Creating Prekindergarten Scientists: Why STEM Must Start Now

Position Statement for Tulsa Regional
Stem Alliance on the
Importance of STEM
In Early Childhood

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Observing bugs, squishing fingers in mud, and pouring water into different sized containers are how children explore through play. They are also examples of STEM activities (McClure et al., 2017). Science, Technology, Engineering and Math (STEM) includes active, focused exploration of objects, materials, and events in children's world that allow for multiple opportunities to observe phenomenon, generate hypotheses, and test their theories (NSTA, 2014). STEM activities are grounded in the idea that science instruction should focus on the content, processes, and attitudes of scientists (NGSS Lead States, 2013). STEM skills will be critical in a future job market based in technology and advanced problem solving.

While STEM classes are becoming increasingly popular in middle and high school, STEM has yet to make an impact in early childhood classrooms (Tippitt & Milford, 2017). However, the time to introduce STEM is when children enter school, in PreK or Kindergarten (McClure et al., 2017). Introducing STEM at this age is developmentally appropriate, as very young children's innate curiosity and interest in the natural world make them capable STEM students (Castori, Heenan, Ramage, & St. John, M., 2015). Teaching STEM early builds foundational skills while also providing benefits to children's reading, language, and math achievement (Greenfield, Alexander, & Frechette, 2017). Engaging in STEM early is one way to help increase the diversity of students who are interesting in STEM and to give all students confidence in their identity as young scientists (French, 2004). While there are barriers to implementing STEM, the advantages of early introduction make it worth the work.

Providing young children with STEM opportunities in PreK classrooms is essential in creating a STEM workforce. Appendix 1 lists facts and figures specific to the USA and Oklahoma with regard to STEM. Two statistics are alarming. First, the estimated size of the

STEM workforce in the U.S. by 2018 is 8,650,000. Second, in 2015, Oklahoma 4th grade students scored on par with students across the nation for NAEP proficiency at a paltry 33% proficient or advanced. However, Black and Hispanic students scored 20 points lower than white students, and students on free/reduced lunch scored 18 points lower than those not on free/reduced lunch. There is a clear demand for STEM jobs in the future, yet Oklahoma students, because of their low science proficiency, may not be able to capitalize on these opportunities, and the STEM workforce may not be diverse as a result. Currently, Oklahoma has in place standards for early learning in science that are supported by STEM curriculum (see Appendix II). Oklahoma appears uniquely posed to offer STEM instruction in PreK, before it is too late.

S: The Science Behind STEM

Children who develop math proficiency in kindergarten continue to have math success in later grades. What is surprising however, is that early math proficiency is also able to predict proficiency in literacy from kindergarten to high school (Duncan et al., 2007). Early math builds skills outside of the content area that children can use. So too, science, and STEM in particular, provides a variety of benefits to students outside of increasing science content (McClure et al., 2017). These benefits include increased vocabulary, engagement and motivation, and cognitive skills. Moreover, teaching through STEM in the early childhood grades helps children to develop critical metacognitive or learning to learn skills that children will be able to engage in problem solving in both the academic and social arenas (Greenfield, Alexander, & Frechette, 2017).

STEM has been associated with increased literacy skills and vocabulary in children (Castori, et al., 2015). Through STEM, children learn to describe what they are seeing and to verbalize and defend theories about what they hypothesize is occurring. Seeing words in authentic situations and in context results in increased overall vocabulary (Conezio & French, 2002) and in domain-specific vocabulary (Guo, Wang, Hall, Breit-Smith, & Busch, 2016). Talking about ideas with others and representing ideas through writing or pictures increases early literacy skills (Conezio & French, 2002). Engaging in STEM early on provides children with science literacy and STEM fluency so that they are comfortable with the language and processes of science.

Increased vocabulary can also lead to further skill development. For example, STEM activities like building with blocks can encourage the use of spatial language in children and adults. This spatial language has been linked with increasing spatial awareness, which improves children's math abilities (Cheng and Mix, 2014). Increased vocabulary has the added benefit of decreasing children's cognitive loads during more sophisticated tasks (Kail, Lervag, & Hulme, 2016). Children who have developed a fluency with content-specific words will more easily be able to use those words in explaining more abstract concepts.

