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The Future of STEM Education

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Abstract

The purpose of this literature review is to examine what quantifies an elite STEM program, what criteria makes STEM education impactful for students, and where the future of STEM education may lie. Integrated STEM is a key aspect of STEM education. STEM perceptions and understandings must be clarified in order to move forward with STEM reform attempts. Learning by doing, using real-world contexts, is vital to the success of integrated STEM education. Successful STEM learning environments must also focus on student engagement and motivation, as well as the incorporation of social-emotional and 21st century skills. Teacher preparation and professional development cannot be forgotten when working towards best practices and the forward progression of STEM programs.

Keywords: integrated STEM, student engagement, 21st century skills, teacher preparation

The Future of STEM Education

STEM education is ill-defined, and even those involved in STEM-related careers often cannot adequately identify how STEM connects to their career, how they use STEM on a day-to-day basis, or the impact STEM has on their given field (Breiner et al., 2012). STEM education began in the 1990's, with the STEM acronym being coined by the National Science Foundation (NSF) (Sanders, 2009). Various theories and agendas over the past decades have not clearly defined STEM education, however the Next Generation Science Standards (NGSS) and Common Core are two recent reforms attempting to clarify and guide STEM education (Kelley & Knowles, 2016).

DoD STARBASE seeks to provide a premier STEM educational program for fifth grade students historically underrepresented in STEM (DoD STARBASE, 2019). The goal of the DoD STARBASE 25-hour program is to motivate students to explore future educational or career STEM opportunities through real-world explorations and experiences, including interactions with military personnel. DoD STARBASE looks to engage students, provide inquiry-based curriculum, and "hands-on, minds-on" lessons in STEM with direct ties to the standards yet remain exciting and innovative.

The STEM acronym labels four distinct fields – science, technology, engineering, and mathematics (Sanders, 2009). Although these four letters are linked together, historically the subjects continue to stand alone in education – even that labeled STEM education (Sanders, 2009). According to Sanders, integrated STEM education seeks to connect two or more STEM disciplines through various teaching and learning methods.

The Next Generation Science Standards (NGSS) are updated, research- and content-based standards (expectations) for what students should know and be able to do (Next

Generation Science Standards, 2020). These standards provide educators a direction to deliver learning experiences which stimulate student interest and prepare them for college, career, or social responsibility. Common Core was drafted in 2009 as a list of college- and career-ready standards for math and English language arts from students from grades K-12 (Common Core State Standards Initiative, 2020). The importance of Common Core was to create equally high standards consistent across the nation – clear expectations to match those of colleges and potential future employers.

The purpose of this literature review is to examine what quantifies an elite STEM program, what criteria makes STEM education impactful for students, and where the future of STEM education may lie – how STARBASE can continue to provide emerging STEM lessons and activities in an ever-changing world.

Literature Review

What is STEM?

Integrated STEM

Current trends and reforms point toward integrated STEM as a key aspect of STEM education (Kelley & Knowles, 2016), and research supports this assertion. The Next Generation Science Standards and Common Core Standards also affirm and encourage integration of STEM subjects (Kelley & Knowles, 2016). Kelley and Knowles define integrated STEM as incorporating two or more STEM subjects and using STEM practices in an authentic context which connects the content in a way which supports student learning.

STEM learning, using an integrated approach, acknowledges each subject can interact with and affect the others, which creates a view of STEM as an indivisible whole (Stergiopoulou et al., 2017). Stohlmann et al. (2012) recognize integrated STEM allows teachers to focus on connections and big ideas which are interrelated between content areas. Wang et al. (2011) clarify the difference between multidisciplinary integration and interdisciplinary integration. Wang et al. compares multidisciplinary integration to chicken noodle soup – different subjects are put together, yet the separate entities can still be identified, while interdisciplinary integration is compared to tomato soup – content areas are completely blended together.

Integrated STEM can deepen student understanding by creating relevant contexts for learning (Wang et al., 2011). Kelley and Knowles (2016) include relevant, stimulating, higher order critical thinking skills, problem-solving skills, and retention of learning as descriptive factors of STEM practices important to STEM education and integration of subject matter. Integrated STEM is also considered more relevant and stimulating as well as student-centered according to Stohlmann et al. Stohlmann et al. additionally include the impact on higher-level thinking and problem-solving skills, in addition to developing students to become innovators, inventors, self-reliant, logical thinkers, and technologically literate. True integration uses real-world problems, includes critical thinking, problem-solving skills, and making connections to relate to personal meaning (Wang et al., 2011)

Even though STEM reform efforts strive to provide clarity for STEM integration (Common Core State Standards Initiative, 2020; Next Generation Science Standards, 2020), preservice teachers, STEM educators, and STEM specialists still lack understanding or fall short of the goal. Radloff and Guzey (2016) surveyed preservice elementary STEM teachers and found only half defined or created a visualization which accurately integrated or connected the subjects, although almost all rated the STEM content areas as being connected. According to Shernoff et al. (2017), a portion of the teachers interviewed had integrated STEM prior to their study. Through interviews, Bell (2016) gathered statements from educators ranging from no knowledge of STEM, to surface identification of content areas, to full understanding and implementation of STEM. Holmlund et al. (2018) found most educators (including staff in traditional settings, staff in STEM focused schools, administrators, and STEM specialists/trainers) described STEM as either integrated or interdisciplinary.

