

STEM Smart Brief

STEM Smart: Lessons Learned From Successful Schools



Nurturing STEM Skills in Young Learners, PreK–3

THE PROBLEM

Young children are avid STEM investigators, eager to explore and invent. Spend five minutes with a 3- to 8-year-old and you will field an astounding array of questions, as their own natural curiosity leads them towards STEM inquiry. “How can we all get a fair share of these cookies?” “How can I make my block skyscraper real tall—but not fall over?” “How can that log float on top of the lake? Isn’t it heavy?” Young children are also the earliest adopters of technology, grabbing for cameras, smart phones, and other tools as soon as they are able.

Supporting and guiding this natural desire to explore STEM ideas and phenomena can have lasting benefits. As noted in the National Research Council’s *A Framework for K–12 Science Education Practices*, “... before they even enter school, children have developed their own ideas about the physical, biological, and social worlds and how they work. By listening to and taking these ideas seriously, educators can build on what children already know and can do.”¹ Yet current data on school readiness and early mathematics and science achievement—data on the “T and E” of early STEM learning is not available—indicate that we are not giving young children the support they need to be “STEM Smart.”

Striking Statistics: Early Education under the Scope

- * Leading economists concur that high-quality early education makes dollars and sense²; an analysis of the economic impact of the Perry Preschool program showed a 7% to 10% per year return on investment based on increased school and career achievement.³
- * Researchers have found that effective early mathematics education can enhance later learning and narrow achievement gaps.^{4,5,6,7,8}
- * Approximately 40% of U.S. children are not ready for kindergarten,⁹ and too many children reach Grade 4 lacking key science and math skills and knowledge.¹⁰
- * Only 34% of Grade 4 students achieved a score of “At or Above Proficient” on the science portion of the National Assessment of Educational Progress (NAEP).¹¹
- * Only 40% of Grade 4 students achieved a score of “At or Above Proficient” on the mathematics portion of the NAEP.¹²

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KEY RESEARCH

A wide array of factors, some related to the complex PreK–3 learning landscape, diminishes the powerful, positive effect that early STEM learning can have. PreK education has been referred to as a “crazy quilt”—composed of child care centers, Head Start, school PreK programs, family child care—funded through a plethora of sources, with different standards, of inconsistent quality, and with scant focus on fostering early STEM learning. At the early elementary level, schools also vary widely in their resources, quality, effectiveness, and time spent on instruction in the disciplines related to STEM education—particularly science, technology, and engineering.

Challenges in three critical areas of the early learning landscape may bar the way to the successful STEM learning of children ages 3 to 8:

- Curriculum and Instruction
- Educator Development
- Standards

It’s key to focus on these challenges across the PreK–3 span of the learning continuum. At ages 5 to 8, children can have more in common developmentally with younger peers than with students in Grade 4.¹³ PreK–3 educators will need to join forces to tackle these challenges, ease transitions between grades, and ensure positive STEM learning outcomes.

Curriculum and Instruction

The “most effective” way to foster young children’s STEM learning is a hot topic of debate that has entangled the field in a false dichotomy: play “vs.” learning. As long as the focus remains on the needs and developmental stage of each child, nurturing early STEM learning need not be an “either/or” proposition. As researcher Kyle Snow suggests, there should be “a place for both direct instruction and play.”¹⁴ Increasingly, a synthesis of instructional approaches is being viewed as key to successful early STEM learning.

Play-based curriculum is widely acknowledged to be a key dimension of effective early learning.^{15,16,17} Play segues smoothly into learning when teachers intentionally plan STEM experiences—focused on key concepts and skills—let children take the lead in exploring, and ask open-ended questions that cause children to reflect, form theories, ask questions, and explore more. Although experts view this type of learning as crucial for PreK children, K–3 children also benefit from this approach. Karen Worth, Chair of the Elementary Education Department at Wheelock College and science advisor for *Peep and the Big Wide World* observes, “For young children, science is about active, focused exploration of objects, materials, and events around them.”

