SUPPORTING ELEMENTARY AND MIDDLE SCHOOL STEM EDUCATION AT THE WHOLE-SCHOOL LEVEL: A REVIEW OF THE LITERATURE

By: Ashley Chiu, M.S., C. Aaron Price, Ph.D, Elsie Ovrahim, M.Ed, Museum of Science and Industry
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"SCIENCE, ENGINEERING, AND TECHNOLOGY PERMEATE NEARLY EVERY FACET OF MODERN LIFE, AND THEY ALSO HOLD THE KEY TO MEETING MANY OF HUMANITY'S MOST PRESSING CURRENT AND FUTURE CHALLENGES."

- The Framework for K-12 Science Education
(National Research Council [NRC], 2012, p.16).

INTRODUCTION

The STEM acronym usually represents the subjects of science, technology, engineering, and mathematics. However, STEM as a concept is not limited to those subjects. It often includes other domains such as social studies, English language arts, art, and more (Bybee, 2010; Sanders, 2009). The basis of STEM education involves integration of these subjects by breaking down the "silos" of discipline-independent teaching that students often encounter throughout the day, and making connections to the context of the real world (National Academy of Engineering and NRC, 2014). STEM education at all schools can help achieve the goals of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and the Next Generation Science Standards (NGSS), the new science education standards that many states in the U.S. have adopted or are in the process of adopting. Schools often approach STEM education in their own ways due to their own unique populations, challenges, and needs. No single school strategy has risen to the top. However, synthesizing lessons from many of those schools may begin to tell a story about how STEM education can be supported in this time of national education reform.

The informal education sector, including museums and science centers, is a critical component in the overall ecosystem of STEM education (NRC, 2009). One key area informal institutions contribute to the ecosystem is through teacher professional development. The Museum of Science and Industry, Chicago (MSI) teacher professional development program, called the Institute for Quality Science Teaching (IQST), offers a rotation of five different science content courses in the domains of life, physical, earth, environmental and space science. In the last nine years, 913 teachers have participated in these in-depth, multi-session courses. By delivering content instruction, modeling research-based pedagogical practices, and providing the physical materials required to implement hands-on science lessons at school, the IQST program model empowers teachers to immediately transform their classroom instruction. MSI collaborates with the nation's third largest school district, the Chicago Public Schools (CPS), neighboring school districts, and private schools in the area. A research study conducted in partnership with the Educational Policy Center at Michigan State University found that the teacher course focusing on energy (physical science) increased teachers' content knowledge and teaching strategies, while also improving students' learning (Rodriguez, 2014; Schmidt & Cogan, 2014).

One of the key lessons learned from IQST is that supporting STEM education means supporting the entire school. As a result, MSI is developing a new program to advance school leadership in science education — the Science Leadership Initiative. The Science Leadership Initiative will address the role of administrators, teacher leaders, and other important stakeholders to ensure every child attends a school that demonstrates exceptional science education. The primary goals of the Science Leadership Initiative are to:

1. Use a "School Support Tool" created by MSI to help K-8 schools gauge their current state of science education and plan next steps.

2. Develop a rewards and recognition

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program for schools that are doing the work of science education reform through the use of MSI's School Support Tool and process.

3. Design additional supports to aid in the success of improving schools, such as strategic professional development targeted at principals and teacher leaders.

Utilizing advisory committee feedback, an extensive literature review on best practices, and surveys of administrators and teachers, the project team is developing a School Support Tool to serve as a primary resource for schools to access and utilize the most significant literature on STEM identified by MSI. The School Support Tool will serve as an information-rich self-assessment for K-8 schools to gauge their level of support of science education.

This white paper is one of three such papers describing the Science Leadership Initiative project. This paper will provide an in-depth explanation of the methods of the literature search and provide a review of the literature used to inform project development and development of the School Support Tool. More information on this project can be found in two other white papers.

The primary questions used to guide the literature review were: "What research-based literature (i.e. supported with empirical studies) exists about what is needed to develop exceptional K-8 STEM education, and how can STEM programs be used as a vehicle for achieving scientific literacy?" Schools looking to support or increase STEM education need to know where to begin, what supports are needed, and from whom they can learn. The search for relevant literature began by using specific key words relating to the research questions, including "characteristics of effective STEM schools," "STEM education perceptions," and "components that support STEM education." Various combinations of these key words and phrases were used with established scholarly indices, such as ERIC, Google Scholar, and university library search engines, focusing on literature with empirical, research-based evidence. Articles published in the year 2000 and later were prioritized. Terms such as "quality," "effective," and "exceptional" were included in search vectors to understand what research has defined these terms to mean. We have identified a total of 52 qualifying publications.

For this project, we have chosen to focus on research supporting K-8th grade education. In order to build the knowledge base for students to be successful in high school, the new Next Generation Science Standards (NGSS) now include a set of performance expectations regarding different core concepts for all grades through the creation of four grade bands (K-2, 3-5, 6-8, and 9-12). Also, within its structured programs, MSI has chosen to focus in large part on the primary grades, with a specific target of 4th to 8th grade teachers—a critical time when science becomes more challenging and many of the teachers in those grades do not have strong science content backgrounds or science teaching expertise.

Eight categories of focus within the literature emerged in our synthesis: Values, Collaboration and Planning, Curriculum and Instruction, Professional Learning, Communication, Technology, Partners, and Money. These categories are based on an analysis of the research literature as well as focus groups held with key project stakeholders and leaders. The Science Leadership Initiative's School Support Tool is organized into eight corresponding Essential Elements that are needed to support science and STEM education at a school. These eight Essential Elements from the School Support Tool are being used to structure this literature review (a categorization of the literature can be found in Appendix A). The fundamental, yet consistent, suggestions from the literature review on how to support STEM education in K-8 schools are being incorporated into our program development process, while simultaneously highlighting directions for future research for the research community.