In email responses to a question asking, “What is STEM?,” full-time faculty at the University of Cincinnati – amid a STEM movement including several initiatives – a portion disclosed they did not know or understand what STEM was (Breiner et al., 2012). Many listed one of the four STEM content areas, while less than half correctly included all four subjects (Breiner et al., 2012). Breiner et al. also found faculty mislabeled ‘M’ as medicine, used both math and medicine, or management. ‘E’ was also mislabeled as electronics (Breiner et al., 2012).

STEM Perceptions

Educators have varying viewpoints, perceptions, and attitudes towards STEM learning (Breiner et al., 2012; Wang et al., 2011). In a study by Breiner et al. (2012), even full-time faculty at the University of Cincinnati, including some working in STEM fields, did not realize how they use STEM on a day-to-day basis. A portion of staff surveyed stated STEM did not impact their lives, half listed personal connections to STEM through their careers, and a smaller number mentioned the connection STEM has to local, regional, national, or global societal issues (Breiner et al., 2012).

In a study by Wang et al. (2011), three teachers participated in a year-long professional development program on the topic of STEM integration. A sixth-grade math teacher, Nate, stated science, engineering, and math are all related – but only in the context of how STEM integration supported applying math skills in the real world (Wang et al., 2011). According to Wang et al., Nate only saw the value of integration if he were able to collaborate with other teachers as his focus was on mathematical content. Like Nate, many of those surveyed by Breiner et al. (2012) still compartmentalized STEM and other academic disciplines rather than making connections and working towards integration.

Wang et al. (2011) found Nate's colleagues on the other hand realized problem solving as a key aspect of STEM integration. Wang et al. discovered Nate's colleagues realized the need for student background knowledge in order to integrate subject matter and found integrating technology to be the most difficult. Nate's other colleague Amy discussed how science and math content knowledge helped students with engineering problem solving (Wang et al., 2011). She found students thought more independently, were more confident in their learning, learned to communicate, and increased teamwork skills through STEM integration (Wang et al., 2011).

Amy also stated in the research of Wang et al. how STEM integration could support learning in other subjects but struggled with how to incorporate more content from various disciplines into her own lessons.

Learning Theory

STEM learning has roots in cognitive learning theory, and research like that by Holmlund et al. (2018) use the idea of sensemaking or construction of knowledge as their basis. Holmlund et al. realized educators who put cognitive learning theory into practice employ real-world problem solving, authentic engagement, or opportunities for all students to participate in their implementation of curriculum. Bell (2016) relied on work by Vygotsky in using experiences to guide student understanding and construction of knowledge. Bell (2016) discovered the greater understanding and internalization of these theories of student construction of knowledge, the more likely secondary teachers were to provide true STEM education (active learning environment, learner focused, and problem solving), which ultimately fosters student learning. Kelly & Knowles (2016) regard situated cognition theory as a critical aspect of student learning – the physical and social context is directly tied to the development of knowledge.

Other researchers, like Strawhacker and Bers (2019), base their research on Piaget’s constructivism – students using their senses, as well as physical objects, to build knowledge. Piaget’s ideas were then taken one step further by Papert and constructionism – using technology to create knowledge – and researchers Kazakoff et al. (2013) and Strawhacker and Bers (2019) explored the impact of computer programming on student learning. Kazakoff et al. (2013) found programming robots made abstract ideas, specifically sequencing, more concrete for pre-kindergarten and kindergarten students at a STEM magnet school in New York City after a one-week workshop. Strawhacker and Bers (2013) used a Scratch coding program with kindergarten through second grade students and explored the impact on student spatial reasoning and causal logic. Strawhacker and Bers (2013) found cognition and memory improved as the age of the student increased.

Stergiopoulou et al. (2017) also relied on theories by Piaget and Papert in the use of educational robotics and their influence on student learning. Sixth graders spent four hours with the program, and students constructed knowledge and developed critical thinking, as well as acknowledged the impact the robotics had on their math and science understanding (Stergiopoulou et al., 2017). Papert's learning by making theory similarly led Williams et al. (2008) to explore the benefits of a two-week summer robotics camp for middle school students. Williams et al. (2008) found the active role the students held, and collaboration, led to an increase in physics content knowledge.

STEM Key Concepts

Classroom

Scientific Inquiry. Scientific inquiry is defined as student activities which guide them towards knowledge construction and understanding of scientific ideas and how scientists study the natural world (Williams et al., 2008). Kelley and Knowles (2016) utilize the phrase hands-on, minds-on to describe true scientific inquiry as opposed to practical and procedurally based activities. Williams et al. (2008) include skills like asking questions, planning and conducting investigations, using tools to gather data, logical and critical thinking, and communicating reasoning as important aspects of scientific inquiry. Williams et al. (2008) specifically explored whether scientific inquiry skills could be increased through a two-week summer robotics camp in which middle school students were exposed to physics problem-based scenarios centered on topics including Newton's Three Laws of Motion, but the increase observed was not significant.

Further research was recommended by Williams et al. (2008) to investigate whether further instruction, more exposure, or instructor training may impact the growth of scientific inquiry skills in students.