Curricula that features direct instruction is also key to building PreK–3 children’s STEM skills and knowledge.^{18,19} Douglas Clements, Executive Director of the Marsico Institute of Early Learning and Literacy at the University of Denver’s Morgridge College of Education notes that research-based learning trajectories²⁰ embedded in curricula are a particularly important facet of effective early STEM education. Clements notes, “STEM learning trajectories start with a goal and involve a developmental progression—students’ successive levels of thinking related to the goal. Based on their understanding of students’ thinking, teachers fine-tune activities to help students move along the developmental progression to achieve the goal.”

All approaches to nurturing PreK–3 children’s STEM skills and knowledge should reflect the following eight indicators of effective PreK–3 curriculum, as identified by the National Association for the Education of Young Children (NAEYC) and the National Association of Early Childhood Specialists in State Departments of Education (NAECS/SDE):²¹

- Children are active and engaged
- Goals are clear and shared by all
- Curriculum is evidence-based

- Valued content is learned through investigation, play, and focused, intentional teaching
- Curriculum builds on prior learning and experiences
- Curriculum is comprehensive
- Professional standards validate the curriculum’s subject-matter content
- Research and other evidence indicates that the curriculum, if implemented as intended, will likely have beneficial effects

All approaches to nurturing PreK–3 children’s STEM skills and knowledge can also give teachers opportunities to build, and help children apply, *executive function skills*.²² These skills include organizing information, staying focused, strategizing, planning, and exercising self-control.²³ Although experts view executive function skills as key to school readiness and success,²⁴ a high percentage of PreK–3 teachers do not know or understand their role in early learning and need tools and training to help them foster children’s skills.²⁵

Susan Carey, Henry A. Morss Jr. and Elizabeth W. Morss Professor of Psychology at Harvard University, says that executive function (EF) skills play a pivotal role in children’s early and later STEM learning. “In math and science class, children learn theories and have to be able to make sense of abstract representations,” she notes. “They have to connect how they understand things now to the new theory they learn—requiring them to make conceptual changes. Children who score higher on EF tasks make those conceptual changes faster.” Although children can strengthen EF skills throughout their lives, the early years present an especially important time to acquire these skills. “EFs are part of the specialization of the pre-frontal cortex,” Carey says, “This part of the brain is massively developing between infancy and ages 6 to 7.”

Regardless of the combination of effective approaches used, it is essential to devote adequate time to nurturing PreK–3 children’s early STEM learning. Currently, that is not

happening. At the PreK level, the emphasis has traditionally been on cultivating young children’s language and literacy development, with a bit of math. “Comprehensive” PreK curricula said to cover math may not necessarily do so; one study of such a curriculum found that just 58 seconds of a 360-minute day were spent on math.²⁶ PreK teachers seldom teach science, and exploring engineering ideas is rarely part of PreK learning. In fact, the Committee on K–12 Engineering Education identified the NSF-funded PreK–1 *Young Scientist Series* as the only preschool curriculum of relevance in its report on the state of U.S. engineering education.²⁷

K–3 teachers spend more time on mathematics instruction. Yet science, technology, and engineering continue to receive short shrift. In part, this might stem from the current testing environment and a strong focus on testing mathematics knowledge and skills. A Horizon Research study found that “...in Grades K–3, reading/language arts and math combined for a total of 143 minutes of the school day on average, while science accounted for 19 minutes of that same day.”²⁸ According to the Committee on K–12 Engineering Education, elementary and secondary school engineering education is “still very much a work in progress.”²⁹

At both the PreK and K–3 level, early technology learning remains a murky area. Concerns linger about how to effectively draw upon technology to enhance learning—best types of technology tools, how much time children should spend exploring technology, uneven access to technology—as well as teachers’ “digital literacy.”³⁰ However, 2013 findings from the *Ready to Learn PreKindergarten Transmedia Mathematics Study* highlight the positive role that judicious use of technology can play in early math learning and teaching and offer useful implications for the effective integration of technology into early STEM instruction.³¹

Educator Development

Teachers are the key ingredient in effective PreK–3 STEM learning. They must be prepared to adeptly draw upon strategies to promote children’s learning and tailor curriculum to meet the needs of each child.^{32,33,34} Yet recent reports indicate that current systems of PreK–3 teacher preparation, licensure, and hiring are often inadequate, and that young children’s educators do not have the training they need to support children’s learning.^{35,36} Focusing on STEM, there are strong indications that, across the PreK–3 continuum, teachers need more support to successfully nurture children’s STEM learning.³⁷

