More Than a Foundation

Young Children Are Capable STEM Learners

Elisabeth McClure

Two second-graders sit on their knees with quiet intensity, stacking unit blocks on a wide tower, higher and higher. A casual observer might think they're simply enjoying the scale of their project and looking forward to knocking it down. Their teacher might see more, understanding that their activities are setting the stage for important spatial skills and physics concepts. Reaching as high as she can, one of the children drops a marble into the top of the tower, which is now over five feet high. Both children observe the tower intently. They hear a click, click, click, click, but no marble is in sight. The marble finally emerges from the bottom of the tower, rolling down a ramp and onto the carpet. The two children jump up and down, clapping and exclaiming, "Yay!"

What is easy to miss in this scenario is the engineering capacity *already present* in these two young children. The children had hidden in their tower a series of zig-zagging ramps—like the ramps in a parking garage—each placed at a precise distance from the previous one and stacked with care at alternating heights. In fact, the children had built and tested several smaller prototypes of the tower to determine the appropriate ramp distances. One of their key discoveries was that putting the ramps too close together resulted in too much marble speed (the marble would shoot out the sides of the tower), but putting the ramps too far apart resulted in the marble dropping straight down through the center of the tower. They worked collaboratively to get the design right, then they built the deceptively simple-looking tower on a larger scale with a complex, invisible inner structure (Van Meeteren & Zan 2010).

Seeing Is Believing

The opening vignette is drawn from a video embedded in *Revealing the Work of Young Engineers in Early Childhood*, by Beth Van Meeteren and Betty Zan, available at http://ecrp.uiuc.edu/beyond/seed/zan.html.

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In the minds of these children, too, there was a complex inner process—one that is hard to see, which often results in adults underestimating young children's current capacities. As new research shows, many people believe that "real" science, technology, engineering, and mathematics (STEM) learning doesn't occur until children are older, and that exposure to STEM concepts in early childhood (birth to 8 years) is only about laying a foundation for the serious STEM learning that takes place later (McClure et al. 2017).

Many people believe that "real" STEM learning doesn't occur until children are older.

This couldn't be further from the truth. A recent two-year research analysis found that young children are capable of engaging in, at developmentally appropriate levels, the scientific practices that high school students carry out (McClure et al. 2017). As one researcher explained, young children "can make observations and predictions, carry out simple experiments and investigations, collect data, and begin to make sense of what they found" (16). Even in the first year of life, babies systematically test physical hypotheses when they see something that doesn't conform to their expectations (McClure et al. 2017). For example, researchers showed 11-month-olds a toy car going off the side of a table and appearing to float; the babies were more likely to observe the strange car for longer than normally behaving toy cars and to try exploring and dropping the car themselves (Stahl & Feigenson 2015). And, as the children building the tower demonstrated, young children are capable of using engineering habits of mind (e.g., systems thinking, creativity, optimism, communication, collaboration, supported persistence, and attention to ethical thinking) in their free-play activities (Van Meeteren & Zan 2010).

The research is clear: when we say children are "born scientists," we're not just being cute; they really are active scientists, *right now*, systematically and intentionally exploring their environments, even from the day they are born.

Never too young for STEM

The misconception about STEM being more meaningful for older students is important for several reasons. First, early STEM exposure is critical for later educational outcomes; when adults downplay its importance in the early years, they also diminish young children's current and future potential. Research shows that among preschool-aged children, knowledge of math is a better predictor of later academic achievement than early reading or attention skills (Duncan et al. 2007). Some argue that early STEM is as critical today as early literacy exposure (McClure et al. 2017). STEM habits of mind—such as critical thinking, persistence, and systematic experimentation—are important across *all* subject areas and may be essential to how children learn to learn (Duncan & Magnuson 2011). This development is not just about the basics like counting and vocabulary, although these skills and background knowledge are important too; it's about problem solving and other higher-level skills that transfer across many domains.