Engineering Design. The Next Generation Science Standards (2020) include scientific inquiry, more specifically engineering design, as one of the three important dimensions of learning science. Engineering design is seen by Kelley and Knowles (2016) as the practice which can equally yoke all four STEM disciplines together through identifying commonalities and building connections. Through learning by doing, applying science knowledge and inquiry (questioning, hypothesizing, and investigating), and supplying an authentic context, engineering design provides a systematic approach and platform necessary for scientific reasoning (Kelley & Knowles, 2016). Shernoff et al. (2017) also describe engineering design as a connecting point for STEM which allows for problem solving, creative thinking, and communication and teamwork.

One specific form of engineering design is known as purposeful design and inquiry (Sanders, 2009) or design-based learning (Vongkulluksn et al., 2018). Sanders (2009) describes design and inquiry as combining technological design and scientific inquiry. Vongkulluksn et al. (2018) studied the impact of design-based learning – designing artifacts in order to solve real-world problems – on student self-efficacy. Third through sixth grade students at an affluent, private school in southern California participated in a design-based makerspace challenge and were observed and interviewed by Vongkulluksn et al (2018). Each student progressed through the six steps of the process – identifying needs and defining the problem (choosing a project with scaffolded support), researching, brainstorming possible solutions, choosing the best solution, building a prototype, and sharing the prototype for feedback and modification – yet student frustration interfered with the process (Vongkulluksn et al., 2018).

Problem Solving and Real-World Context. Problem-based learning, project-based learning, inquiry-based learning, or experiential learning are all terms Shernoff et al. (2017) explored when interviewing K-12 STEM teachers and math/science supervisors who had previously attended a five-day integrated STEM Academy. Although Shernoff et al. (2017) uncovered teacher needs and challenges which hindered implementation of problem-based learning in classrooms, the impact of student-centered learning design on student inventiveness, creativity, critical thinking, and logical thinking was desired by the educators as evidenced by their participation in the STEM Academy.

Holmlund et al. (2018) interviewed and collected concept maps from teachers, administrators, and STEM educators, including teachers and administrators from Ridgeview STEM Academy, which includes project- or problem-based learning in their vision statement. Holmlund et al. (2018) found approximately half of the educators identified real-world problem solving and two-thirds of the educators identified problem- or project-based learning or engineering design challenges as key aspects of STEM education.

Three teachers interviewed and observed by Wang et al. (2011) confirm the importance of real-world problem solving and context. Nate – a sixth-grade math teacher – as reported by Wang et al. (2011), stated STEM allows students to realize how the mathematical skills one has and how one can apply the different mathematical concepts to solve real-world problems. Nate gave the example of using knowledge of measurement of polygons to being applied to designing a package to fit an item (Wang et al., 2011). Amy, a sixth through eighth grade engineering teacher, also used a real-world concept in her lesson planning – Wang et al. (2011) reported on her chair unit where students combined science knowledge of body structures and mathematical measurements of a human body to design, budget for, and build chairs according to ratios.

Beyond STEM. Garner et al. (2018) incorporated other disciplines into their learning program. Often, the arts are a key subject included into STEM learning and the acronym becomes STEAM (Garner et al., 2018). Garner et al. (2018) also included concepts from social studies, civics, health and wellness, and life-skills and found students were able to identify and label skills learned after participating in the lessons. As reported by Wang et al. (2011), Amy also included the art teacher, art concepts, and art students in the aesthetic design and construct of the chairs in her unit. Wang et al. (2011) reiterated teacher beliefs that real-world problems naturally lead to integrated STEM education as most problems encountered in real life involve cross-disciplinary concepts.

Social-Emotional Learning. Garner et al. (2018) integrated social-emotional learning (SEL) concepts into the STEAM curriculum. SEL skills include the ability to understand and regulate emotions, setting positive goals, understanding viewpoints of others, creating positive connections socially, responsible decision making, showing empathy, and navigating social challenges (Garner et al., 2018). Each themed lesson focused on various STEAM concepts appealing to a variety of student interests with social challenges, collaboration, character development, or global citizenship concepts built into the lesson (Garner et al., 2018). Kelley and Knowles (2016) also include the importance of learning in community, as communication and collaboration further the growth of student knowledge. Wang et al. (2011) describe how working together makes learning more meaningful for students, and the practice of collaboration provides a connection for students to build upon in their learning. Although Garner et al. (2018) specifically included SEL concepts, critique provided insight into the importance of explicit versus implicit instruction of these skills. Students need to be taught how a skill can directly support their progress towards a goal, and which specific skill may be needed to complete a particular activity (Garner et al., 2018). Almost all students in the study by Garner et al. (2018) were able to at least one SEL skill they learned through the lesson(s), but instructors recommended students were given more time to reflect on how the SEL skill impacted their learning and to allow time for open dialogue about social-emotional concepts and their impact on learning, real-life problem solving, and future experiences students will encounter.

Literacy. In 2000 the International Technology Education Association (ITEA) defined technological literacy as the content students need for the 21st century in regards to technology – including both the objects or tools of technology as well as the impact technology has culturally, socially, economically, politically, or environmentally (Kelley & Knowles, 2016). Sanders (2009) reiterates that integrated STEM education makes connections between science, math, and technology in order to guide students toward technological literacy which will support not only educational efforts, but also have an impact on the cultural and global competitiveness of students.

