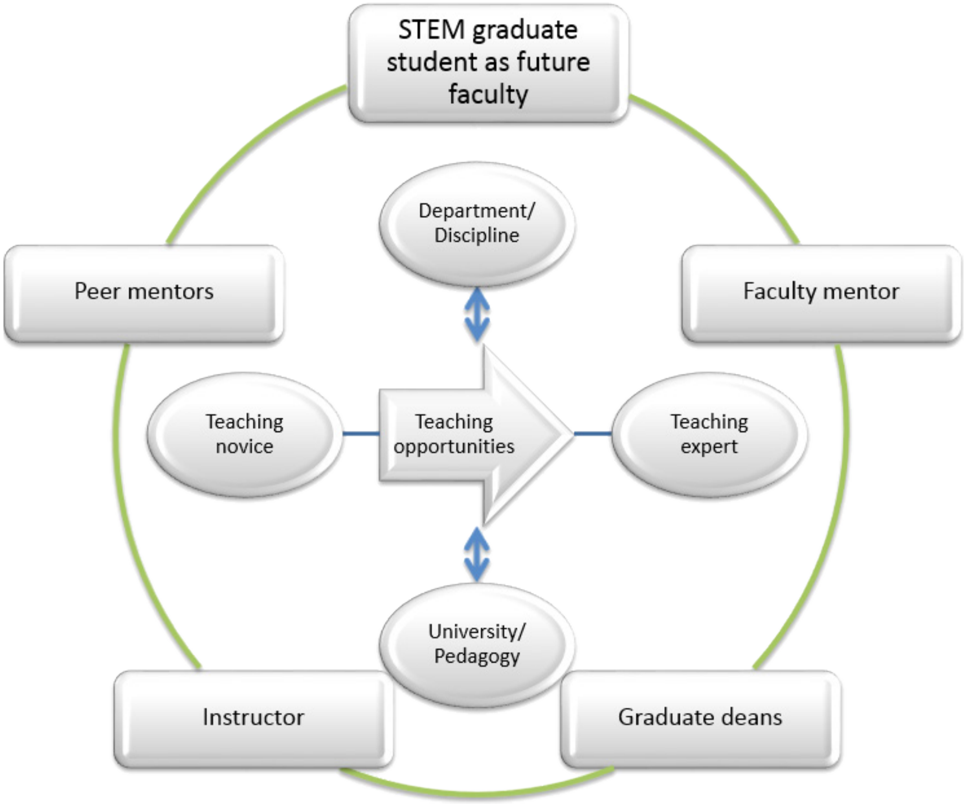

Figure 1. Conceptual model of graduate student professional development in teaching (Cherrstrom et al., 2012) applied to the STEM teaching development course.

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research yielded a conceptual model of graduate student professional development in teaching. The purpose of this study was to examine future faculty's perceived teaching development during a semester-long STEM teaching development course.

Conceptual Framework

For the STEM teaching development course and associated study, instructors and researchers adapted the conceptual model of graduate student professional development in teaching (Cherrstrom, Fowler, & Richardson, 2012) and the course design cycle (Fowler, Sandoval, Layne, & Macik, 2011) as a framework.

Graduate Student Professional Development in Teaching

The adapted conceptual model of graduate student professional development in teaching's core (see Figure 1) depicts a progression (Prieto & Meyers, 2001) from *teaching novice* toward *teaching expert*, which requires teaching opportunities. Whereas novices struggle to construct meaning from new information, experts make connections, identify patterns, and organize and process information into new solutions (Bransford, Brown, & Cocking, 2000). As graduate students begin the progression from teaching novices, they begin a lifetime journey toward teaching experts. Such progressions necessitate departmental partnerships for access to discipline-specific academic and pedagogical content (Ronkowski, 1998) and university-wide programs for knowledge and resources in teaching and learning (Mintz, 1998). The model's outer layer depicts this study's key stakeholders, comprising the STEM graduate student as future faculty, his or her faculty mentor (Kost, 2008; Park, 2004), other graduate students as peer mentors (Davis & Kring, 2001; Harris, Froman, & Surles, 2009), the course instructor, and their graduate dean.

