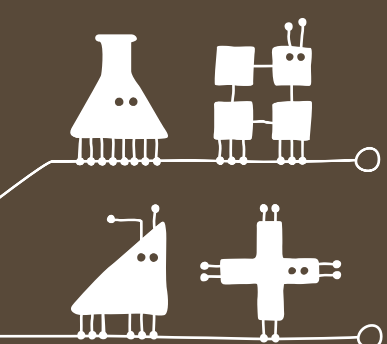
STEM starts early

Grounding science, technology, engineering, and math education in early childhood



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Winter 2017

The Joan Ganz Cooney Center at Sesame Workshop
New America

This material is based upon work supported by the National Science Foundation under Grant No. 1417878. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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Suggested citation
McClure, E. R., Guernsey, L., Clements, D. H., Bales, S. N., Nichols, J., Kendall-Taylor, N., & Levine, M. H. (2017). *STEM starts early: Grounding science, technology, engineering, and math education in early childhood*. New York: The Joan Ganz Cooney Center at Sesame Workshop.

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I. executive summary

Watch a group of very young children engaged in planting a community garden. What are they learning? They are starting to grasp fundamental concepts about science and the natural world—how much water is needed, what roots are for, how a plant's growth changes with the seasons, and so forth. These are ideas that lay the groundwork for deeper learning about environmental science and plant biology, critical thinking skills, problem solving, and trial and error. Whether it is gardening, building forts, stacking blocks, playing at the water table, or lining up by height in the classroom, children demonstrate a clear readiness to engage in STEM learning early in life. And research from several disciplines is converging to show the importance of a new national commitment to early learning generally. Brain and skills-building experiences early in life are critical for child development, and high-quality early STEM experiences can support children's growth across areas as diverse as executive function and literacy development.

In fact, just as the industrial revolution made it necessary for all children to learn to read, the technology revolution has made it critical for all children to understand STEM. To support the future of our nation, the seeds of STEM must be planted early, along with and in support of the seeds of literacy. Together, these mutually enhancing, interwoven strands of learning will grow well-informed, critical citizens prepared for a digital tomorrow.

So why is science, technology, engineering, and math (STEM) learning not woven more seamlessly into early childhood education? An examination of the environments and systems in which children live reveals that it is not due to a lack of interest or enthusiasm on the part of children, teachers, or parents. The barriers to STEM learning for young children are more complex, subtle, and pervasive than decision-makers currently realize. For example, in December 2013, the National Science Foundation (NSF), the Smithsonian Institution, and Education Development Center cohosted a *STEM Smart* workshop to reach early childhood practitioners. Participants were delighted to learn of evidence-based practices and tools, but many declared that they felt too constrained by current school structures and policies to apply what they were learning. They voiced concerns about the misapplication of new education standards, disconnects between preschool and elementary school practices, and an underprepared workforce.

In response to these concerns and the growing scientific consensus about the importance of early STEM learning, the Joan Ganz Cooney Center at Sesame Workshop and New America embarked on an exploratory project, funded by the NSF, to: (a) better understand the challenges to and opportunities in STEM learning as documented in a review of early childhood education research, policy, and practice; (b) make recommendations to help stimulate research and policy agendas; and (c) encourage collaboration between pivotal sectors to implement and sustain needed changes. We also accounted for new research on widely held public assumptions about what young children need and how they learn, assumptions that may be barriers to progress. This report is the culmination of those efforts.

To gain perspectives from stakeholders in each of the early childhood areas—research, policy, and practice—we invited their input. First, we interviewed prominent early STEM researchers, policy makers, and teacher educators. Second, we conducted two focus groups with teachers, one with child care and preschool educators and one with early elementary school teachers. The insights we gained from the interviews and focus groups shaped the focus of this report; quotes from them are featured throughout.[a] Third, we commissioned experts to contribute to an early draft of this report, and their work is evident throughout this paper. Once a working draft of the report was complete, we invited experts from research, policy, and practice to discuss it and to help inform a national action agenda at a two-day meeting at New America in Washington, DC.