Think of it this way: as we learn new skills, our brains weave skill strands into ropes we use to solve problems, meet challenges, and, in turn, acquire new skills. When children have opportunities to practice framing questioning, collecting data, and solving scientific problems, they build strong ropes that can be used in many ways, now and throughout life (McClure et al. 2017).

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Take, for example, the profound ties between STEM learning and language learning. Early STEM instruction leads to better language and literacy outcomes (Sarama et al. 2012), and exposure to more spatial language during block play in infancy and early childhood leads to improved spatial thinking abilities (Pruden, Levine, & Huttenlocher 2011). Furthermore, math skills and reading skills at kindergarten entry are equally predictive of reading skills in eighth grade (Business Roundtable 2016), and background knowledge about the world and how it works (much of which falls within the realm of STEM concepts) is critical for listening comprehension throughout life and for reading comprehension once children are able to sound out words (Guernsey & Levine 2015). So when adults do not fully appreciate the importance of STEM learning in early childhood, they do children a serious disservice, weakening their potential development across many other domains such as literacy and executive function.

But just because children are born scientists doesn't mean they can do all this alone; they need adults to help them realize and expand their STEM capacities (Early Childhood STEM Working Group 2017). This leads to the second reason this misconception is so important: adults' attitudes and beliefs about STEM learning often transfer to children. For example, one recent study found that the strongest predictor of preschoolers' math learning was their teachers' belief that math education was appropriate for their age (Seker & Alisinanoglu 2015). These beliefs also lead to concrete changes in the methods and amount of time teachers spend on STEM topics: when teachers hold negative attitudes toward early mathematics, for example, these feelings lead to avoiding math instruction, and teaching math in ineffective ways (McClure et al. 2017).

When we say children are "born scientists," we're not just being cute. Children really are intentionally exploring their environments.

Teachers come by these feelings honestly and may even be passing on what they themselves were taught. A recent study of teacher-preparation faculty members in California and Nebraska reported that they considered including early mathematics less important than other domains in the preparation of early childhood teachers. And the cycle may not end there—the faculty members also said that they themselves feel less prepared to teach math than they do other subjects (Austin, Sakai, et al. 2015; Austin, Whitebook, et al. 2015). In other words, there is a misconception about the suitability

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of STEM topics for young children that is passed from one generation of teachers and teacher educators to the next. It is time to break the cycle.

Parents' beliefs also play a critical role in their children's STEM success. For example, parents' beliefs about their child's ability in math are a stronger predictor of the child's self-perception in math than the child's previous math *scores* (Gunderson et al. 2012). In other words, when teachers and parents don't think that young children are capable of real STEM learning, *children believe them*. This results in a self-fulfilling and detrimental STEM prophecy. But there is reason for hope: when the adults in a child's life believe in and support a child's STEM capacity, the child's natural abilities are both acknowledged and then expanded (McClure et al. 2017).

Incorporating STEM into early learning

To appropriately bring STEM into early learning, teachers need support, including high-quality, proper preservice training and ongoing professional development. This will require an enormous investment from universities, school systems, funders, and society at large. Adults at every level of a child's complex ecosystem will need to commit to the importance of early learning generally, and of early STEM learning in particular (for a framework describing the commitments necessary at each level, see McClure et al. 2017).

The role of a good STEM teacher is often to resist directly answering children's questions.

In the meantime, what can teachers do, without having to wait for systemic changes in the broader systems in which they work? Realizing that young children have enormous capacity for STEM learning *now* can go a long way. Understanding that supporting children's growth is about encouraging STEM habits of mind, educators can incorporate engaging STEM practices in their classrooms in simple ways. Educators can start by recognizing three research-supported facts, each of which is explained in the following sections: you don't have to be an expert; you're not alone; and teaching STEM is not an either/or exercise.