Kazakoff et al. (2013) takes technological literacy one step further and defines digital literacy as skills used to find, evaluate, create, and communicate information. Kazakoff et al. (2013) describe digital literacy as the combination of technological and cognitive skills – using computers to not only gather information, but also to understand and evaluate that information. Communication and collaboration, through the use of the internet or other technological tools, is also included in digital literacy according to Kazakoff et al. (2013).

Content Knowledge. Literacy may ultimately result in an increase in student content knowledge. Using the *Think Like an Astronaut* curriculum, Moreno et al. (2016) found a significant increase in student content knowledge – even in areas not directly included in the research. Kim et al. (2015) reported student growth in math, science, physics, engineering design, and STEM content knowledge through various STEM programs, although the change was not significant in their specific study.

Student Engagement

Perceptions and Attitudes. Student perceptions and attitudes toward STEM also vary and change through exposure to STEM experiences. The importance of incremental engagement, goal-based learning, situational learning, and inclusion of procedural knowledge was a key aspect of a study by Leonard et al. (2016). Gomoll et al. (2016) describe the four phases of interest development which are the backbone for building student engagement. The four phases include sparking student interest, retaining student interest, students asking and answering questions, and students working through challenges to gain feedback and reach goals (Gomoll et al., 2016). Gomoll et al. (2016) also describe four types of engagement – behavioral or on task, social or collaboration, cognitive or task-related, and conceptual-to-consequential or applying knowledge to a given problem. Yanowitz (2016) identified the importance of providing opportunities for students to be successful in STEM to raise student self-efficacy and engagement. Yanowitz (2016) also stated observation of peer success also impacts student self-efficacy. Through the opportunity of solving various crime scene situations, Yanowitz (2016) created a camp experience where students could experience successful completion of science related tasks which also supported an increase in student self-efficacy.

Shifts or Growth. Identifying shifts in perceptions and attitudes can be difficult. Moreno et al. (2016) found that although student attitudes did not change significantly during their study using the *Think Like an Astronaut* curriculum, statements by teachers pointed to positive increases in student mindsets. Also in 2016, Leonard et al. found positive increases in student self-efficacy when using a combination of robotics building, coding, and writing code as well as a gaming curriculum which incorporated programming. However, students involved in only the gaming curriculum saw a drop in self-efficacy scores. Leonard et al. (2016) reported STEM attitudes towards science content grew but discovered a decline in student thoughts of math and engineering/technology. Students who already have a high interest in STEM or future careers in a STEM discipline may not display positive self-efficacy growth due to high pre-test data and a ceiling effect limiting post-test growth scores or stable scores being observed (Stevens et al., 2016). Although immediate feedback showed significant increases in student self-efficacy scores, in post-camp and follow-up surveys, Yanowitz (2016) discovered no significant change in self-efficacy, but students described more involvement in informal STEM activities including museums, literature, media, and activities due to their camp experience. Students also expressed an increase in STEM content knowledge, more enjoyment and interest in STEM activities, increased self-confidence in STEM, the importance of creating new relationships and building social skills, as well as planning for STEM to be included in their future (Yanowitz, 2016).

Student Age. Student age can also affect student perceptions and engagement with STEM. Vongkulluksn et al. (2018) reported most students had positive responses to STEM activities, however younger students were more positive than older students, and showed less frustration with STEM challenges. Carlone et al. (2014) also reported a decrease in student STEM interest as students grew older. Over the course of two years, all students observed were described to be less scientific by Carlone et al. (2014). Vongkulluksn et al. (2018) discovered student self-efficacy did not drop below the median, but did decrease over the course of their research, especially in higher grade levels. Self-efficacy scores dropped significantly during the first half of the semester but remained even during the second half of the semester, which could attributed to older students choosing more complex projects which led to higher frustration levels, incompletion of goals, and ultimately making poor judgements of self and ability (Vongkulluksn et al., 2018). Vongkulluksn et al. (2018) pointed out younger students had a more optimistic outlook while older students were aware of what they could not do. Vongkulluksn et al. (2018) suggest earlier scaffolding and guidance in choosing appropriately challenging tasks could counter negative impact on student self-efficacy.

Teacher Impact. Teachers and other mentors also affect student interest and self-efficacy in STEM. Carlone et al. (2014) described how fourth grade students who were encouraged to take risks and explore with curiosity, were urged to use scientific explanations, problem solving, collaboration, and sharing became more focused on getting the right answer and being good students when they reached sixth grade due to a more task-oriented approach to STEM curriculum. Due to lower-level tasks, less hands-on experiences, and more lectures and worksheets, students were reported to lose their scientific identity (Carlone et al., 2014). Stevens et al. (2016) stated mentor relationships were categorized highly by students and reported a student waiting list for participation in the STEM program. Stevens et al. (2016) include the impact of caring adults among effective STEM practices as well as critical thinking, collaboration, real-world application, and hands-on learning. Students were impacted by teachers to realize good and smart science students learn to think critically, solve problems, develop scientific explanations, and show care and understanding to their peers (Carlone et al., 2014). Yanowitz (2016) lists the need for trained instructors who can provide positive encouragement, as well as developing a program with low student-teacher ratios, as important to building student interest and future engagement with STEM.