The multiple perspectives that shape this report are a reminder that no child develops in a vacuum. Children are affected by their home and school environments, the policies and practices that inform those environments, the cultural values that scaffold them, and the complex relationships between these factors. Many of the experts we consulted during this project were eager to see these factors considered more often in concert, and to see leaders from multiple sectors engaged in more consistent dialogue and collaboration. For this reason, we have presented the evidence and our recommendations using Urie Bronfenbrenner's ecological systems theory.

Findings

Our examination of the STEM landscape and the players in it produced five key findings:

1. Both parents and teachers appear to be enthusiastic and capable of supporting early STEM learning; however, they require additional knowledge and support to do so effectively.

- Many parents and teachers experience anxiety, low self-confidence, and gendered assumptions about STEM topics, which can transfer to their children and students.
- Both groups can benefit from reconsidering STEM in the context of developmentally-informed, playful learning—like block play, gardening, and exploring puzzles—which engages their own and their children's curiosity and wonder.

[a] The names of interview and focus groups participants are not revealed in the report.

- Teachers will benefit especially from a greater understanding of children's developmental learning progressions, which they can use to tailor instruction.
- Parents and teachers are receptive to high-quality training in these areas.

2. Teachers in early childhood environments need more robust training and professional development to effectively engage young children in developmentally appropriate STEM learning.

- Pre- and in-service training must be substantive, interconnected, and ongoing, and instruction must include STEM content, child developmental learning progressions in STEM, and well-modeled and practiced pedagogy.
- STEM learning is already present in classrooms and can be emphasized to both teachers and students. Teachers should be trained to think of STEM as mutually inclusive of their other teaching domains and encouraged to weave STEM seamlessly into their existing curricula and play times.
- To counter pre-existing anxiety and attitudes about STEM topics, teachers need to experience the very same hands-on, engaging learning environments and practices as we hope to see for America's young children. Teacher educators should encourage intrinsic curiosity and joy, and model sensitivity to developmental trajectories and best pedagogical practices.

3. Parents and technology help connect school, home, and other learning environments like libraries and museums to support early STEM learning.

- Parents, teachers, technology, museums, and libraries create a web of charging stations where children can power up and extend their STEM learning. Immersion in this web of STEM learning leads to STEM fluency.
- Parents can help activate a child's in-school learning by engaging in related activities at home or outside the home.
- Museums and other learning environments are effective engagement points for both parents and children, and even brief parental instruction at these venues can have an important impact on how parents support STEM learning.
- High-quality educational media, like the Bedtime Math app and those created by the PBS Ready to Learn initiative, can support and extend school learning into the home and beyond. These tools provide an important scaffold for parents who may experience anxiety about supporting STEM learning.

4. Research and public policies play a critical role in the presence and quality of STEM learning in young children's lives, and both benefit from sustained dialogue with one another and with teachers in the classroom.

- Education policies must focus on greater alignment (the coherence of policy expectations and instruments) and continuity (connections across grade levels) across the early grades, starting with preschool.

- Researcher-practitioner partnerships, in which practitioners are involved as ongoing partners as early as the research design stage, play an essential role in supporting the iterative process of education reform.
- Current early STEM research funding appears to be skewed toward older children.

5. An empirically-tested, strategic communications effort is needed to convey an accurate understanding of developmental science to the public, leading to support for meaningful policy change around early STEM learning.

- The public holds misconceptions about STEM learning (i.e., it is for older students, children should learn other topics first, it is only important for those who especially excel in these areas, that STEM and other learning topics must be taught separately). When communicators do not carefully frame their messages, they can inadvertently activate and strengthen these misconceptions.
- The use of research-tested messages about early STEM learning makes a statistically significant, meaningful, and positive difference in the public's support for early STEM learning.

Recommendations

To successfully integrate STEM learning into early childhood education, we should consider all the systems surrounding children: We must prioritize STEM learning, while also engaging members across the child's environments. Both small and large steps can be taken, both sequentially and simultaneously, to move in the direction of greater STEM learning in early childhood.