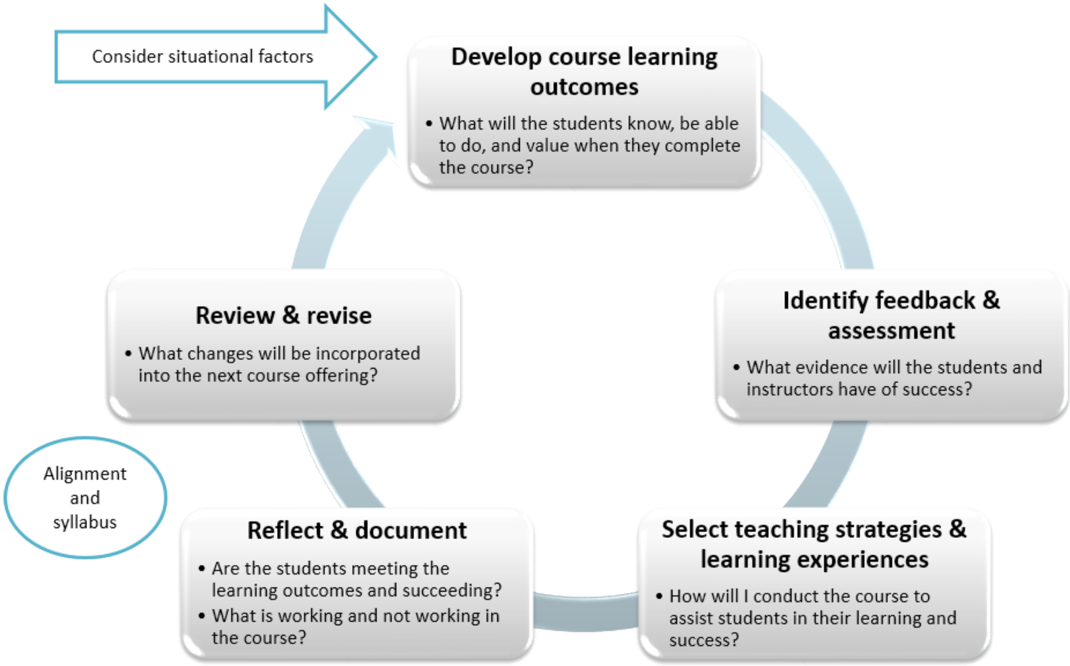

Figure 2. Course design cycle (Fowler et al., 2011).

Course Design Cycle

In addition, instructors used the university's teaching development center's five-step course design cycle (see Figure 2) to design the STEM teaching development course. As part of the course, they also presented the cycle to STEM future faculty as an instructional design tool for their course assignments and future teaching activities. Guided by the model and cycle as a framework, instructors developed and created teaching opportunities within a new STEM course.

STEM Teaching Development Course

To foster STEM future faculty's progression from teaching novices toward teaching experts, the university's teaching development center and two STEM-related colleges (engineering and science) partnered to create and facilitate a STEM teaching development course. The teaching development center provided instructional design, cofacilitation, and expertise in general pedagogy. Graduate deans in the participating colleges secured funding from the university's graduate studies office to support the course. In some cases, the funding compensated students or programs for lost research assistant time because most participants were advanced doctoral students actively involved in research projects. In addition, the graduate deans recruited STEM faculty as expert mentors to create teaching opportunities within their courses and guide the novice STEM future faculty. This mentor–novice pairing was central to the course's design, and faculty mentors cofacilitated with instructors to deliver discipline-specific pedagogy and content. The resulting one semester credit hour, blended learning course met six Friday afternoons throughout the spring semester in a 2-hour workshop format, which was supplemented with online learning content, group learning activities, and discussions.

Following the course design cycle (see Table 1), instructors prepared by analyzing the STEM teaching development course's situational factors, specifically the context of the course, institution, environment, students, and instructor (Fink, 2005). For course design, they first developed four learning outcomes. Second, to assess such outcomes, they identified feedback and assessment methods (described below). Third, they selected teaching strategies and learning experiences, including lecture, activities, small- and large-group discussion, reflective writing, and designing and teaching a lesson. After verifying the alignment of learning outcomes, assessments, and strategies or learning experiences, instructors finalized the course syllabus (see Table 2 for topics and essential questions). Fourth, instructors reflected on the course design process, their experiences, and STEM faculty assessments. Last, after verifying alignment among the steps and an organized syllabus, they conducted this study to enhance reflection and documentation, leading to course review and revision.