Beyond the Classroom

Student self-efficacy directly affects future educational and career decisions as well as growth of important workforce skills. Yanowitz (2016) identified the middle years of a student's education as an important time in which career development can be affected. Through research based on summer camp experiences, Yanowitz (2016) found more than half of students affirmed an impact on their career aspirations. Mark (2016) listed the impact STEM programming had on student confidence, which directly impacted future educational course selection and career investigations. Mark (2016) describes how on the job STEM training, including paid research intern positions, supported learning of transferable STEM skills. Students were able to learn directly from STEM experts and mentors in various career fields (Mark, 2016). These STEM mentors directly impacted student STEM career knowledge, exploration of specific STEM careers, knowledge of requirements for those specific careers, and educational planning (Mark, 2016). Connecting students with STEM professionals was also identified by Holmlund et al. (2018) as important for students in regard to career explorations.

Specifically, the need for 21^{st} century skills is necessary for student trajectories into STEM fields. Skills identified as beneficial in life and needed for professional competency include solving real-world problems, critical systems thinking, logical thinking, communication skills, collaboration skills, ownership of responsibility, and skills in areas of computers and programming (Smyrnova-Trybulska et al., 2017). Holmlund et al. (2018) also include problem solving, collaboration, critical thinking, and communication skills as needed 21^{st} century skills, but additionally list the importance of creativity, innovation, and perseverance. Studying job skills, knowledge, and work activities, Jang (2016) identified adaptability, complex communication skills, problem solving, self-management and self-development, and systems thinking as key areas students need to develop beyond specific STEM skills necessary for STEM career aspirations. Specifically, Jang (2016) rated the following skills as high need: active listening, speaking, decision making, time management, and social perceptiveness. Knowledge skills Jang (2016) rated high include administration, management, and customer and personal service. Work activities rated high include decision making, interacting with computers, and updating and using relevant knowledge (Jang, 2016). Garner et al. (2018) also describe the importance of global citizenship development – developing students to be globally competent, socially responsible, and to have self- and social-awareness, relationship management skills, responsible decision making, time management, and collaboration skills.

Examples of Integrated STEM

Robotics

Robotics is one emerging field being incorporated into STEM learning environments which encompasses many of the themes discussed previously. First, robotics lends itself to building knowledge and growing content area skills. Kim et al., (2015) states how robotics activities and STEM content are effortlessly linked in the field of robotics. Fifth through eighth grade students, in a study by Leonard et al. (2016), increased computational thinking skills, reinforced science subject matter, as well as learned engineering and technological skills while creating a game. Robotics were also found to influence math literacy skills and the growth of science and technological information understanding (Smyrnova-Trybulska et al., 2017). Kim et al. (2015) shared how robotics improved both elementary and middle school students' math achievement and STEM knowledge, elementary students' science achievement, and middle school students' physics content knowledge. Kazakoff et al. (2013) described robotics as a new form of manipulatives which can support student understanding of mathematical concepts. Even non-STEM content areas are impacted by robotics. Kindergarten and pre-kindergarten students showed a significant increase in picture sequencing skills after taking part in a robotics and programming intervention using both physical and computer-based robotics blocks, while a control group showed no significant increase in the same skills (Kazakoff et al., 2013). Kim et al. (2015) also reported a link between robotics and picture sequencing skills.

Student perceptions of STEM and engagement can also be affected by robotics learning. Students in research by Stergiopoulou et al. (2017) made STEM connections, recognized relationships among STEM subjects, and realized the value and importance each content area provided robotics curriculum. Stergiopoulou et al. (2017) reported sixth graders enjoyed robotics activities and that math and science skills supported their learning. Smyrnova-Trybulska et al. (2017) also related how creating a robot kept students engaged and motivated, and even teachers even recognized the importance of self-motivation in the study. The fact that robotics combines games with learning allows students to create a positive attitude about what they are learning (Stergiopoulou et al., 2017). Gomoll et al. (2016) reported robotics held student interest and that students were engaged both cognitively and socially. Behavioral engagement (students taking initiative and participating fully without distraction) and emotional engagement (including confidence boosts and greater interest in STEM) – described as autonomous motivation – were reported by Kim et al. (2015), as well as greater STEM interest, motivation, and self-confidence. A decrease in negative emotions toward STEM was also reported by Kim et al. (2015).

Scientific inquiry, engineering design skills, and problem-solving skills are also benefitted by student robotics exposure. Kim et al. (2015) discovered an increase in middle school students' engineering design and problem-solving skills. Middle school students were exposed to this benefit at a summer camp, and researchers realized the need for knowledgeable instructors, a specific focus on the scientific inquiry process, and balancing free play and problem solving when using new materials in order to encourage students to remain focused (Williams et al., 2008). Longer term experiences may also be beneficial according to Williams et al. (2008) rather than short-term camp exposure to these skills. Gomoll et al. (2016) reported how project-based learning and solving real-world problems supported students in robotics programming. Using the engineering design process, students were able to demonstrate understanding of and utilize portions of the engineering design process in varying degrees (define the problem, ask questions, imagine, collect information, develop and test ideas, explain reasoning, improve ideas) (Gomoll et al., 2016). Leonard et al. (2016) reported growth of problem-solving skills in fifth through eighth grade students after building, coding to move, and writing advanced code for a robot.