Engage parents: Support parent confidence and efficacy as their children's first and most important STEM guides.

- Parent educators, advocates, and researchers should reach out to parents about early STEM learning *where they are* in engaging ways, through blogs, child care centers, pediatricians, parenting magazines, and publications like *Zero-to-Three* and *Young Children*.
- Communicators should emphasize what early STEM learning actually looks like, providing a variety of clear and accessible examples of early STEM exploration (e.g., participating in a community garden, testing which bath toys float and sink) that make it clear that STEM can happen anytime, anywhere, even with minimal resources.
- Resources for parents should go beyond simple early STEM tip sheets for parents; policy makers, community leaders, and media producers should work to make comprehensive, long-term training on early parental STEM support more accessible to more parents using mobile technology.

Support teachers: Improve training and institutional support for teaching early STEM.

- Education leaders should ensure that efforts to improve the workforce include interconnected and ongoing STEM training and support, which is meaningfully woven into teachers' existing classroom practices.
- Teacher preparation and training programs—both pre- and in-service—should include, in interconnected and meaningful ways: STEM content, training in children's developmental learning progressions in STEM, and well-modeled and practiced pedagogy situated in the classroom.
- To counter existing attitudes towards STEM, preparation and training programs should be designed to allow teachers to experience STEM learning in the same ways that the children will. Teacher education should be driven by curiosity, should allow for tinkering and exploration, and should help teachers weave a holistic understanding of the topic areas so they can empathize and model this learning for their students.
- Researchers should disseminate findings in formats accessible to teachers, addressing teacher concerns (for an excellent example, see the new report *Early STEM Matters*). Demonstrations of successful early STEM teaching should be made more accessible, enabling educators to easily find, understand, and apply the lessons in their work.

Connect learning: Support and expand the web of STEM learning "charging stations" available to children.

- Leaders in museums, libraries, and community organizations should prioritize early STEM in informal learning environments. Exhibits and interactive features should engage children, and also provide direct instruction to parents on how to engage with their children around STEM features and continue their learning beyond that environment.
- Education and technology leaders should ensure digital equity by providing access to high-speed Internet and other Digital Age infrastructure for all families with young children and the professionals who work with them.
- Public and private funders should continue to fund initiatives like Ready to Learn, which support family engagement in STEM learning.
- Media officials should undertake projects that build public interest in early STEM and form a bridge for home-school learning connections.

Transform early childhood education: Build a sustainable and aligned system of high quality early learning from birth through age 8.

- All levels of government, along with state and community leaders, should apply existing and new funding resources to improve general early childhood teaching and quality.

- Special attention should be paid to address professional preparation, staff development, and continuing education, with attention to the vast disparities in compensation, benefits, and work conditions that exist between K–12 educators and their counterparts in early learning settings.
- Federal and state policy leaders should look to the recent report from the Institutes of Medicine and the National Research Council, *Transforming the Workforce for Children Birth Through Age 8*, for 13 important recommendations for creating the professional standards to support high quality early learning.

Reprioritize research: Improve the way early STEM research is funded and conducted.

- Leaders at the federal and state levels should take stock of what research is being funded on early STEM learning across agencies and research organizations, in order to identify knowledge gaps and form the basis for a government-wide strategy to support early STEM learning research and development.
- Program designers should encourage studies that enable a two-way street between research and practice. Use insights from communications science to build public will for integrating early STEM learning into early education.
- National research agency leaders should establish an interagency and interdisciplinary research program with emphasis on early learning and STEM.
- Philanthropic organizations should continue to use their research grants and convening power to engage policymakers, community leaders, and private investors in early STEM efforts.
- The National Science Foundation, an exemplary agency for early STEM funding, should take the following steps to model changes for other funding organizations: increase funding for research on STEM learning among very young children, linking the preschool years to the early elementary school years; prioritize cross-disciplinary research and dissemination on early learning; and reward innovation in design and expand project funding for applied work.