Course Assignments

The course included formative and summative course assignments. Formative assignments comprised a pre- and post-knowledge survey and Brookfield's (2006) Critical Incident Questionnaires to identify what aspects of each classroom session were most engaging, distancing, affirming, puzzling, and surprising to STEM future faculty. Summative assessments comprised four assignments (see Figure 3), which instructors graded using rubrics. The final course grade was pass or fail with pass defined as 75% or greater on the grading scale.

As the first assignment, STEM future faculty drafted a teaching philosophy statement prior to the course's second session that was based on session one and the assigned readings. As stated

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in the syllabus, "documenting your teaching philosophy is a highly reflective process regarding what teaching and learning mean to you" (Autenrieth & Fowler, 2012, p. 2). Two months later, the STEM future faculty finalized their teaching philosophy statements after receiving instructor feedback on the drafts, participating in additional course sessions, and completing their classroom teaching experiences.

Table 1
Course Design Cycle Applied to STEM Teaching Development Course

Course design cycle	Applied to STEM teaching development course design
Preparation: Situational factors (Fink, 2005)	Context • Course: Graduate-level elective in colleges of engineering and science • Institution: Large, southwest research institution • Environment: Classroom workshops and online • Students: STEM graduate students interested in positions requiring teaching experience • Instructor: Associate director of university's teaching development course, associate deans, faculty mentors
1. Develop learning outcomes	By the end of the course, STEM future faculty will be able to • develop a reflective and purposeful approach to teaching • develop a teaching philosophy statement • practice self-assessment and peer assessment of teaching • apply principles of integrated course design in the development of a course within their discipline
2. Identify feedback & assessment methods	• Formative assessments ▪ Pre- and post-knowledge surveys ▪ Critical Incident Questionnaires (Brookfield, 2006) • Summative assessments ▪ Drafted (15%) and final (15%) teaching philosophy statements ▪ Multifaceted classroom teaching experience (40%) ▪ Syllabus for proposed class in future faculty's discipline (30%)
3. Select teaching strategies & learning experiences	• Lecture • Activities ▪ Small- and large-group discussion ▪ Reflective writing ▪ Designing and teaching a lesson
4. Reflect & document	• Critical Incident Questionnaires (Brookfield, 2006) • Course assignments
Alignment and Syllabus	
5. Review & revise	• Instructor reflection • This study's findings • Course revision

Table 2
Session Schedule for STEM Teaching Development Course

Face-to-face session	Topic(s)	Essential question(s)
Session 1: Late January	• Course intro: What will the semester bring? • Knowledge survey • Course Design Cycle • Teaching philosophy	• Who are we as a cohort and how will that support our learning experience? • What do I know about college teaching and student learning? • How do we promote learning through informed course design?
Session 2: Mid-February	• Situational factors/learning outcomes • Blooms Taxonomy	• Who are we teaching? • What do we expect from them?
Session 3: Late February	• Intellectual development of scientists and engineers	• How does the intellectual development of undergraduate students effect how we teach?
Late February to late March	• Individual consultations with faculty and CTE (optional) • Classroom teaching experiences	• Where do I begin my design? • Who will I be teaching?
Session 4: Late March	• Assessment and rubrics • Student experiences/teaching methods	• How do we know when the expectations have been met and how do we communicate that to students? • How can we best utilize class time?
Session 5: Mid-April	• Reflection and feedback on our teaching • Teaching as research • Peer review	• How can we use reflection to integrate what we've learned and deepen our understanding of learning and good teaching?
Session 6: Late April	• Syllabus development • Final peer review—key learning experiences • Special topics	• How does the type of class influence how we teach? • How do we create an environment that is welcoming for all learners?

The second assignment, the multifaceted classroom teaching experience, was the course's central focus. STEM future faculty analyzed situational factors and used the course design cycle to create and implement a lesson for a course in their discipline. Specifically, they began by thinking about what they wanted students to learn during the lesson and formulated learning outcomes. Although it is challenging to incorporate feedback and assessment into one lesson, instructors encouraged STEM future faculty to do so in order to determine if students achieved the learning outcome. In addition, because teaching strategies tended toward lecture, instructors encouraged STEM future faculty to engage learners in some way during the lesson.