LITERATURE REVIEW: VALUES

The concept of "values" evokes a variety of definitions. For the purposes of this paper, it is defined as establishing a school culture emphasizing shared beliefs, norms, and support of STEM education. For this to occur, schools and districts need to create a shared culture for both science and learning. One driver of this is the school's mission and/or vision statement. A comparative case study of characteristics of 10 STEM-focused high schools found that their mission statements had an overall impact on school culture (Scott, 2012). When comparing successful STEM schools, Scott (2012) found that although the mission statements between the 10 schools were different, there was a clear connection to the mission statement and the characteristics of the programs that each school provided. The Opportunities Structures for Preparation and Inspiration in STEM (OSPrI) project out of The George Washington University has provided an in-depth look at one type of STEM school, the Inclusive STEM High School (ISHS), which has been successful at bringing opportunities to underprivileged students and underrepresented minorities (Lynch, Behrend, Peters-Burton, & Means, 2013; Peters-Burton, Lynch, Behrend, & Means, 2014; Spillane et al., 2013). These ISHSs design new school models in the context of their individual local communities, with the help of parents. They have specific mission statements and goals, along with student supports that provide new opportunities for their underrepresented student populations to achieve success (Lynch et al., 2013). These examples indicate the driving force that such mission and vision statements provide for the overall school culture, and ultimately, the influence they have on the programming they offer to their students.

Next to a mission and vision statement for the school, an important driver toward the creation of any kind of school culture is school leadership. A longitudinal study published by the Consortium on Chicago School Research at the University of Chicago (CCSR) specifically highlights principal leadership and its impact on school success or stagnation (Bryk, Sebring, Allensworth, Luppescu, & Easton, 2010). Leithwood, Harris, and Hopkins (2008) assert that school leaders—in particular principals—improve teaching and learning through their influence on staff motivation, commitment, and working conditions. Principal effectiveness plays a large part in school effectiveness and in student performance (Leithwood & Riehl, 2003; McCollum, 2012; Rice, 2009). Support of science and STEM education is more successful when principals drive and support the school components and change needed in schools. A principal can work to improve student learning in science through a variety of means, including advocating for science time in the school day, providing money for science equipment and lab space, or holding professional development to increase teacher knowledge and effectiveness—whereas a principal who does not support science or science learning could do just the opposite.

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An overarching sense of community and safety is another important aspect of the school culture important to successful STEM schools. Focus group and interview transcriptions of a study of six STEM schools showed that a school culture that supported its students and its faculty helped to build student identity, establish a sense of community, and help students feel comfortable asking for assistance (Bruce-Davis et al., 2014). The OSPrI project also found that academic and affective support were key at successful STEM high schools because the students who attended these schools may also need additional support to navigate the challenging learning environments of an advanced STEM high schools (Spillane et al., 2013). Lastly, in a case study describing conflicts in developing an elementary STEM magnet school, a school district found that a lack of articulated vision held their staff back from creating a standards-based STEM curriculum. Only after school staff participated in a vision-building exercise were they able to take ownership of the process of reform in their school (Sikma & Osborne, 2014). Maintaining the school culture is important, and creating norms and additional supports to assist students and school staff is important for that maintenance to occur.

Schools aiming to become STEM schools or incorporate STEM curricula look to successful schools as models. However, most models of STEM programs that exist are focused on high schools. There is scarce information on STEM at the elementary level because the most common model of instruction in elementary schools is self-contained, where a single classroom teacher teaches all of the subjects within the day (Hansen, 2013), thus not supporting specialization. The early years are critical for STEM teaching and learning, but are given low priority in discussions about STEM education (C-STEMEC, 2013). Cotabish, Robinson, Dailey, and Hughes (2013) describe elementary teachers as being the “gatekeepers to fostering the gifts and talents of future STEM innovators” (p.216). We found no documented research about effective models of STEM-focused elementary schools.

Lastly, while the creation of a school culture for science and learning is important, the creation of this attitude must also be cultivated amongst the students. Ejiwale (2013) stated the lack of inspiration of students as a barrier to successful implementation of STEM education. This was echoed by the President’s Council of Advisors on Science and Technology (PCAST) in their 2010 report (PCAST, 2010). They conclude that our nation must focus on preparation and inspiration of our students in order to improve STEM education. Specifically, they emphasize the need to prepare all students to be proficient in STEM, including girls and minorities that are underrepresented in these fields, as well as to inspire these students to learn STEM and motivate them to pursue careers in these fields. The creation of a school culture supporting science education is important for the initiation of whole-school science education reform. However, to sustain the school culture, the importance of science learning, the application of science, and its future for students, this attitude of inspiration must be reflected and cultivated within school staff and all students.

Because STEM is not discipline- or place-specific, all teachers can participate in the planning and implementation of a STEM curriculum, regardless of their content area of instruction. Basham, Israel, and Maynard (2010) suggest that teachers should work together as a team to make instruction authentic, rather than in individual classrooms. Brown, Brown, and Merrill (2011) introduce the idea that science, technology, engineering, and math teachers teach multiple concepts that lend themselves to possible collaboration on a daily basis. They note that there are common characteristics and content that unite the STEM disciplines, especially in science and technology, which establishes the need for collaboration and ways for these teachers to work together within schools. In a case study of teachers participating in a year-long professional development program on STEM integration, one teacher felt that he needed to work together with teachers in other STEM disciplines because he taught mathematics (Wang, Moore, Roehrig, & Park, 2011). He wanted a networking system with other teachers so that they could align classes to build STEM challenges or projects together and better integrate STEM into their required curricula.