STEM activities promote increased engagement and motivation (Kermani & Aldemir, 2015). Learning about STEM is intriguing to young children and causes them to be naturally engaged and attentive (Conezio & French, 2002). Compared to children exposed to science instruction focused on memorizing discrete facts, children in STEM classes are more engaged in the lesson because they are actively manipulating their environment (Patrick, Mantzicopoulos, & Samarapungavan, 2009). Inquiry-based science also leads to increases in learning related behaviors like persistence and attention (Bustamante, White, & Greenfield, 2016). This increased engagement and attention has been associated with better recall of information in the long run (NSTA, 2004).

STEM activities have been associated with increased cognitive skills because they provide natural opportunities to problem solve (Tippett & Milford, 2017). With scaffolding from teachers and parents, children are encouraged to persist, take risks, wonder, and ask questions. These skills help children learn how to learn, how to become engaged in the classroom.

Engaging in STEM builds executive function skills (EF), like working memory and cognitive flexibility, allowing children to acquire newer skills at faster rates. EF helps children more quickly connect new material with what has already been learned, and in the context of STEM, this can enable children to link new observations with previously stored theories. It also helps children focus on the task at hand and inhibit the desire to engage with other materials and to persist with planned experiments, even when the first experiment fails (Greenfield et al., 2009). Executive function skills are often listed as a key to school readiness and success, and the time between ages three to five represent a period of rapid growth in EF (Center on the Developing Child, 2011). This provides an especially important reason to include STEM activities in PreK classrooms.

T: Teaching in STEM

In one STEM classroom, kindergarten children are engaged in a class study of balls. In the beginning, children collect balls from their houses and set about sorting them. After a while a child brings a marble, and children are challenged to fit this object within their classification system. Children asked questions about which balls would bounce the highest and roll the farthest and are able to conduct experiments. Children are encouraged to make predictions and then are asked “what makes you think so?” so that they develop the basis of their opinions. Children create ramps and slopes to test the effect on the ball’s roll and measured distances with standard and nonstandard units of measure as well as circumference and weight. Children also look inside the balls and explored vocabulary like hollow, empty, full, solid.

STEM exemplifies many of the instructional strategies that cater to how children learn best—play-based and hands on. Exploratory play supports children's understanding of causal models (Schulz & Bonawitz, 2007). During exploratory play, children are encouraged to discover characteristics of a phenomenon—what does the ball look, smell, feel, like. Children use this information to create theories about these items. Teachers can then ask children to explain why dirt is gritty or why it smells like bugs, requiring children to develop causal models. Explanation and Causality are critical process skills which scientists often use; engaging in this kind of thinking through play with a thoughtful adult helps children connect and verbalize what they are doing.

Researchers have established the benefits of manipulatives for students' math skills (Kinzer, Gerhardt, & Coca, 2016). So too, STEM activities that are hands on increase conceptual understanding and help with problem solving. Encouraging children to use their hands in activities (through building, counting, and tinkering) engages neural networks for problem solving while also allowing children to demonstrate conceptual understanding they may not be able to articulate (Goldin-Meadow et al., 2012).

Katz (2010) distinguished between academic and intellectual goals in early childhood, and this distinction exemplifies the importance of STEM in early childhood classrooms. Academic goals are concerned with acquiring small discrete bits of disembedded information, while intellectual goals emphasize reasoning, hypothesized, predicting. K-12 Science in early childhood should focus on developing and testing theories rather than on scientific explanations. Thus, STEM, in its emphasis on hands on problem solving, helps children master intellectual goals and enables them to develop theories about the natural world. These learning to learn skills help children develop school readiness much more deeply than memorizing facts.

E: Early Start is Essential

Teachers and researchers alike cite key skills to develop in our youngest students to be school ready—receptive vocabulary, self-regulation and problem solving. STEM is able to help children master all three. It helps to establish neural pathways, promote healthy mindsets, and to decrease the achievement gap. While people may feel infants, toddlers, and preschoolers are too young to learn STEM, nothing could be farther from the truth. Infants can display an interest in science concepts, and children's natural curiosity and questioning make them avid budding scientists (ECSWG, 2017). Beginning STEM early is critical to capitalizing on children's innate curiosity and setting them off on the STEM path.