Most STEM future faculty implemented the lesson in their faculty mentor's undergraduate

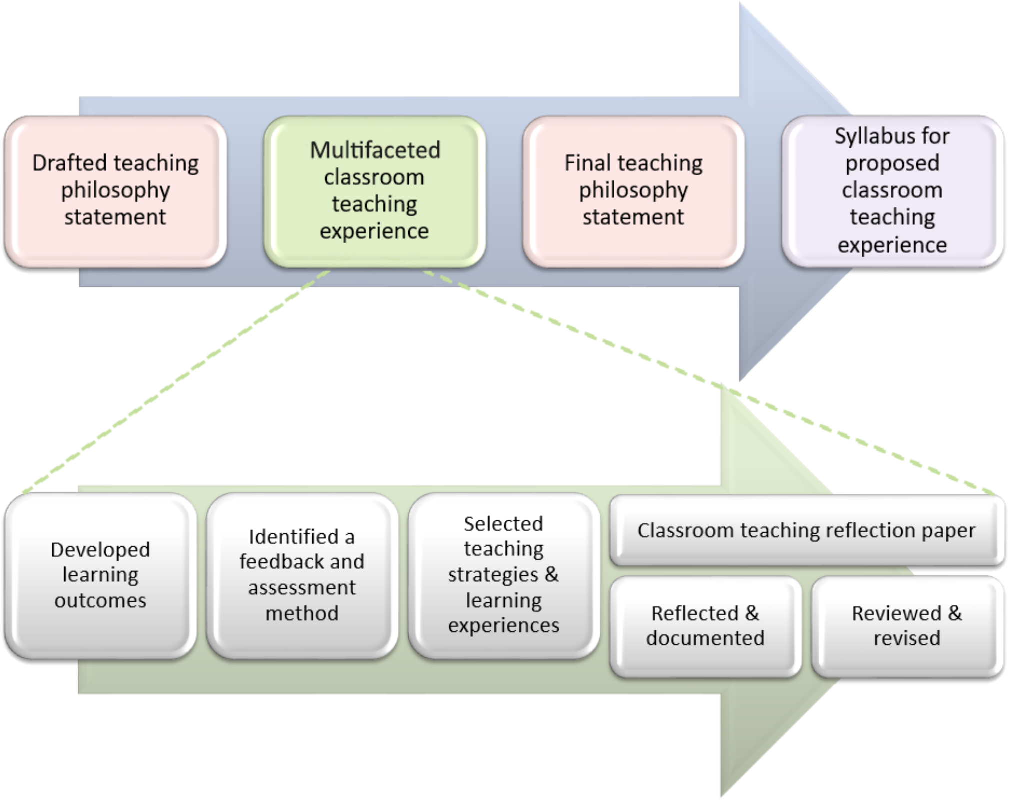

Figure 3. Four summative assessments for the STEM teaching development course (top arrow). The second assessment, multifaceted classroom teaching experience, included several components (bottom arrow).

classroom, but a few taught a graduate seminar or group of volunteer graduate students. STEM future faculty engaged in peer review, observing and providing feedback on the classroom teaching experience of at least two peers. As a result, each STEM future faculty member received feedback from two peers, the course instructors, and some faculty mentors. Last, STEM future faculty wrote a classroom teaching reflection paper based on their experience and feedback, including how they would teach the lesson differently the next time.

For the final assignment, STEM future faculty created a syllabus for a proposed discipline-specific course. In addition, they developed a rationale for the course and identified where it would fit into a larger program or degree. In addition to sharing information about a course, the syllabus facilitates instructor–student communication, including anticipating and addressing course issues (Eberly, Newton, & Wiggins, 2001). The syllabus assignment required STEM future faculty to begin with situational factors (Fink, 2005), develop learning outcomes, identify feedback and assessment methods, and select teaching strategies and learning experiences, including lesson content. Such course assignments inspired us to conduct this qualitative case study to improve the course and share findings.

Research Design

A qualitative case study methodology supported the study's purpose: to examine future faculty's perceived teaching development during a semester-long STEM teaching development course. Qualitative research seeks to understand the meaning-making process, how people make sense of their lives and interpret their experiences (Merriam, 1991). In this Institutional Review Board approved study (IRB2012-0029D), we were interested in understanding how graduate students perceived their teaching development construction and interpreted their teaching experience. Case study qualitative research explores a real-life bounded system over time (Creswell, 2013), in this study, that was the STEM teaching development course.