Teachers should understand the value of collaborating with other teachers around evaluation of student work. This collaboration can help teachers understand preconceptions or misconceptions of students and make decisions on adapting instruction. Collaboration time is essential for systemic, sustained, and positive changes to occur (DePaul, 2013). Several subjects have areas in which natural overlap occurs and connections can be made.

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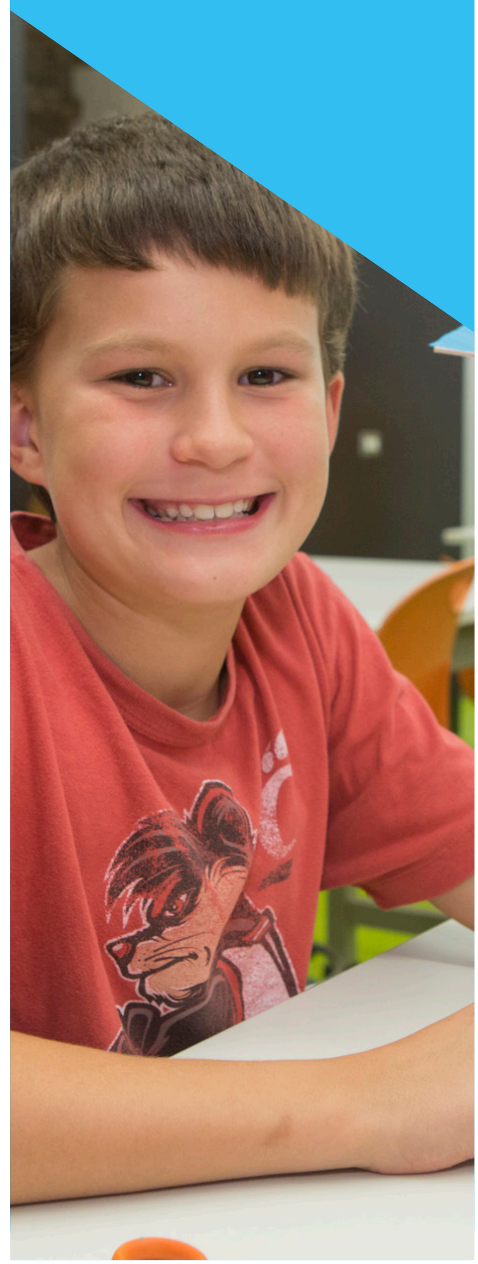

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Since teachers have different professional backgrounds and qualifications, it is important for schools to provide support and time for collaboration. Teachers of different disciplines should work together to ensure they are maximizing student learning and reinforcing similar concepts and information in different classes (Stohlmann, Moore, & Roehrig, 2012). Goddard et al. (2010) argue that productive teacher collaboration is greater when principals engage in instructional leadership, monitor classroom instruction, and share leadership with teachers. Administrator willingness to share leadership responsibilities with teachers helps to optimize school success (Sublette, 2013). Teacher leaders can also help drive whole-school change through collaboration with leadership at schools, mentoring of other teachers in their departments, and leading professional development. Working together is key for understanding what and how others teach specific concepts, and is important for understanding overall student knowledge. In the "real world," life is not subject-specific. Teacher collaboration is a step toward the integration of disciplines, better mirroring what actually happens outside the classroom.

CURRICULUM + INSTRUCTION

The curriculum that is utilized in a school and its instructional practices are important pieces to look at when considering student achievement. STEM educational strategies must move beyond discipline-specific education. Integrating all disciplines offers students the opportunity to make sense of the world in an authentic way (Basham, Israel, & Maynard, 2010). Integration of STEM fields across the curriculum is one of the main consistent characteristics of STEM education, but the literature has not united around a specific way for its integration. The NRC (2011) states that, "Effective instruction actively engages students in science, mathematics, and engineering practices throughout their school (p.18)." They cite inclusive STEM schools as being successful because they provide students with opportunities to learn science, mathematics, and engineering by addressing problems that have real-world applications. STEM-focused career and technical schools and programs are also successful because they use unifying themes such as engineering as a mechanism for making content relevant.

The 2014 joint National Academy of Engineering and the National Research Council report states that advocates of more integrated approaches to K-12 STEM education argue for teaching STEM in a more connected manner, and they provide limited contextualized examples of how schools have done so. They also argue that placing STEM in the context of real-world issues makes the subjects more relevant to teachers and students. Bruce-Davis et al. (2014) identify two current curricular and instructional strategies and practices of six STEM high schools as real-world problem solving (Problem-Based Learning) and challenging students through questioning. STEM schools have been successful at integrating STEM across the curriculum by integrating science and engineering. Instructional materials aligned to the NGSS to implement science curriculum are carefully constructed to align with the three dimensions of the *Framework* (Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas) over a period of time. The curriculum selected should have a coherent storyline connected to the real world to allow students to develop a conceptual framework within which to organize their understanding of science (DePaul, 2013). To aid in this process of integration of NGSS, Achieve and the US Education Delivery Institute published an Adoption and Implementation Workbook for states to use to guide the adoption and preliminary implementation of NGSS in their state and eventually in their schools (Achieve, 2013). Teachers should use practices true to the NGSS and diverse instructional strategies, drawing upon literacy and mathematical practices outlined in the Common Core State Standards (CCSS) to reinforce the interconnected nature of science with other content areas. Science teaching is inherently related to student learning in literacy and mathematics, and the NGSS draw specific connections to the CCSS-English Language Arts and Math and are philosophically aligned (DePaul, 2013).