You don't have to be an expert

Many people believe that supporting STEM learning means having STEM expertise to offer students. This makes sense, given other common misconceptions: when adults are not aware of young children's capacity to engage in real STEM practices, they tend to focus on expanding children's content knowledge. But, as in other academic domains, STEM knowledge and skills grow together. Through experiential learning (combining hands-on investigations with informative read-alouds and discussions), young children develop their conceptual understanding, acquire new facts, and engage in essential skills such as observing, forming hypotheses, collecting evidence, revising hypotheses, devising experiments, and so on (NSTA 2014). They also develop STEM understandings and habits of mind from interacting with their everyday environments in curiosity-driven ways with support from teachers and other adults.

The role of a good STEM teacher is often to resist directly *answering* children's questions. Teachers can encourage STEM habits of mind and facilitate learning by *asking* purposeful questions and then supporting children as they investigate for themselves. Classrooms that rely primarily on lecture-based instruction, in which teachers control decision making and discussion, are the least effective at fostering self-reliance and resilience, two characteristics that are foundational to STEM inquiry and practices (Van Meeteren & Zan 2010).

Supporting children's curiosity and self-direction requires intention and practice. Teachers must learn to facilitate children's open and focused exploration and promote children's reflection through representation and conversation (Hoisington 2010). One of a teacher's most important roles in encouraging children's natural STEM capacities is to help children persist when they might otherwise give up. When a child encounters frustration, it is important that a teacher not resolve the tension with an answer. Instead, teachers can help the child develop persistence by showing enthusiasm about the challenge at hand, modeling wonder and curiosity. They can ask questions that reengage the child's intrinsic desire to understand the issue. Asking questions that encourage experimentation—such as "What do you think would happen if . . .?"—rather than implying a single correct answer (e.g., "Did the ball go up or down?") help children persist and

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experience the wonder of STEM discovery (Hoisington 2010). When teachers get into the habit of asking questions like these, they may find that they themselves experience the most joy when they *do not* know the answer. When teachers are pulled into the wonder of exploration, they become immersed in the learning experience with their students, demonstrating that STEM exploration has lifelong value.

You are not alone

Some adults have the misconception that real STEM learning only happens inside classrooms, which may leave teachers feeling isolated and unsupported. But when adults recognize that even very young children are capable of meaningfully engaging in STEM inquiries anytime, anywhere, they can extend that STEM learning in multiple ways to many aspects of children's lives. As with learning a new language, children become *fluent* in STEM habits and more knowledgeable about STEM topics when they are *immersed* in them (McClure et al. 2017). The more opportunities they have to explore STEM—at museums, at libraries, and at home—the more fluent they will become.

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Understood in this way, early STEM learning is a communitywide effort, with many individuals outside of schools who can be tapped for guidance and ideas. Ideally, the community forms a network of learning, engaging young children in a variety of STEM experiences and, as needed, offering teachers and parents reviews of concepts as varied as the attributes of levers and pulleys, why mold forms, or why rainbows appear. Informal learning environments like museums are very effective at helping adults engage children's interest in STEM with thoughtful questions and conversations (Haden et al. 2014). In fact, many museums and libraries offer free resources for teachers, sometimes even including STEM professional development programs.

Teachers can encourage family engagement by sharing local STEM resources with parents. Since parents may feel anxious about supporting their child's STEM learning, it is important to communicate to them the enormous capacity of their child for STEM inquiry and the impact parents can have by modeling curiosity and asking *wh* questions—*who, what, when, where,* and *why*—throughout the day. Technology can be a powerful partner when extending children's learning at home. For example, teachers can encourage parents to use the Bedtime Math app (http://bedtimemath.org/apps/), which aims to make math part of families' everyday routines, just like a bedtime story. Using the app at home, even as little as once a week, has been shown to put children ahead by the equivalent of three months in math achievement by the end of the school year; and it is most effective for children whose parents are anxious about math (Berkowitz et al. 2015).