Course participants included 24 doctoral students who registered for the STEM teaching development course, 15 of whom participated in and completed the study. The doctoral students self-selected by registering for the course or were recruited by graduate deans or faculty members. The teaching development center and participating colleges intended the course to target advanced doctoral students who had passed preliminary exams and were nearing their dissertation defense. The resulting STEM future faculty participants represented the full range of doctoral students from finishing course work to defending proposals and dissertations to applying for faculty positions. In addition, 21 current STEM faculty members, eight of whom participated in the study, mentored the graduate students.

To examine STEM future faculty's perceived teaching development, data collection comprised the course's assigned classroom teaching reflection paper and a STEM future faculty focus group, which was supplemented by a faculty mentor survey. In the classroom teaching reflection paper, 15 STEM future faculty reflected on open-ended questions about their classroom teaching experience and peer, instructor, and mentor feedback. The following were questions from the classroom teaching reflection paper: (1) "What was the most significant thing you learned in the course," (2) "what did you learn by conducting the teaching session," and (3) "considering how the teaching session went, what would you do differently and why?" In addition, four graduate students participated in a postsemester focus group. During the 1-hour focus group interview, coresearchers used a semistructured interview guide to ask open-ended questions and recorded answers. Last, eight faculty mentors responded to an anonymous online survey consisting of open-ended questions at semester end.

Data analysis consisted of multiphase content analysis to interpret meaning from the collected data as well as systematic coding and identifying themes. To begin, we collected, organized, and read all the data in their entirety to gain an overall sense of the data. For the classroom teaching reflection papers, we identified individual item statements using Chi's (1997) process to quantify qualitative analyses of verbal data. Next, we used conventional and directed content analysis to systematically code and identify categories (Hsieh & Shannon, 2005). Specifically, for the first and second reflection questions, we used conventional content analysis with codes and categories emerging from the data. For the third reflection question, we manually used directed content analysis with codes and themes developed from relevant theory. Using the resulting coded individual item statements, we transformed qualitative data into quantitative data, represented by categories and counts of individual item statements. Similarly, for the focus group and survey data, we coded individual item statements and identified major categories; however, due to the small sample size, we did not perform quantitative data analyses. This data analysis resulted in the study's findings.

Discussion and Recommendations

The purpose of this study was to examine future faculty's perceived teaching development during a semester-long STEM teaching development course. The STEM teaching development course created opportunities for future faculty to teach in a classroom; engage with experienced

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STEM instructors, mentors, and deans; and begin their progression from teaching novice to teaching expert. Logically, asking STEM future faculty to design and teach a classroom learning experience would be beneficial to their pedagogical development, but how did they perceive their teaching development? This section discusses the findings, which are organized by three questions from the classroom teaching reflection papers, and offers recommendations.

Based on the data analysis, we identified three themes related to future faculty's perceived teaching development during a semester-long STEM teaching development course: (a) teaching confidence and skill development, (b) greater skill awareness than student awareness and self-awareness, and (c) a focus on knowledge-centeredness for future classroom teaching experiences.

Teaching Confidence and Skill Development

The first reflection question asked, "What was the most significant thing you learned in the course?" The main themes identified from the responses of STEM future faculty in this study were teaching confidence and skill development in instructional design, preparation, and facilitation (see Table 3). The faculty mentor surveys provided insight into how the course supported such teaching confidence and skill development. For example, according to faculty mentors, the course:

- "provided the tools for my student to be successful teaching in the future,"
- "gave [students] a broad overview of teaching and permitted them an opportunity to develop a course before they actually have to do it for real,"
- "improved their writing and encouraged them to think about their approach to teaching," and
- "helped [STEM future faculty] to be better prepared when going to the academic job market."

One faculty mentor highlighted the difference between *learning and teaching:*

> Students were able to see the amount of effort one can put into teaching and the positive payoff associated with that effort. They were also able to see that "learning" is not the equivalent of "teaching."

Table 3
Teaching Confidence and Skill Development

Theme		Select student excerpts
Teaching confidence		"Confidence, I can teach." "I have more confidence now." "I do have the ability and confidence to teach."
Skill development in	Instructional design	"Do not provide too much material." "Students appreciate interactive learning." "I would remove some slides to provide more time for discussion."
	Preparation	"I learned preparation is a lengthy process." "Prior planning is a must." "I learned a lot on how to prepare a course and some mistakes to avoid."
	Facilitation	"Speak s-l-o-w-l-y." "I kept a clock on my personal laptop to keep track of time." "Enthusiasm of the instructor can be motivating to students."