There is evidence that many PreK teachers do not—and do not know how to—effectively promote young children’s early math and science learning.^{38,39} For decades, the PreK workforce has grappled with complex challenges—insufficient pre-service preparation, different licensing criteria, extremely low pay for long hours, high turnover—that undermine its ability to fully support children’s learning. Kimberlee Kiehl, Executive Director of the Smithsonian Early Enrichment Center, reflects: “When you talk about the PreK world, teachers often come into the job having had no coursework in STEM at all. They’re not prepared for it, and there’s very little professional development out there for them.” One survey of hundreds of PreK educators found that 94% were interested in participating in professional development in mathematics.⁴⁰

At the early elementary school level, recent reports highlight the need to improve the preparation and professional development of mathematics and science teachers.^{41,42} A Horizon Research study found that only 39% of elementary school science teachers “feel very well prepared to teach science.”⁴³ Slowly, some states are making progress in strengthening their systems of PreK–3 teacher preparation. For example, Georgia requires PreK–3 teachers to complete several courses that deepen their understanding of mathematics and how to support children’s early math learning; prospective PreK–3 teachers attending the University of Central Florida must complete a

course, “Teaching Science and Technology to Young Children,” that prepares them to promote children’s STEM learning.⁴⁴

Innovative professional development work is also underway. In Connecticut, Massachusetts, and Rhode Island, PreK teachers have completed *Foundations of Science Literacy*, a 6-month, credit-bearing, college-level course that combines face-to-face instruction with mentoring and performance-based assignments.⁴⁵ The course draws upon *The Young Scientist Series* PreK–1 curriculum and has been found to improve teachers’ inquiry-based science instruction, lead to gains in teachers’ science content knowledge and pedagogical content knowledge, and increase children’s ability to solve scientific challenges.

Standards

Standards-based reform has brought challenges and opportunities to PreK–3 STEM education. These standards and guidelines spotlight what young children need to know and be able to do at different ages—and have the potential to help PreK–3 teachers enhance STEM education. Yet concerns and caveats accompany the standards.

At the PreK level, there are concerns that the Common Core State Standards (CCSS) and Next Generation Science Standards (NGSS) might create pressure for children to tackle Kindergarten-level STEM content and skills before they are ready to do so, in ways they do not learn best, and to the diminishment of other kinds of support (e.g., social-emotional). Concerns have also arisen regarding how states are implementing and assessing early learning standards—and how well state early learning standards align with the CCSS and NGSS.

At the K–3 level, there are concerns that a narrow focus on the CCSS and NGSS, high stakes testing, and ensuring that children “test well” might take center stage—at the expense of fostering students’ deep STEM investigations and understanding.

NAEYC’s and NAECS/SDE’s elements of effective early learning standards⁴⁶ might be useful for the field to consider as it moves forward to implement new K–3 STEM-related standards, as well as to continue to implement PreK early learning standards:

- Emphasize significant, developmentally appropriate content and outcomes—by NAEYC’s definition, this entails knowing what is typical at each stage of early development based on research; understanding and addressing each child’s interests, abilities, and progress; and ensuring that standards are implemented in ways that are meaningful, relevant, and respectful for each child and family
- Implement and assess standards in ways that support all young children’s development—this includes maintaining methods of instruction that include a range of approaches, including the use of play and both small- and large-group instruction
- Provide support to early childhood programs and professionals—including tools and professional development—and to families in understanding the standards and how they can support their children’s learning

PROMISING PROGRAMS

The National Science Foundation supports a wide range of STEM programs—both promising and proven to have positive outcomes—for early learners. Here are four examples.

Building Blocks⁴⁷

Designed by researchers at the University at Buffalo, the Building Blocks software-based curriculum helps PreK–2 teachers weave mathematics learning into the fabric of classrooms through art, puzzles, block corner explorations, songs, and more. This approach to “mathematizing” children’s activities builds on their ability to learn math relevant to their lives. Building Blocks develops children’s mathematical thinking and reasoning abilities.