Children in early childhood, particularly from three to five years old, experience a great amount of neural development, as early experiences form connections that build brain architecture. Children's rapid neural development make them uniquely suited to study STEM, and teaching through STEM serves only to strengthen these neural pathways. One capacity is cognitive flexibility (CF), being able to see multiple solutions or flip between multiple systems or rule sets. Without this flexibility, children are not able to adapt their thinking after the introduction of novel stimuli. Gopic and Sobel (2000) found CF in very young children. In a STEM context, this can enable them to develop varied theories to explain observed phenomenon, which can help in explaining cause and effect. Compared to adults,… Another capacity, found as early as infancy, is statistical inferencing, being able to generalize from samples to populations (Xu & Garcia, 2008). Infants were able to understand a sorting rule and expressed surprise when they saw something that went against a sorting rule. Inferencing in a STEM context helps children make generalizations about the way the world works based on their observations.

Engaging in STEM early is also important to help children develop positive attitudes towards science (Archer et al., 2010). Children's attitudes towards science concepts and learning science are shaped during the early years and become resistant to change later on (Kermani & Aldemi, 2015). Thus, it is critical that children understand that science is something they are capable of.

Finally, The US Department of Education (2011) emphasizes that children from low-oncome and minority families perform at lower levels in language and math subjects**.** However, more recent research has found that an achievement gap in science also exists, and it may be more detrimental than the math or reading gap because the gap is larger and more resistant to change (Morgan, Farkas, Hillemeier, & Maczuga, 2016). The achievement gap in science begins in pre-k, and those children who are behind in science may never catch up. However, Kermani and Aldemir (2015) found that an integration of math and science learning serving children in low SES made a significant improvement in their math/science scores.

M: Misconceptions and Barriers to Stem Education

Given the numerous benefits of STEM education, there are still several barriers to its full implementation. These include lack of teacher knowledge and discomfort with teaching STEM, misconceptions about who should learn STEM, and creating opportunities in the day to teach it.

Science instruction typically is last on a teacher's to do list. In a survey of instructional time in PreK to 3rd grade, Banilower et al. (2013) found that science received about 11% of the instructional time in a classroom. Farran, Lispey, Watson and Hurley (2007) reported that 58 seconds of a 360-minute day were spend on math, and science was seldom taught. Early childhood classrooms may typically focus on early literacy in an effort to teach children to read, with math taught intermittently (Manzicopoulos, Samaraoungavan & Patrick, 2009). In addition, some have found that current science and math concepts emphasized in early childhood classrooms do not progress beyond teaching some discrete math and science topics such as rote counting and memorizing facts (Duschl, Shouse, & Schweingruber, 2007). Or, science may consist of low quality experiments taught intermittently (Brenneman, Stevenonson-Boyce & Frede, 2009). High quality STEM instruction is possible alongside literacy instruction. STEM curricula can naturally infuse literacy elements, often leading to increases in language and literacy skills (Gonzalez et al., 2010). STEM opportunities naturally exist in children's play and outdoor explorations. There is plenty of time in the day if teachers seize these critical opportunities

One common misconception is that certain kind of people are science people. This mindset suggests that while literacy is critical to future success, failing to develop proficiency in math or science is acceptable (Greenfield et al., 2009). This mindset is dangerous, particularly when children are younger. McClure et al., (2017) found that young children have not developed fixed mindsets about who is capable to do what discipline. For example, young children have not developed ideas about whether it should be appropriate for girls to be engineers. Patrick et al. (2009) found that in inquiry-based classrooms, no gender differences existed in who reported liking science; this was not the case for more traditional science instruction, where boys preferred science more than girls. If the message that science is for boys is conveyed to young children, the message often sticks, turning girls away from science.

There may be barriers to implementing STEM even with the correct mindsets. STEM requires strong content knowledge and pedagogical knowledge in addition to an understanding of how children’s learning in science progresses (McClure et al., 2017). Many teacher education programs do not include STEM coursework (ECSWG, 2017), and teachers often do not feel comfortable teaching STEM. In order to do STEM well, teachers will need more professional development (Greenfield et al., 2017). Teacher education programs will also need to include more opportunities for STEM coursework.