Note. Reflection Question 1: "What was the most significant thing you learned in the course?"

The next two sections describe specific findings related to awareness during instructional practices as well as attributes of designing environments for optimized learning.

Skill Awareness, Student Awareness, and Self-Awareness

The second reflection question asked, "What did you learn by conducting the teaching session?" The main theme identified from responses to this question regarded STEM future faculty's perceived skill awareness, student awareness, and self-awareness (see Table 4). Specifically, they reported greater skill awareness than student awareness and self-awareness. This question's greater skill awareness parallels the first reflection question's skill development. Although future faculty did perceived student awareness and self-awareness, future course enhancements could help to improve STEM future faculty's awareness in those two areas.

Student awareness is vital to designing learning environments, supports student achievement (Bransford et al., 2000), and contributes to new faculty success (Boice, 2000). Understanding students' prior knowledge (including preconceptions and misconceptions), expectations, and goals helps instructors design optimized learning environments by considering the diversity of learners. Furthermore, when future faculty become new faculty, classroom experiences are often the difference between success and failure in academia (Boice, 2000). For example, new faculty often do not connect with students, focusing on content and excluding the process of teaching and learning.

STEM future faculty could enhance their students' learning experiences by maintaining a purposeful awareness of students. To improve such student awareness, we recommend greater emphasis and time spent considering the situational factors: context of the course, institution, environment, students, and instructor (Fink, 2005). Furthermore, we recommend that STEM future faculty develop a data-driven decision-making approach to student awareness. Multiple data types can inform STEM future faculty's decisions regarding instructional approach, pace, and focus in the classroom. Specifically, systematic data application and analysis from low-stakes classroom assessments (Angelo & Cross, 1993) provide information about students' prior knowledge and reactions to content and instruction. For example, the background knowledge probe (assessing

Table 4

Three Areas of Teaching Awareness

Theme		% of individual item statements	Examples
Awareness	Skill	50%	time management, lesson planning, instructional methodology, technology-enhanced instructional practices, and facilitation challenges
	Student	30%	learning motivators, multimodal aspects of knowledge acquisition, attitudes and behaviors toward learning, and prior experience with the content material related to knowledge construction
	Self	20%	evaluative sense of self as related to personal speech patterns; personal assumptions, idealist expectations, and preferences (biases); confidence and assurance; and metacognitive practices

Note. Reflection Question 2: "What did you learn by conducting the teaching session?"

student's prior knowledge) and teacher-designed feedback forms (assessing students' reactions to content and instruction) may increase STEM future faculty's awareness of how students are experiencing learning and improve student success in the classroom.

Self-awareness is also instrumental in designing learning environments (Bransford et al., 2000). For example, Brookfield (2006) suggested "that skillful teaching is a highly variable process that changes depending on any number of contextual factors" (p. 17), including instructor beliefs and assumptions about and styles of teaching. To develop STEM future faculty's self-awareness, we recommend more proactive and deliberate instructional practices. Specifically, exercises supporting critical reflection may prove instrumental in increasing self-awareness in STEM future faculty. For example, the role model profile (Brookfield, 1995) asks instructors to think about an ideal teacher from the past and answer four questions about his or her teaching styles, abilities, and actions. Talking about teachers whom we admire and why we admire them alerts us to prescriptive assumptions that frame our teaching practice. In addition to responding to Critical Incident Questionnaires (Brookfield, 2006), as students in the teaching development course, STEM future faculty can use such questionnaires to collect, analyze, and reflect on formative feedback from their students. Last, engaging STEM future faculty in small- or large-group debriefs about critically reflective aspects of teaching may support the application of pedagogical theory in learning experiences. Although the nature may vary, these debriefs prompt STEM future faculty to discuss elusive questions such as "How are students experiencing learning in my classroom?" and "How effectively am I teaching?"