A specific challenge to advancing STEM education is actively incorporating technology and engineering into school programs (Bybee, 2010). The scale at which technology and engineering appeared in school curricula is generally quite low and Bybee (2010) suggests scaling up the courses and appropriately including them in science and math education. Stohlmann et al. (2012) are also in favor of integrating engineering into curricula. They wrote that, "Engineering is becoming more prevalent in K-12 schools and can provide great problem solving opportunities for students to learn about mathematics, science, and technology while working through the engineering design process (p.30)." An example of one such implementation is in the Dayton Regional STEM Center's STEM Education Quality Framework engineering design process (2011). It includes 10 STEM learning quality components that are important elements in creating quality STEM-learning experiences. The design of this framework helps educational leaders to conceptualize and communicate around STEM-learning by making informed decisions and initiating collaboration between educators and STEM professionals.

In the classroom, constructivist approaches, problem-based learning, and making connections to the real world often characterize effective STEM education when implemented using

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inquiry-based strategies. Techniques such as active learning and forming cooperative learning groups are central to achieving the most important outcomes of STEM (Smith, Douglas, & Cox, 2009). Other curricular and instructional strategies that were found to be effective include questioning techniques, guided independent research studies, and discussion groups (Bruce-Davis et al., 2014). Adoption of a STEM-focused curriculum, reform instructional strategies, project-based learning, and integrated and innovative technology are in use by independent STEM high schools (Lynch et al., 2013; Peters-Burton et al., 2014). Reviews of elementary schools with successful STEM emphasis demonstrated that improved student learning in mathematics and reading shared five common elements: professional capacity of faculty and staff, parent-community ties, a student-centered learning climate, and instructional guidance (NRC, 2011).

DePaul Science Working Group (2013) found that a hallmark of a high-quality science education includes teachers making authentic assessment practices a priority, with the understanding that science is not about getting the "right answers," but rather about developing an understanding of the natural world by using evidence to support claims and engaging in the critique of scientific ideas. Additionally, the most effective way to assess students is through the use of classroom-based authentic assessments that can be implemented in everyday instruction.

These techniques do not seem specific to STEM learning; rather, these can be used in any classroom or school to better engage students. The literature that we found lacks explicit examples of successful problem-based or inquiry-based learning content for teachers to use within the classroom. New standards have been adopted by many states and given to teachers to implement within the classroom, without full understanding of their structure or their purpose. Additionally, the literature suggests integrating STEM into the curricula, but does not give examples of specific curricula for schools to adopt that integrate STEM within the school. Examples like Project Lead the Way and Engineering is Elementary provide ways to integrate STEM, but are limited to the subjects, units and lessons they provide. Much of the literature regarding curriculum and instruction offers broad suggestions and recommendations for schools to follow, but provides limited examples or ways for schools to move forward.

PROFESSIONAL LEARNING

Stem Problem-Based Learning involves a shift from a teacher's role as transmitter of knowledge to facilitator of knowledge, in order to help students identify and utilize relevant sources to solve real-world problems (Asghar, Ellington, Rice, Johnson, & Prime, 2012).

Education is constantly changing, and continuing education/professional development is one way of staying up-to-date on the most current knowledge and practices. Effective STEM programs also place an emphasis on teacher preparation and education (NRC, 2011). Typical elementary education preparation programs require pre-service teachers to complete only two math and science courses and the shift to an integrated curriculum requires teachers to have broader content knowledge and expertise than what was previously needed (Nadelson et al., 2013). One barrier to successful STEM education is the lack of investment in the professional development of teachers to build a strong knowledge base in science, which has been attributed to poor student performance (Ejiwale, 2013). Professional development offered to and sought out by teachers enables them to acquire new knowledge, apply it to their practice, and reflect on the results with colleagues (DePaul, 2013). Different types of professional development can help better prepare teachers by increasing their confidence and efficacy for teaching STEM, as well as their perceptions. Peer coaching coupled with inquiry-based practices in the classroom has been linked to higher student achievement (Cotabish, et al., 2013). Other key features of professional development include a dedicated time set aside for teacher training, the encouragement of teacher leadership, and a collaborative nature (Sublette, 2013). Professional development programs can simultaneously help existing teachers develop deeper understanding of the subjects they teach while exploring mechanisms for integration across STEM and non-STEM disciplines (Wang et al., 2011).

Even deeper, there is the need for a broader discussion around individual and institutional barriers that science and math teachers face while learning and using integrative STEM Problem-Based Learning (PBL) in their practice. It [using STEM PBL] involves a shift from a teacher's role as transmitter of knowledge to facilitator of knowledge, in order to help students identify and utilize relevant sources to solve real-world problems (Asghar, Ellington, Rice, Johnson, & Prime, 2012). Common science-related professional development topics include inquiry-based science, science content and process skill development, and science content development and concept connections (Cotabish et al., 2013). Sustained professional development programs are reported to have a positive effect on teacher instruction and student achievement. These programs can also utilize a mentor or peer coach, allowing teachers to apply their learning in the classroom while being supported by a peer coach (Cotabish et al, 2013).