Across all these recommended actions, use insights from communications science to build public will for and understanding of early STEM learning.

- All stakeholders and advocates of early STEM, across all the child's environments, should use a unified communications plan to ensure that they do not activate negative pre-existing cultural attitudes about early STEM. A one-page Communications Guide is included on the final page of this Executive Summary.
- National, state, and local leaders should convene multi-sector summits on the future of early learning and STEM to build awareness and maintain a cohesive action plan across stakeholders.

The complete findings and a more detailed set of recommendations can be found in the full report.

II. introduction

Motivation

Take a walk around a great neighborhood and you will find America's youngest children learning through discovery. Enter a preschool classroom, where children are splashing each other and giggling around a water table, learning about volume and displacement. At the elementary school, a small group is taking a nature walk, investigating the blossoms on a flowering tree, while another group is measuring the dimensions of a jungle gym and creating drawings of its construction. These early learners are engaged in science, technology, engineering, and math (STEM), subjects that were once seen as too "hard" to teach young children but which are now recognized as critical to weave into their growing understanding of the world. Unfortunately, their experiences are not yet the norm for millions of young children in the United States.

Research on the early childhood years has spotlighted how children's environments and interactions with adults are catalysts for their growth and development. This has prompted policy makers, practitioners, and researchers to ask how those years can be filled with opportunities for all children to explore, investigate, and see themselves as learners. It is even more critical to provide vibrant learning environments for children from underserved communities and in vulnerable families. What needs to change to ensure that richer learning experiences are provided in all of today's child care settings, pre-K classrooms, and elementary schools? How can researchers, policy makers, and practitioners work together to ensure that all young children have access to high-quality instruction and learning environments?

When tilted toward the specific fields of STEM, these questions take on even more significance, and research is playing a significant role in helping policymakers and educators better support children's needs and potential. Studies are pointing to the importance of STEM for children's success in school and in their ability to attain good jobs as adults. Research also shows that STEM support should start early: children in disadvantaged circumstances, especially, start school lacking the foundation for that success. A 2016 study, for example, examined learning experiences in more than 7,750 children from kindergarten entry to the end of eighth grade, and found that early acquisition of knowledge about the world was correlated with later science success. Among children who entered kindergarten with low levels of general knowledge, 62% were struggling in science in third grade and 54% were still struggling in eighth grade.[1]

Other lines of research are uncovering the major barriers teachers face, starting with teacher training, that affect their ability to effectively teach STEM and promote positive attitudes toward STEM learning. Teacher educators—the faculty in educational schools and other institutions of higher education that prepare teachers—have hurdles to overcome too. For example, the Center for the Study of Child Care Employment has found that faculty members in California and Nebraska—the first states the center has studied—consider it less important to include early mathematics than other domains in the preparation of early childhood teachers; they also say that they themselves feel less prepared to teach math than they do other subjects.[2,3]

Meanwhile, professional education organizations, policymakers, and multi-sector collaborative groups like the Early Childhood STEM Working Group are starting to prioritize STEM learning in their recommendations regarding staffing, standards, and professional learning opportunities. Synthesizing and translating this new

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A note on terminology

Throughout this report,[b] we use the words ***early childhood*** to describe the period from birth through age 8. Today's young children spend their days in a variety of settings across these early years, including their homes and their relatives' or neighbors' homes, informal learning environments such as libraries and museums, child care centers and home-based family care settings, pre-K classrooms, kindergarten classrooms, and primary or elementary schools.

We use the terms ***practitioners, teachers,*** and ***educators*** of young children to refer to those who are paid to work with children across the birth-through-8 age span. However, because there are many differences in compensation, training, and standards between practitioners who work with children under 5 and those who work in the K–3 grades, we have made an effort throughout this report to be explicit about the ages being taught and to avoid confusion about whether research is focused solely on K–3 educators, solely on pre-K educators, or spanning both.