Knowledge-Centered Learning Environment

The third reflection question asked, "Considering how the teaching session went, what would you do differently and why?" Designing learning environments in higher education is significant and relevant to STEM future faculty's professional development in teaching. The Committee on Developments in the Science of Learning (Bransford et al., 2000) identified "four interrelated attributes of learning environments that need cultivation" (p. 23). Their framework for optimizing learning calls for: knowledge-centered, assessment-centered, learner-centered, and community-centered learning environments. Knowledge-centered learning environments support teaching in ways that lead to student learning, understanding, and transfer of such learning and understanding to new contexts. Assessment-centered learning environments offer students multiple opportunities for feedback and to revise assignments. Learning-centered environments incorporate students' skills, attitudes, and beliefs into the lesson cycle. Last, in community-centered learning environments, students feel connected to each other and the larger civic community related to learning. Expert teachers skillfully leverage all four attributes.

In this study, STEM future faculty predominately reflected one attribute, knowledge-centeredness, missing the other three attributes and the powerful interrelationship among all four attributes in designing learning environments (see Table 5). This could result in a distorted view of and approach to instructor and student practices in the classroom. To address this challenge, we recommend using intentional and deliberate practices to instruct students in the balanced design of STEM learning environments, including the effective management of all attributes. For example, to foster assessment-centeredness, we suggest reinforcing formative and summative assessments as part of the classroom teaching experiences. To foster learner-centeredness, we suggest applying recommendations from the earlier discussion of student awareness. Last, community-centeredness

Table 5
Four Interrelated Attributes of Designing Environments for Optimized Learning (Bransford et al., 2000)

Theme		% of individual item statements	Focus and opportunity
Centeredness	Knowledge	63%	STEM future faculty would augment one or more aspects of their learning environments related to knowledge
	Assessment	7%	Development opportunity
	Learner	3%	
	Community	3%	

Note. Reflection Question 3: "Considering how the teaching session went, what would you do differently and why?"

may have been low due to designing and facilitating a single classroom teaching experience. To foster this attribute, we recommend adding a more explicit community learning experience in the STEM teaching development course and incorporating a community learning experience into their classroom teaching experiences.

Additional Course Recommendations

Based on the findings and our teaching reflections, we recommend four additional course design changes to enhance STEM future faculty's teaching development. First, to increase faculty mentor and peer mentor interaction, incorporate small-group discussion during the six face-to-face sessions. Small-group discussions create opportunities for STEM future faculty to ask questions and share ideas. Second, increase the number of teaching opportunities from one to two by having STEM future faculty teach their small groups a current teaching and learning topic during class time in addition to their discipline-specific lesson. Third, videotape the classroom teaching experience and utilize stimulated recall to facilitate STEM future faculty's review, self-reflection, and discussions with their faculty mentor. Videotape review will assist STEM future faculty in identifying their implicit beliefs about teaching that could influence their classroom teaching (Meade & McMeniman, 1992). Last, we recommend assigning an e-portfolio with reflective prompts to house a student's course artifacts, enhance student reflection throughout the course, and provide evidence of teaching. Based on the study's findings, we offer implications and directions for future research.

Implications and Future Research

The STEM teaching development course case study offers implications for theory and practice and directions for future research. In regard to theory, the study expands the literature beyond teaching assistants to include nonteaching graduate students and the novice to expert literature with a focus on teaching in general and graduate students specifically. In regard to practice, the study contributes to instructional design in graduate student professional development in teaching. The course is an example of how to create learning opportunities for future faculty teaching novices as they develop towards teaching experts. Directions for further research includes similar studies within and beyond the STEM fields of future faculty development in teaching. Such studies may include using different combinations of the conceptual model's components for graduate student professional development in teaching, for example, various or additional teaching strategies and methods. Furthermore, execution of the additional course recommendations discussed above merits further study.

Conclusion

In summary, graduate school is an important time for future faculty to develop teaching skills, but teaching opportunities are limited. Discipline-related course work and research do not provide the pedagogy, strategies, and skills to effectively teach and compete for higher education jobs. When future faculty become new faculty, efficient and effective teaching saves time and supports success. In addition, STEM future faculty will influence the future of science, technology, engineering, and mathematics. The purpose of this case study was to examine future faculty's perceived teaching development during a semester-long STEM teaching development course. Findings included STEM future faculty teaching confidence and skill development in instructional design, preparation, and facilitation; greater development in skill awareness than student awareness and self-awareness; and a focus on knowledge-centered development for future classroom teaching experiences.

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