COMMUNICATION

Despite its ubiquity in education policy since its creation by the National Science Foundation (NSF) in the 1990s, STEM is an acronym that means many things to many people (Sanders, 2009). Most professionals in STEM-related fields lack an understanding of the term, and most who responded to a survey on "perceptions of STEM" linked it to "stem cell research" or plant anatomy (Bybee, 2010). Only 25% of the faculty body at a large university understood what STEM stood for, mirroring responses from the public and parents of school children (Breiner, Harkness, Johnson, & Koehler, 2010). Already, these statistics show a range of what STEM may mean to people. A survey of educational professionals in Northeast Tennessee found that educators have a variety of definitions of STEM, including varied and contradictory terms such as student-focused, integration, hands-on, and project-based education (Turner, 2013). Similarly, a study of over 200 teachers and administrators in the state of Illinois found that less than half understood the concept or could describe it. The teachers in STEM fields also had varying levels of understanding of STEM (Brown, Brown, Reardon & Merrill, 2011). A major finding of the joint project by Carnegie Mellon University and the Intermediate 1 Center for STEM education was that there is a need for greater awareness of all educators as they contribute to the preparation of our students to be STEM literate (Tsupros, Kohler, & Hallinen, 2009). Bybee (2010) refers to the use of STEM as, "The education community embrac[ing] a slogan without really taking the time to clarify what the term might mean beyond a general label (30)." STEM means something different to many people even within the context of a single school. There is a significant need for raised awareness at the administrator and teacher levels. FrameWorks Institute, an organization aimed at making research available and useful to non-profits working on societal issues, reports overlap and gaps between public and professional perceptions of STEM (Volmert, Baran, Kendall-Taylor & O'Neil, 2013). Overlap included the identification of science as an exploratory subject requiring hands-on, inquiry-based learning, STEM education being important for workforce development, and how informal learning settings can enhance STEM education. However, gaps in understanding between the populations included the public's perception of STEM as science, and not math, engineering, or technology. Children's perceptions also echo this disconnect. Surveys of grade 4-12 students show a lack of awareness of STEM careers, little opportunity to engage with STEM industries, and declining student attitudes in STEM subject areas (Wiebe et al., 2013; Mahoney, 2010). From the literature, it is evident that the term STEM has several meanings. Communication is key, and it should occur within the school and externally within the community and with families of students. In order to move forward with supporting schools, administrators, and teachers in implementing STEM education, all parties (even the most tangential) must understand what STEM means and then incorporate and educate their parents and community members.

It is evident that the term STEM has several interpretations.

TECHNOLOGY

The 21st century has brought many technological advances that transformed learning. The *Framework for K-12 Education* defines "technology" as all types of human-made systems and processes, not just modern computational and communications devices (NRC, 2012). Technology is not limited to computer and internet use, and students should have hands-on experiences with calculators, probes, scales, microscopes, etc. to enhance their capacity to complete tasks, solve problems, or manage projects (Dayton, 2010). Technology should be part of a school, and not just unique to a school looking to incorporate STEM. Computing technology should be pervasive in all disciplines and enhance learning. Technology is a tool (C-STEMEC, 2013) and schools need to understand what technologies teachers need to foster and enhance student learning and behavior, rather than compete with it (DePaul, 2013). Some teachers may need to be taught how to use technology in their classrooms as a means to integrate STEM (Wang et al., 2011).

Technology has the ability to support and enhance science education. Affordances of technology for science education include, but are not limited to, means of collection and analysis of data, effective ways of modeling and communicating results, and representing information in dynamic and interesting ways (Kim, Hannafin, & Bryan, 2007). Technology alone, however, is not sufficient for effective learning to occur; but, coupled with appropriate scaffolding from teachers and other experts, technology supports inquiry-based learning (Barab & Luehmann, 2003). Technology should not just be seen as an information resource for students, but as a multimedia environment that helps students establish learning environments that situate or contextualize the content being learned (Barab, Hay, & Duffy, 1998). This is transferrable from science education to other STEM disciplines and non-STEM subjects throughout K-12 education.

Few studies give explicit examples of use of technology to support STEM education at the whole-school level. Manor New Tech High School (MNTH), one of the original 32 T-STEM sites, has the goal of "transforming schools into innovative learning environments." MNTH emphasizes the use of technology that is both instructional and infrastructural. Part of their curriculum involves courses with technology as the "invisible tool," where students learn technology to do a project, activity, or job. Technology is integrated and blended into the fabric of the school (Spillane et al., 2013). A critical component of all ISHSs includes their integrated, innovative technology use (Peters-Burton et al., 2014). Hew and Brush (2007) found six main categories of barriers to technology integration at a school, and recommended that schools work from the ground up in creating a vision for the school and then articulating a formal technology integration plan, along with other suggestions on overcoming barriers. This is similar to how ISHSs incorporate technology into their schools.

There is limited literature on how technology supports STEM specifically. In contrast, there is a lot of research on how technology supports and enhances science education, one component of STEM. Technology is a main component of STEM education, not only being a part of its acronym, but important to 21st century learning. The literature search yielded many results providing vague definitions of what technology is and should be for STEM schools. Examples of how STEM schools are using technology within their schools can be generalized for non-STEM schools and for elementary and middle schools. The use of some technology in younger grades can pose a challenge for school staff, and some feel that it is not necessary or useful at these grade levels. While it would be rare to find an argument against having technology in classrooms and schools, the literature does not recommend having technology for the sake of having technology. Rather, it recommends having technology and utilizing it in specific ways to enhance and transform the learning practices of students.

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PARTNERS

Teaching and learning do not happen only within the walls of a school. Successful STEM programs have partnerships within the community, industry, businesses, and with different individuals. These partnerships have not only been identified as important to successful STEM schools, but also for promoting STEM and STEM careers and making connections between classroom work and real-world problems (Watters & Diezmann, 2013; Brown et al., 2011; Swift & Watkins, 2004). Partnerships with colleges and universities can help provide high quality science education aligned with the NGSS, especially with pre-service science teacher programs, professional development opportunities, and job-embedded learning and collaboration between teachers (DePaul, 2013). An example of such a partnership is between the University of Chicago's Center for Elementary Mathematics and Science Education (CEMSE) and the Urban Education Institute (UEI) with two Chicago area charter schools and seven Chicago Public Schools. This partnership explored professional development structures and mechanisms of support while implementing a new mathematics curriculum provided by the university (Leslie, 2011).