Robotics also connects to social-emotional learning for students. Stergiopoulou et al. (2017) lists an impact on student cooperation and trust between students and teachers. Peer social interactions are can be cultivated using robotics stated Kazakoff et al. (2013). Robotics supported social competencies, including communication and teamwork skills, according to Smyrnova-Trybulska et al. (2017). Kim et al. (2015) also reported growth in communication and collaboration skills due to robotics learning. Gomoll et al. (2016) specifically cites how human-centered robotics may be important for connecting girls with STEM. The emphasis robotics places on the social side of science and technology led teenagers in an after-school club towards social-emotional growth – including students taking on leadership roles they had not previously (Gomoll et al., 2016).

Lastly, robotics has been reported to lend itself to the growth of 21st century skills. Smyrnova-Trybulska et al. (2017) recorded a robotics connection to critical thinking, logical thinking, and critical systems thinking. Spatial visualization skills and proportional reasoning increased in fifth through eighth grade students, according to Leonard et al. (2016). Kim et al. (2015) reported students were more strategic, increased critical thinking skills, and had improved spatial ability and creative thinking after robotics programming. Stergiopoulou et al. (2017) also stated sixth grade students developed critical thinking in their research.

Coding

While coding is often incorporated into many robotics curriculums, stand-alone coding instruction also benefits student learning. Strawhacker and Bers (2019) reported connections to student verbal, visual, causal, spatial, and social reasoning skills. Tucker-Raymond et al. (2016) listed math literacy, problem solving, math reasoning and communication, and game design as student growth areas affected by coding instruction. Other positive connections include concrete symbol recognition (letters and numbers) and working memory. Strawhacker and Bers (2019) studied kindergarten through second grade students and recognized no gender-based differences when using Scratch Jr. coding but did identify how developmental stages impacted student success as student age increased. The importance of using coding to perform a purposeful task or meet a goal was discussed by Strawhacker and Bers (2019). High school students in research by Tucker-Raymond et al. (2016) applied coding to turn physical games into digital games for elementary students to practice learning concepts. According to Tucker-Raymond et al. (2016), the cascading model of instruction used in their Young People's Project (YPP) allows students from colleges, to high-schools, down to elementary-aged students to have access to STEM related content by removing traditional institutional barriers – students take ownership by realizing they cannot teach something until they understand it themselves. By creating new roles for students as not only learners, but also leaders, teachers, and organizers, the program fosters relationships and connections to the community as well as continued engagement and motivation for students (Tucker-Raymond et al., 2016).

Future

Teacher Preparation

The importance of teacher training is equally important in preparing students to follow STEM paths and providing quality STEM programming. Radloff and Guzey (2016) concluded preservice STEM teachers require effective STEM instruction after researching STEM perceptions and understandings amongst current educators. Wang et al. (2011) reported integrated STEM instruction often follows a path comfortable to the teacher, and by impacting beliefs and highlighting the purpose of STEM integration teacher practices will be affected. Research by Bell (2016) also concluded the necessity of training teachers in STEM subjects in order to produce qualified and motivated STEM educators. Bell (2016) described four stages of STEM perception and understanding – external knowledge, internal engagement with knowledge, knowledge transferred to understanding, and synthesized knowledge for full understanding – and ultimately aims for STEM educators to progress towards the fourth stage in which they have confidence and students will learn through purposeful, engaging, creative, and active learning.

Professional Development

Teachers often perceive barriers to providing quality STEM education. Stohlmann et al. (2012) reported difficulties with time management, while lack of resources, poor student attitudes, student gaps in understanding or range of student abilities, lack of time for planning and collaboration, and lack of administrative support were reported by Shernoff et al. (2017). Shernoff et al. (2017) also uncovered deficiencies in content knowledge, school organization or structure, absence of resources, financial limitations, and poor training as obstacles to providing integrated STEM instruction. Stohlmann et al. (2012) found these barriers may lead to less commitment from educators, and suggests dedicated, organized, and knowledgeable teachers are needed who can be committed and supported with time for collaboration in order to find success. Staff build confidence through sharing ideas (Bell et al., 2018) which may come formally or informally. Educators may rely on formal professional development, but opportunities may be limited and barriers of cost and time away hinder some staff from participating (Bell et al., 2018). Informal opportunities in the form of networking or independent research, including virtual opportunities, were also found to be effective by Bell et al. (2018). Lack of collaboration can lead to division among colleagues or between content areas, but mutual respect leads to infinite learning possibilities with new STEM knowledge and best practices being voluntarily distributed (Bell et al., 2018). The President's Council of Advisors on Science and Technology (2010) incorporates the need for developing, employing, and rewarding high-quality STEM teachers who can create STEM experiences which engage all students. The National Research Council (U.S.) (2011) list guidance which includes employing educators with strengths in content and pedagogy, valuing professional development, and empowering school leadership to initiate and influence change.

Best Practices

Yanowitz (2016) identifies best practices to include student-centered lessons, inquiry learning, active participation including group learning, use of the scientific method, using data to support conclusions, and social construction of knowledge. These characteristics were modeled and described by Carlone et al. (2014) as equitable teacher qualities of scaffolding, holding high expectations of students, showing enthusiasm and pushing students further with questioning, encouraging explanation of ideas, and modeling social skills and empathy. Mark (2016) based research on these same qualities – guiding students, providing access to challenging material, and allowing for social and academic peer interactions.