Teaching STEM is not an either/or exercise

Many teachers feel burdened by overwhelming curricular requirements and are skeptical about adding instructional blocks to their days. But recall that STEM habits of mind are transferable and that STEM knowledge encompases essential concepts and vocabulary; they strengthen all kinds of skills ropes,

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including literacy and attention development. When early STEM learning is understood as the development of both knowledge and inquiry-based habits of mind, teachers can begin to discover ways to infuse STEM practices and concepts into their existing curriculum. For example, a teacher may notice that many of the books she reads aloud include these STEM-like features: a problem to be solved, an evidence-driven solution that is attempted (and often iterated and reattempted), and the discovery of a method that works. Even simple books, like the lift-the-flaps board book *Where's Spot?*, by Eric Hill, contain this progression: the mother dog looks in many locations for her puppy, and to the delight of children who search along with her, she finds other silly creatures hidden along the way—a bear behind the door, a monkey in the closet. By noticing and emphasizing the mother dog's use of the scientific method, the teacher can show that STEM is everywhere and that there is an inherent drama to STEM exploration. She can also highlight the mother dog's persistence in her systematic search, the joy in the *error* of the trial-and-error-laden journey (children love finding the wrong animal behind each door), and the evidence the mother collects and uses to eventually find Spot.

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Explicit STEM-based activities can be used to enhance other curriculum blocks as well. For example, one preschool class was engaged in a segment on the book *Lost and Found*, by Oliver Jeffers, about a lost penguin finding his way home on a boat. Teachers asked the 3-year-olds to build and test boats made from aluminum foil to transport a small penguin figure across the water table. The children were deeply engaged in the activity, which enhanced their experience with the book and encouraged them to talk at length about the story, while providing an immersive and meaningful STEM experience (Draper & Wood 2017).

Conclusion

Fully embracing the enormous capacity of young children to engage in real STEM learning will take time and focused effort. Early childhood program directors and elementary school principals will need to provide space and flexibility for their educators to experiment with new ways of investigating STEM concepts together with young children. But once early educators start to embed these approaches to teaching, they will be in a prime position to help each other—and the wider

Resources

Professional development information

- Foundations of Science Literacy
  http://foundationsofscienceliteracy.org
- Early Childhood STEM Conference (annual)
  www.ecstem.org
- PBS STEM Alive
  https://whut.pbslearningmedia.org/collection/stemalive/#.WYR8odPyui4

Curriculum information and STEM activities

- Ramps and Pathways
  https://regentsctr.uni.edu/ramps-pathways
- STEM from the Start
  http://stemfromthestart.org
- PEEP and the Big Wide World
  www.peepandthebigwideworld.com/en
- Boston Children's Museum, STEM Sprouts (Teaching Guide and Parent Tip Sheets)
  www.bostonchildrensmuseum.org/stem-sprouts
- National Science Teachers Association blog "Early Years"
  http://nstacommunities.org/blog/category/earlyyears/

STEM books

- *Science Is Simple: Over 250 Activities for Preschoolers*, by Peggy Ashbrook (Gryphon House)
- Young Scientist Series curriculum guides: *Exploring Water with Young Children, Discovering Nature with Young Children,* and *Building Structures with Young Children* (Redleaf)
- *Making and Tinkering with STEM: Solving Design Challenges with Young Children*, by Cate Heroman (NAEYC)
- *Ramps and Pathways: A Constructivist Approach to Physics with Young Children*, by Rheta DeVries and Christina Sales (NAEYC)

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public—see the remarkably sophisticated, and often hidden, STEM capacity of young children *in the present*, and to see how powerful early STEM experiences can be in shaping the minds of the next generation.

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About the author

Elisabeth McClure, PhD, is a research specialist in creativity and learning at the LEGO Foundation. She is a former research fellow at the Joan Ganz Cooney Center at Sesame Workshop and the lead author of the 2017 report *STEM Starts Early: Grounding Science, Technology, Engineering, and Math Education in Early Childhood*. Elisabeth conducts research on families, young children, and digital media.
mcclure.sesame@gmail.com

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