Partnerships with institutions such as museums, science centers, and businesses can provide schools with both in-school and extra-curricular opportunities to facilitate teachers' implementation of a STEM curriculum. Also, partnerships with families and the community helps to build an understanding of the rigor of science education and helps parents develop an appreciation of the beauty and wonder of science (C-STEMEC, 2013). Partnerships with businesses can provide schools with resources and opportunities for the study of science and engineering that are not available in the school setting alone (DePaul, 2013). Resources go beyond money, and a regional partnership can provide access to stakeholders that are able to pull together resources and expertise (Basham, 2010). Traphagen and Traill (2014) go beyond the classroom and school, and focus on cross-sector collaborations that provide STEM learning opportunities for students. These programs link the home, school, after-school/summer programs, and STEM-focused institutions to provide a STEM learning ecosystem. Schools can also find valuable partnerships within their community. Traphagen and Traill state that cross-sector professional development opportunities and communities of practices improve pedagogy and build knowledge among educators. Furthermore, work from the Center for Advancement of Informal Science Education (CAISE), an organization that works in collaboration with the Association of Science and Technology Centers (ASTC) in Washington, D.C., argues for the collaboration between formal and informal education contexts for the purpose of combining authentic, multimodal experiences over time at informal settings with the pedagogical expertise found in formal education (Bevan et al., 2010).

Partnerships that schools form outside of their walls provide many opportunities for students and teachers alike. Universities, industry, and different informal institutions and organizations support STEM learning in different ways, and provide students with different enrichment opportunities, teachers with different learning opportunities, and schools with grants and other monetary support, among many other examples. Partnerships enhance the capabilities of the school, and the literature reflects this in the many examples of partnerships that schools can form to support STEM learning.

MONEY

Education is an expensive endeavor. In the 2010-2011 school year, an average of over $12,000 in public funds were spent per student in the United States (U.S. Department of Education, 2013). While limited research literature exists on how to directly support STEM monetarily, the current education system may not have sufficient resources to provide quality STEM education for all students (Basham et al., 2010). The policy debates on this issue are vast, but the research at the whole-school level of funding and expenditures is limited. Rather, schools and states usually take a trial and error approach, using budgets from years past and political philosophies to guide their approaches.

From a federal perspective, a 2005 study by the Government Accountability Office (GAO) found that federal STEM education programs are heavily geared toward attracting college graduates into pursuing STEM careers. In fact, elementary and secondary students are the least frequent group targeted by federal STEM education programs (Kuenzi, 2008). The NSF's Directorate of Education and Human Resources (EHR) supports research on STEM learning and education from child to adulthood, including grades K-8. The fiscal year 2015 budget for EHR was $866 million. The EHR percentage of the overall NSF budget has been flat at around 12-15% over the last decade. Although budgetary pressures on the NSF seem to be more applied to their education programs than their core research programs (Gonzalez, 2012), it is interesting to note that only 3% of the $3 billion given to the NSF as part of the American Recovery and Reinvestment Act in 2009 was assigned to EHR.

Ejiwale (2013) admits that many schools are not equipped with the needed facility structure, tools, equipment, or required instructional media to adequately support STEM. Money is not allocated to all subjects and disciplines equally. At present, more money is used to support school initiatives and subjects that are deemed as more or most "important." Some examples are subjects that are weighted heavily by other standards, like language arts and mathematics (C-STEMEC, 2013). A full science program at a school involves expenditures like textbooks, lab spaces, equipment, materials, and curricula, which can quickly become costly. Allocating adequate levels of funding to prioritize STEM education, as well as maintaining this funding, is not only important for STEM education, but for all education.

DISCUSSION + NEXT STEPS

Several reports and studies highlight next steps to take in order to better incorporate STEM education into schools. Recent work by Bybee (2013) introduced a model pathway for successful STEM integration, which he refers to as progression from STEM 1.0 to STEM 4.0, with progression outlined by integrating the four subjects. A key component is the creation of an action plan in which goals and steps are clearly defined and laid out. Additional recommendations include devoting adequate instructional time and resources to science in grades K-5, assessing curricula and incorporating standards such as Common Core and NGSS, enhancing the capacity of K-12 teachers, and providing instructional leaders with professional development that helps them to create the school conditions that support student achievement, among others (NRC, 2011; C-STEMEC, 2013; NRC, 2013; Traphagen & Traill, 2014). Ejiwale (2013) identified 10 barriers to successful implementation of STEM education. Those that have not been previously mentioned include a lack of research collaboration across STEM fields, poor preparation of students, a lack of connection with learners, a lack of support at the school level, poor content preparation, delivery and method of assessment, poor laboratory facilities and instructional media, and a lack of hands-on training for students. He recommended addressing these barriers throughout K-12 education in order for STEM to achieve its goals and objectives. Another study highlighted the need for broader discussion around individual and institutional barriers that science and math teachers confront while trying to utilize integrative STEM problem-based learning in their curriculum (Ashgar et al., 2012). Several reports and studies also identify the need for a common definition of STEM education (Breiner et al., 2010; C-STEMEC, 2013; Bybee, 2010). Lastly, the Public Schools of North Carolina provide an example of a strategic plan for achieving high-quality STEM education through a set of priorities, aligned goals, and a set of recommended strategies in the shared public and private sector vision for STEM education (Public, n.d.).