Reform

The goal of STEM reform should be to promote learning, thinking, and interest in STEM (Kelley & Knowles, 2016). Weis et al. (2015) reports reform should focus on instructional quality, overall attitudes and expectations, and course advisement rather than specific course offerings or sequencing. The President's Council of Advisors on Science and Technology (2010) also recommends students be prepared to have a strong STEM foundation for personal and professional applications and for students to be motivated and excited about STEM careers. The National Research Council (U.S.) (2011) also lists increasing STEM literacy and student interest and motivation as necessary conditions for successful STEM programming. Weis et al. (2015) testified to how current educational policies and structures can undermine reform attempts. Low student proficiency scores, prerequisite course requirements, or goals (such as increased graduation rates) can take away from variety of or depth of courses offered (Weis et al., 2015) when students have reduced access to courses or when available resources are necessary to meet low-performing student needs rather than focus on STEM reform strategies. Both the National Research Council (U.S.) (2011) and the President's Council of Advisors on Science and Technology (2010) recommend development of common standards and improved leadership or policy support to allow for STEM program growth.

Future Research

Future recommended research includes the areas of STEM program material content, the balance of activities which will positively impact student motivation and interest, best practices for STEM instruction to support underrepresented or underserved students, as well as on the benefits of robust STEM teacher training. First, research is needed to identify STEM activities which can be applied in settings with students of differing levels of ability – STEM programming which will allow for differentiation to meet the needs individual students. Second, research which will identify an appropriate balance between exploration, free-play, and structured learning/application of scientific processes is needed to maintain student motivation and interest yet support learning of content area material. Meeting the needs of and providing opportunities for underrepresented or underserved students is vital to removing barriers to their exploration of and participation in STEM learning and future STEM work trajectories. Lastly, research to clarify and refine teacher training and staff development, which will best support educators to find success in integrated STEM classrooms and programs, is critical to STEM reform and the future of effective STEM education.

Conclusion

The aim of this literature review was to determine what quantifies an elite STEM program, what makes STEM education impactful for students, and where the future of STEM education may lie – to facilitate STARBASE in continuing to provide emerging STEM lessons and activities in an ever-changing world. The importance of integrated STEM, and ensuring educators, students, and stakeholders understand and support the efforts of integrated STEM instruction is the first step towards successful STEM programming. Learning by doing, using a constructionist approach, is vital to providing classroom experiences which support student exposure and growth in scientific inquiry skills, application of the engineering design process, problem solving (including real-world scenarios), social-emotional growth, content literacy, as well as understanding connections between and among not only STEM subject matter, but across all content areas. Effective STEM curriculum will also engage student interest, keep students motivated, and build student self-efficacy. Beyond the classroom, students will build 21st century skills which will impact future learning and preparation for society and careers. Two specific examples of integrated STEM which currently stand out in STEM programming are robotics and coding. These two areas can be a reference point for emerging trends in STEM fields and how to integrate them into student instruction. Ongoing training for educators and proper preparation of new teachers is continually necessary so that instructors and programs remain effective and relevant for student learning. In doing so, best practices and reform attempts will not be held at bay. STARBASE will benefit from acknowledging and applying these findings in the continued development and implementation of superior STEM programming.

References

Bell, D. (2016). The reality of STEM education, design and technology teachers' perceptions: A phenomenographic study. *International Journal of Technology and Design Education, 26*(1), 61–79. https://doi.org/10.1007/s10798-015-9300-9

Bell, D., Morrison-Love, D., Wooff, D., & McLain, M. (2018). Stem education in the twenty-first century: Learning at work – an exploration of design and technology teacher perceptions and practices. *International Journal of Technology and Design Education*, *28*(3), 721–737. https://doi.org/10.1007/s10798-017-9414-3

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C.M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112(*1), 3-11. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Carlone, H.B., Scott, C. M., & Lowder, C. (2014). Becoming (less) scientific: A longitudinal study of students' identity work from elementary to middle school science. *Journal of Research in Science Teaching, 51*(7), 836-869. http://dx.doi.org/10.1002/tea.21150

Common Core State Standards Initiative. (2020). *Frequently asked questions.* Core Standards. http://www.corestandards.org/about-the-standards/frequently-asked-questions/

DoD STARBASE. (2019). *Annual Report 2019: Increasing diversity, equality, & inclusion in STEM.* DoD STARBASE. https://dodstarbase.org/wp-content/uploads/19-27796-STARBASE-ANNUAL-REPORT-FY2019-3-30-20-1.pdf

Garner, P.W., Gabitova, N., Gupta, A., & Wood, T. (2018). Innovations in science education: Infusing social emotional principles into early STEM learning. *Cultural Studies of Science Education*, *13*(4), 889–903. https://doi.org/10.1007/s11422-017-9826-0

Gomoll, A., Hmelo-Silver, C. E., Šabanović, S., & Francisco, M. (2016). Dragons, ladybugs, and softballs: Girls' STEM engagement with human-centered robotics. *Journal of Science Education and Technology*, *25*(6), 899–914. https://doi.org/10.1007/s10956-016-9647-z

Holmlund, T.D., Lesseig, K., & Slavit, D. (2018). Making sense of "STEM education" in K-12 contexts. *International Journal of Stem Education*, *5*(1), 32–51. https://doi.org/10.1186/s40594-018-0127-2