Building Blocks uses print, manipulatives, and computers to extend children’s prior mathematics learning. The curriculum builds the skills and knowledge outlined in the NCTM PreK–2 standards and prepares children for successful learning throughout their academic careers.

Teachers can use Building Blocks as a complete PreK mathematics curriculum or draw upon the materials to supplement and enrich K–2 curricula (with extensions to Grade 6). The curriculum supports teachers in integrating assessment into instruction to gauge children’s needs.

Peep and the Big Wide World⁴⁸

Peep is a newly hatched chick who explores his world with friends Chirp (a robin) and Quack (a duck)—finding science and fascination at every turn. WGBH Boston and 9 Story Entertainment, in association with TVOntario, produced this animated series for children ages 3 to 5.

Each half-hour episode contains two stories that highlight specific science concepts, plus two related live-action shorts presenting real kids playing and experimenting in their own worlds. The Peep website includes games, videos, handouts, and activities for families, and resources for educators who want to bring Peep into their classrooms.

The Peep team works with early childhood teachers, public libraries, museums, community-based organizations, and families to motivate their support of preschoolers’ innate curiosity and interest in exploration.

ScratchJr⁴⁹

Developed by the Lifelong Kindergarten group at MIT Media Lab, the free Scratch software enables students ages 8 to 16 to learn how to code and create their own interactive stories, games, and animations. Today, students in 150 countries and thousands of schools use Scratch.

Building on Scratch's success, MIT teamed up with the DevTech Research Group at Tufts, the Playful Invention Company, and early childhood education leaders to create ScratchJr. This prototype software and curriculum-in-development will allow children ages 5 to 7 to easily learn how to program using Scratch. The overarching goal of the ScratchJr team is to develop innovative technologies and curricular materials to support integrated STEM learning in early childhood education. Public release is scheduled for 2014.

ScratchJr features a developmentally appropriate interface and a library with STEM, math, and literacy curricular modules that meet federal and state early childhood education mandates. In ScratchJr's virtual resource community, teachers can ask questions about the software, share projects, and get feedback and parents can learn how to extend children's classroom learning.

Tools of the Mind⁵⁰

Developed by Deborah Leong and Elena Bodrova, Tools of the Mind is a yearlong play-based curriculum inspired by Vygotsky that features 40 activities that promote the development of EF skills, as well as building numeracy and literacy skills.

There are two versions of Tools of the Mind, one for children ages 3–4 and one for kindergarteners. Currently, over 30,000 children are learning from the curriculum—in Head Start programs, public and private preschools, and kindergartens.

Studies have identified positive outcomes from Tools of the Mind. A large study of inner-city classrooms serving children at risk for poor EF development randomly assigned classrooms to follow Tools of the Mind or a control curriculum that also focused on numeracy and literacy skills. The Tools curriculum had large effects on standardized measures of EF, measures deriving from computerized tasks that were totally unlike anything in the curriculum.

CONCLUSIONS

Ensuring every child has a high-quality early STEM education is one of the best investments our country can make. Tomorrow's engineers are building bridges in the block corner today. Tomorrow's scientists are doing "field work" at recess, inspecting the structure of a fallen leaf.

To keep them exploring and ensure their positive outcomes, the full array of early childhood stakeholders must come together to create a strong, smooth continuum of PreK–3 STEM learning that features:

- Teachers who have received high-quality pre-service and in-service training focused on STEM disciplines, effective instruction and curriculum, and how to draw upon standards and assessment to enhance each child's STEM learning
- Teachers who have received high-quality pre-service and in-service training focused on the executive function, self-control, and social skills necessary for successful learning in any subject, including STEM subjects
- Sufficient time spent on STEM learning, every step of the way from PreK–3 and beyond
- Research-based STEM curricula that makes use of learning trajectories to progressively build children's skills and knowledge
- STEM-focused play and hands-on learning in formal and informal settings that gives children free rein to explore STEM, guided by knowledgeable educators
- Collaboration among PreK programs, schools, informal learning environments, and families focused on enhancing children's STEM learning

Creating such a continuum will require significant commitment and coordination, yet will yield astronomical pay-offs—a STEM-capable workforce and citizenry—in the future.

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