This literature review was conducted with members of the Science Leadership Initiative team to understand what research exists on STEM education and learning. The purpose is to create a program with a clear and coherent research base to support schools, teachers, and administrators

There is not a clear definition of STEM education for grades K-8 and little research exists on elementary and middle school STEM education and pedagogy.

in providing students with a quality science education. Overall, the literature provides a framework for creating such a program. The confusion regarding what STEM is and means reflects the need for adopting a common definition as a first step to creating an understanding of the concept at all levels. Second, the identification of school components of successful STEM programs and schools will provide a foundation of items for which our program can support schools to realize their overall goals and outcomes for their students. Several different studies agree that a mission statement can be a driver for a school and staff to create an environment that is more conducive to STEM learning. Third, when it comes to delivery of STEM, teacher professional development is an avenue for better preparing teachers for the shift toward an integrated curriculum. Proven effective professional strategies include problem-based learning, inquiry-based practices, and peer coaching, which are specific to STEM. Key STEM-related professional development helps teachers to integrate between content areas. However, literature on better preparing teachers seemed to focus on teachers who teach in self-contained classrooms, while the content-specialized teachers were taught more inquiry-based practices due to their more focused content knowledge of the subjects. Although there were many studies on professional development programs as a whole, few studies were completed on programs that were sustained over a significant amount of time, which the literature cites as being the most effective. It is also difficult to generalize between different populations of schools. One must note that implementing characteristics that the literature has identified as hallmarks of high achieving schools in science and math does not equate to instant success or improvement. Rather, these characteristics can be targeted in existing schools to create a stronger and more successful overall school program. The literature (Bruce-Davis et al., 2014; Goddard et al., 2010; Harris & Hopkins, 2008; Leithwood & Riehl, 2003; McCollum, 2012; NRC, 2011; Rice, 2009) mostly suggests very generic characteristics as components that support successful STEM education. Characteristics such as professional capacity of faculty and staff and principal leadership, along with other findings do not seem very specific to STEM and it seems that these could improve any school, not just a STEM school.

Brown (2012) explored the research base of STEM education and found 61 articles that directly identified themselves as STEM education articles utilizing a number of different methods, addressing different outcomes, and studying various populations. This literature search, focused on the K-12 population, found results that mostly mirrored that of Brown (2012). Brown's work suggests that research should expand beyond the STEM education research base to help further inform faculty and teachers. Our review differs in that the focus is on grades K-8. There is not a clear definition of STEM education for grades K-8 and little research exists on elementary and middle school STEM education and pedagogy. Much of the STEM research focus is on high school and higher education. Although there is research on the perceptions of STEM of various populations (such as students, teachers, parents, and school administrators), further research could enable the generalizability to greater populations. The various studies that were identified did not fully disclose methodology and sampling processes. Further avenues for research include identifying STEM school components, examples of STEM school models, and effective STEM education specifically at the elementary and middle grades.

CONCLUSION

There are many different factors that go into supporting STEM education at a school. Each single factor alone is necessary but not sufficient to support STEM to achieve quality science education. As with the acronym STEM, the whole represents more value than just a sum of its parts, and a path for achieving successful STEM education has not currently been identified. At present, the literature is not united in its suggestions and findings regarding supporting STEM at the whole-school level. A review of over 50 research-based articles has yielded many different suggestions on how to support STEM education at the whole school level. This literature was categorized into eight different categories: Values, Collaboration and Planning, Curriculum and Instruction, Professional Learning, Communication, Partners, Technology, and Money. The amount of literature varied between the different categories, with a heavier presence in some categories over others. There are few consistent themes or best practices identified in the literature, but this process of of supporting STEM education at a school has been identified. Many avenues and opportunities exist for new research in this field.

As with the acronym STEM, the whole represents more value than just a sum of its parts, and a path for achieving successful STEM education has not currently been identified. At present, the literature is not united in its suggestions and findings regarding supporting STEM at the whole-school level.

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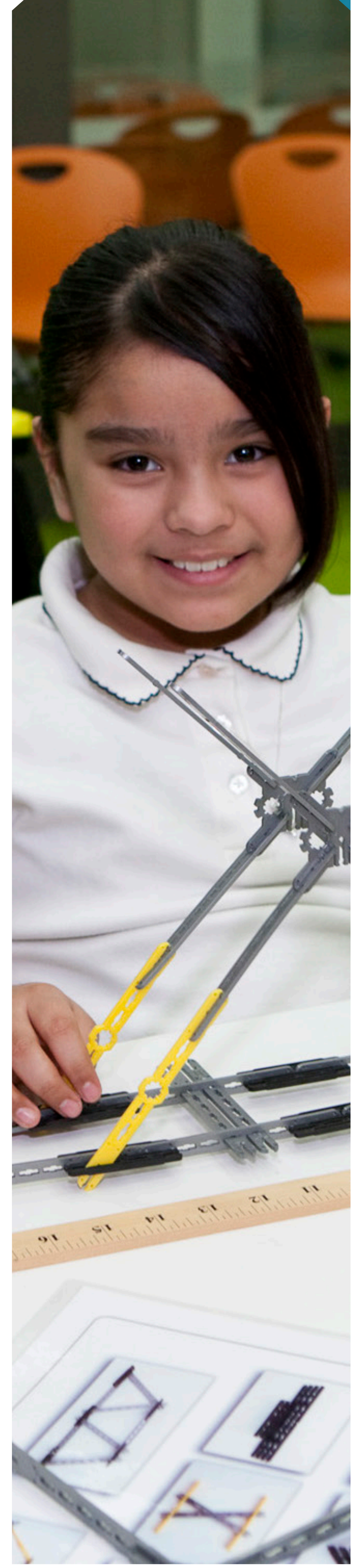