Jang, H. (2016). Identifying 21st century STEM competencies using workplace data. *Journal of Science Education and Technology*, *25*(2), 284–301. https://doi.org/10.1007/s10956-015-9593-1

Kazakoff, E.R., Sullivan, A., & Bers, M.U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*(4), 245–255. https://doi.org/10.1007/s10643-012-0554-5

Kelley, T.R. & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 1-11. https://doi.org/10.1186/s40594-016-0046-z

Kim, C.M., Kim, D., Yuan, J., Hill, R.B., Doshi, P., & Thai, C.N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, *91*, 14–31. https://doi.org/10.1016/j.compedu.2015.08.005

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O.S., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology*, *25*(6), 860-876. https://doi.org/10.1007/s10956-016-9628-2

Mark, S. L. (2016). Psychology of working narratives of STEM career exploration for non-dominant youth. *Journal of Science Education and Technology*, *25*(6), 976–993. https://doi.org/10.1007/s10956-016-9646-0

Moreno, N.P., Tharp, B. Z., Vogt, G., Newell, A. D., & Burnett, C.A. (2016). Preparing students for middle school through after-school STEM activities. *Journal of Science Education and Technology*, *25*(6), 889-897. https://doi.org/10.1007/s10956-016-9643-3

National Research Council (U.S.). (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academies Press. https://www.nap.edu/read/13158/chapter/1

Next Generation Science Standards. (2020). *Get to know the standards.* NGSS. https://www.nextgenscience.org/

President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K–12 education in science, technology, engineering, and math (STEM) for America's future*. Executive Office of the President, President's Council of Advisors on Science and Technology. https://nsf.gov/attachments/117803/public/2a--Prepare_and_Inspire--PCAST.pdf

Radloff, J., & Guzey, S. (2016). Investigating preservice STEM teacher conceptions of STEM education. *Journal of Science Education and Technology*, *25*(5), 759-774. https://doi.org/10.1007/s10956-016-9633-5

Sanders, M. (2009). STEM, STEM education, STEMmania: A series of circumstances has once more created an opportunity for technology educators to develop and implement new integrative approaches to STEM education championed by STEM education reform doctrine over the past two decades. *The Technology Teacher*, *68*(4), 20-26. https://vtechworks.lib.vt.edu/bitstream/handle/10919/51616/STEMmania.pdf?sequence

Shernoff, D.J., Sinha, S., Bressler, D.M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of Stem Education*, *4*(1), 1–16. https://doi.org/10.1186/s40594-017-0068-1

Smyrnova-Trybulska, E., Morze, N., Kommers, P., Zuziak, W., & Gladun, M. (2017). Selected aspects and conditions of the use of robots in stem education for young learners as viewed by teachers and students. *Interactive Technology and Smart Education*, *14*(4), 296–312. https://doi.org/10.1108/ITSE-04-2017-0024

Stergiopoulou, M., Karatrantou, A., & Panagiotakopoulos, C. (2017). Educational robotics and STEM education: A pilot study using the H&S electronic systems platform. *Advances in Intelligent Systems and Computing, 560,* 88-103. https://doi.org/10.1007/978-3-319-55553-9_7

Stevens, S., Andrade, R., & Page, M. (2016). Motivating young Native American students to pursue STEM learning through a culturally relevant science program. *Journal of Science Education and Technology*, *25*(6), 947–960. https://doi.org/10.1007/s10956-016-9629-1

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28-34. https://doi.org/10.5703/1288284314653

Strawhacker, A., & Bers, M.U. (2019). What they learn when they learn coding: Investigating cognitive domains and computer programming knowledge in young children. *Educational Technology Research and Development*, *67*(3), 541–575. https://doi.org/10.1007/s11423-018-9622-x

Tucker-Raymond, E., Lewis, N., Moses, M., & Milner, C. (2016). Opting in and creating demand: Why young people choose to teach mathematics to each other. *Journal of Science Education and Technology*, *25*(6), 1025–1041. https://doi.org/10.1007/s10956-016-9638-0

Vongkulluksn, V.W., Matewos, A.M., Sinatra, G.M., & Marsh, J.A. (2018). Motivational factors in makerspaces: A mixed methods study of elementary school students' situational interest, self-efficacy, and achievement emotions. *International Journal of Stem Education*, *5*(1), 1–19. https://doi.org/10.1186/s40594-018-0129-0

Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2), 1-13. https://doi.org/10.5703/1288284314636

Weis, L., Eisenhart, M., Cipollone, K., Stich, A. E., Nikischer, A. B., Hanson, J., Leibrandt, S. O., Allen, C. D., & Dominguez, R. (2015). In the guise of STEM education reform: Opportunity structures and outcomes in inclusive STEM-focused high schools. *American Educational Research Journal, 52*(6), 1024-1059. https://doi-org.ezproxy.nwciowa.edu/10.3102%2F0002831215604045

Williams, D.C., Ma, Y., Prejean, L., Ford, M.J., & Lai, G. (2008). Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. *Journal of Research on Technology in Education*, *40*(2), 201–216. https://files.eric.ed.gov/fulltext/EJ826076.pdf

Yanowitz, K. L. (2016). Students' perceptions of the long-term impact of attending a "CSI science camp." *Journal of Science Education and Technology*, *25*(6), 916–928. https://doi.org/10.1007/s10956-016-9635-3