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

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Abstract

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

Keywords: Teacher education; Technology and engineering education; STEM

Introduction

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

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

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

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

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

DeJarnette (2012) noted that

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

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

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

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

Review of Literature

Importance of STEM Education

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

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

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

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

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

Why Deliver STEM in the Elementary School?

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

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

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

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

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

In secondary education,

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

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

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

Kelley (2010) noted that

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

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

University of Arkansas STEM Education in Elementary Teacher Education

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

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

The second course, Creativity and Innovation in STEM Education, is an introductory course in technology and engineering education, which focuses on the development and introduction of technology and engineering-based activities to support science and mathematics instruction in the elementary classroom. Through hands-on, project based learning challenges, students develop an understanding of the engineering design process and the integration of science, technology, engineering, and mathematics (STEM) often used to solve real-world problems. Students are exposed to the process of engineering design, invention and innovation, trouble-shooting, technical and procedural processes, research and development, and experimentation. They are also given the opportunity to learn about the tools, materials, and processes needed to implement project-based learning using engineering design challenges to strengthen student understanding of mathematics and science concepts.

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

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

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

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

Collaboration and Synergy

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

Conclusion

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

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

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