STEM is a win-win situation. On the one hand, teaching STEM increases science and math content knowledge. In addition, it increases vocabulary and literacy skills. Children are naturally engaged in STEM activities and are motivated to become scientists. Teaching STEM early helps children develop the critical mindset that they are capable of STEM, no matter their background. Teaching STEM early capitalizes on children’s rapid neural development occurring at that time, leading to cognitive skills that help children in other content areas. There is no reason why STEM should not be taught to our youngest scientists. If we want to prepare students for the kinds of jobs they will need in the future, we must equip teachers with skills and knowledge to engage in STEM by asking the right questions. We must also let our children smell the flowers, make mud cakes and watch roly polys.

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Appendix 1: Facts and Figures

U.S. Facts and Statistics

- 8,650,000 is the estimated size of the STEM workforce in the U.S. by 2018. (Source: U.S. Bureau of Labor Statistics)
- ***84%*** of working professionals currently in science and engineering jobs in the U.S who are white or Asian males. (Source: National Science Foundation)
- The number of STEM occupations in the U.S. will grow by 8.9 percent between 2014 and 2024. (Source: U.S. Department of Commerce STEM Jobs 2017 Update
- STEM access and opportunities in high school rely on high-quality instruction, but with only .17% and .43% of STEM-interested students indicating plans to pursue science or math education. (Source: https://www.act.org/content/dam/act/unsecured/documents/STEM/2017/STEM-Education-in-the-US-2017.pdf
- 64% of 4th graders scored below proficient on the NAEP science assessment (Source: https://www.nationsreportcard.gov/)

Oklahoma Facts

- In the Spring 2017, 57% of Oklahoma 4th graders scored below proficient on the state science test. Students scored the worst in Life science (42% proficient), compared to Earth science (36% proficient) and physical science (33%). (Source: 2017 State Summary Report, retrieved from http://sde.ok.gov/sde/assessment-administrator-resources-administrators)
- Oklahoma 4th grade students scored on par with students across the nation for NAEP proficiency at 33%profiecnt or advanced. However, Black and Hispanic students scored 20 points lower than white students, and students on free/reduced lunch scored 18 points lower. (Source: http://sde.ok.gov/sde/sites/ok.gov.sde/files/2017%20Oklahoma%20NAEP%20Math%20%26%20Reading%20Results.pdf
- 19,794 Oklahoma students, or 47%, had an interest in STEM, but only 6,620 (16%) had both an expressed interest (they plan to pursue a STEM major or career) and a measured interest (Source: https://www.act.org/content/dam/act/unsecured/documents/STEM/2017/Oklahoma-State-of-STEM-2017.pdf
- Oklahoma is ranked by the U.S. Chamber of Commerce Foundation as 16th in STEM job growth in the nation. The number of STEM degrees and certificates conferred at state system colleges and universities reached a record high during the last academic year, with more than 6,000 students receiving degrees and certificates in STEM fields (*Degrees of Progress* Newsletter, 2016)

Oklahoma has opportunities for STEM funding and STEM careers:

- Oklahoma's five major industry sectors are the backbone of our economy: Aerospace & Defense; Agriculture & Biosciences; Energy; Information & Financial Services; Transportation & Distribution. (Source: stateofsuccess.com/industries).
- Tulsa Fab Lab: Tulsa is one of over 2,000 MIT-chartered Fab Labs in more than 78 countries, it is one of a very few independent non-profit labs in the U.S., and the first in the southeastern region of the United States. Furthermore, we are one of the top labs globally in terms of leadership, organization, support, size and capabilities, and an excellent example of the impact a fab lab can make on a community.
- Organizations, like the OERB and the OKC Thunder Explorers program (with Devon Energy) provide materials and professional development for teachers and students in STEM

Appendix II: Oklahoma Science Standards in Early Childhood

Table 1

Oklahoma Early Learning Guidelines for science

Age Range	Standards
Infants and Toddlers	• Use senses to explore environment • Begin to develop scientific skills such as observing, comparing objects and exploring in the environment • Investigate objects with physical properties and basic concepts of the earth • Observe and investigate living things
Pre-k and 3-5 Years Old	• Investigate and experiment with objects to discover information • Investigate and describe objects that can be sorted in terms of physical properties • Observe and investigate plants and animals • Investigate and observe the basic concepts of the Earth o Earth Materials o Daily Weather o 4 Seasons Preserving the environment