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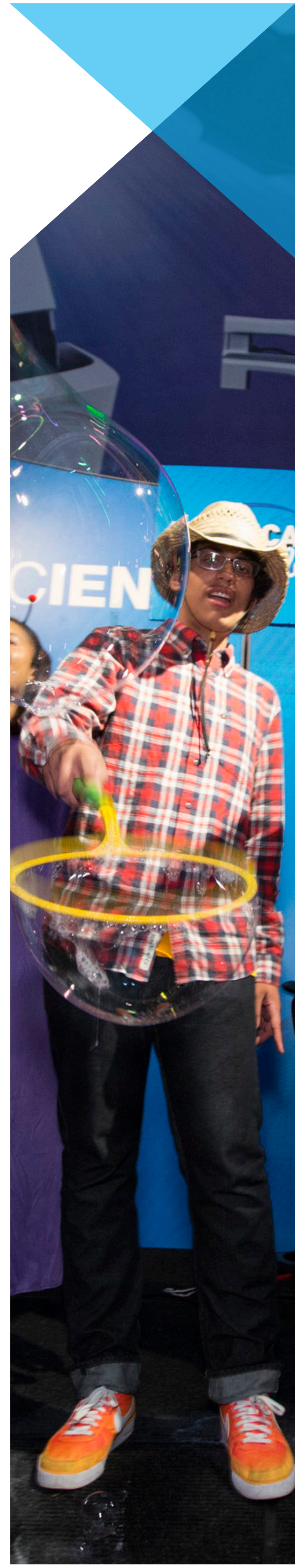

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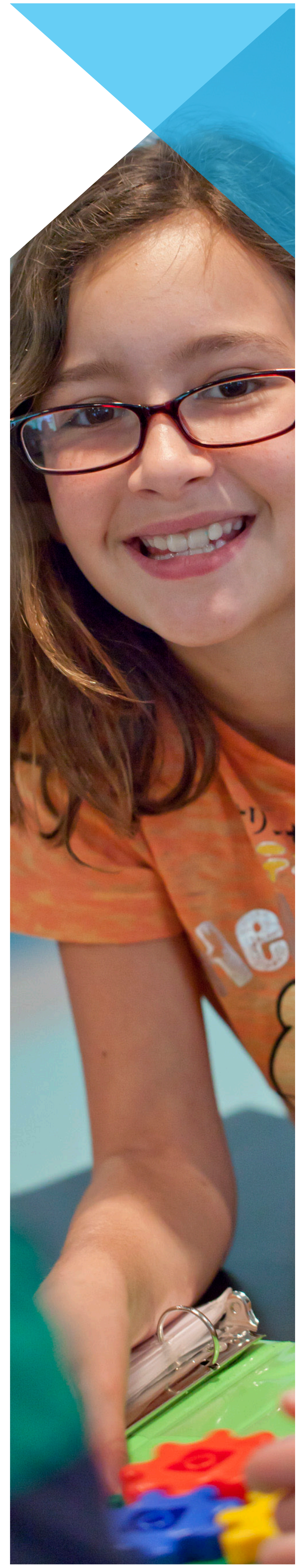

APPENDIX A: CATEGORIZED REFERENCES

VALUES	Bruce-Davis et al., 2014 Bryk, Sebring, Allensworth, Luppescu, & Easton, 2010 Cotabish, Robinson, Dailey, & Hughes, 2013 Ejiwale, 2013 Leithwood & Riehl, 2003 Leithwood, Harris, & Hopkins, 2008 Lynch et al., 2013 Lynch, 2014 McCollum, 2012 NRC, 2013 Peters-Burton, Lynch, Behrend, & Means, 2014 President's Council of Advisors on Science and Technology, 2010 Rice, 2009 Scott, 2012 Sikma & Osborne, 2014 Spillane et al., 2013
COLLABORATION + PLANNING	Basham, Israel, & Maynard, 2010 Brown, Brown, & Merrill, 2012 DePaul, 2013 Goddard et al., 2010 Stohlmann, 2012 Sublette, 2013 Wang, Moore, Roehrig, & Park, 2011
CURRICULUM + INSTRUCTION	Basham, Israel, & Maynard, 2010 Bruce-Davis et al., 2014 NRC & NAE, 2014 NRC, 2011
PROFESSIONAL LEARNING	Asghar, Ellington, Rice, Johnson, & Prime, 2012 Cotabish, Robinson, Dailey, & Hughes, 2013 DePaul, 2013 Ejiwale, 2013 Nadelson et al., 2013 NRC, 2011 Schmidt & Cogan, 2014 Sublette, 2013 Wang, Moore, Roehrig, & Park, 2011

COMMUNICATION	Breiner, Harkness, Johnson, & Koehler, 2010 Bybee, 2010 Mahoney, 2010 Sanders, 2009 Tsupros, Kohler, & Hallinen, 2009 Turner, 2013 Volmert, Baran, Kendall-Taylor, & O'Neil, 2013 Wiebe et al., 2013
TECHNOLOGY	Barab & Luehmann, 2003 Barab, Hay, & Duffy, 1998 C-STEMEC, 2013 Dayton, 2010 DePaul, 2013 Hew & Brush, 2007 Kim, Hannafin, & Bryan, 2007 NRC, 2012 Peters-Burton, Lynch, Behrend, & Means, 2014 Spillane, 2013 Wang, Moore, Roehrig, & Park, 2011
PARTNERS	Basham, Israel, & Maynard, 2010 Bevan et al., 2010 Brown, Brown, Merrill, 2011 DePaul, 2013 Leslie, 2011 NRC, 2009 Swift & Watkins, 2004 Traphagen & Traill, 2014 Watters & Dietzmann, 2013
MONEY	Basham, Israel, & Maynard, 2010 Ejiwale, 2013 Gonzalez, 2012 Kwenzi, 2008