Lastly, we use the term ***pre-K*** to describe pre-kindergarten settings that employ trained teachers to lead educational experiences in a classroom or learning center for children who are a year or two away from kindergarten (usually ages 3 and 4). This includes Head Start and many other private and public programs known as preschool.

[b] The names of interview and focus groups participants are not revealed in the report.

research evidence is critical so that it can be applied in teacher preparation programs, classrooms, and homes to help reduce disparities and help more children succeed.

> "I'm trying to teach them the scientific vision: You look at that, so what do you see? You touch it, so what do you feel? And in this way, the entire class can be a science center."
>
> —Pre-K Teacher

To apply research findings effectively, STEM teaching must also be aligned with developmentally informed approaches to working with young children. In other words, they need to be based on a solid understanding of how young children learn. Efforts to improve STEM learning in the early years could help to erase the false dichotomy often drawn between children's play and their cognitive, social, intellectual, and academic development.[4] Children actively explore and investigate the world using all their senses from the moment they are born.[5] As toddlers and preschoolers they exhibit many of the characteristics of young scientists and engineers in their play, including an almost insatiable desire to take things apart, figure out how they work, and put them back together.[6] Studies show that skilled and knowledgeable teachers can facilitate children's emerging understanding of STEM concepts, practices, and habits of mind, while harnessing their natural curiosity and fostering developmentally appropriate, STEM-infused play.[7] Teachers can help children to question, explore, and reflect on their ideas about the world and how it works, all while getting their hands dirty digging for worms.

An ecological systems approach

Children grow and learn in a complex, intertwined web of relationships, experiences, and environments, yet our research frameworks, educational policies, and assumptions about what young children need do not always reflect this simple truth. In 1977, Urie Bronfenbrenner made an innovative and powerful argument: a full understanding of human development requires us to go beyond the simple one-to-one relationships between children and their immediate surroundings or caregivers. It demands that we also examine the complex, interrelated environments in which they live and the larger contexts that may affect them indirectly.[8] The ecological systems theory that developed out of this proposition has become an important tool for researchers, policy makers, and practitioners alike, influencing everything from the frameworks used by development scientists in their research[9] to the design of policy initiatives like Head Start.[10]

In education, the impact of multiple, interrelated environments and systems on the child is considerable and affects everyone involved. Educators cannot successfully teach without adequate training and resources, the support of their schools, and parent engagement; researchers cannot produce relevant studies without the support of available funds, the contribution and support of educators in the classroom, and an understanding of the political systems in which their work will be applied; policy makers cannot institute effective policies without the comprehension of the public, the cooperation of teachers, and the support of solid research; and children cannot learn at their full potential without the alignment of all these factors. For this reason, we have chosen to present this report within the framework of the ecological systems model.

Bronfenbrenner suggested that children develop within nested systems of influence. Imagine a set of concentric circles, with the child at the center (see Figure 1). The **microsystem** is the first circle around the child, the environments in which he or she is rooted. These include home, classroom, child care or after-school program, and church or other local community settings—and, of course, the people and experiences within those settings. The next circle is called the **mesosystem**, which acknowledges the relationships *between* the microsystem environments. For example, the ways that the child's schooling affects his or her home life and vice versa, directly or indirectly, or the ways that an adult's training and level of stress could affect that person's ability to make a positive impact on the child would be included in this system. The **exosystem** includes the societal structures and institutions that do not directly contain the child but can directly or indirectly affect him or her—for example, government policies and the research that spurs those policies. Finally, the outermost circle, called the **macrosystem**, consists of the cultural frames, paradigms, values, and models that shape the environment within which the child learns.

We begin our discussion with a brief review of the research that demonstrates the ways in which STEM learning positively affects the child at the center of all these systems. Then we move outward, through each of the ecological systems, laying out the ways in which our current structures foster or limit STEM learning during early childhood. Finally, we offer six recommendations based on these observations, which we believe will help nurture the growth of America's children by planting STEM education deep in early childhood: a STEM with *roots*.

Figure 1: Bronfenbrenner's ecological systems theory [8,10]

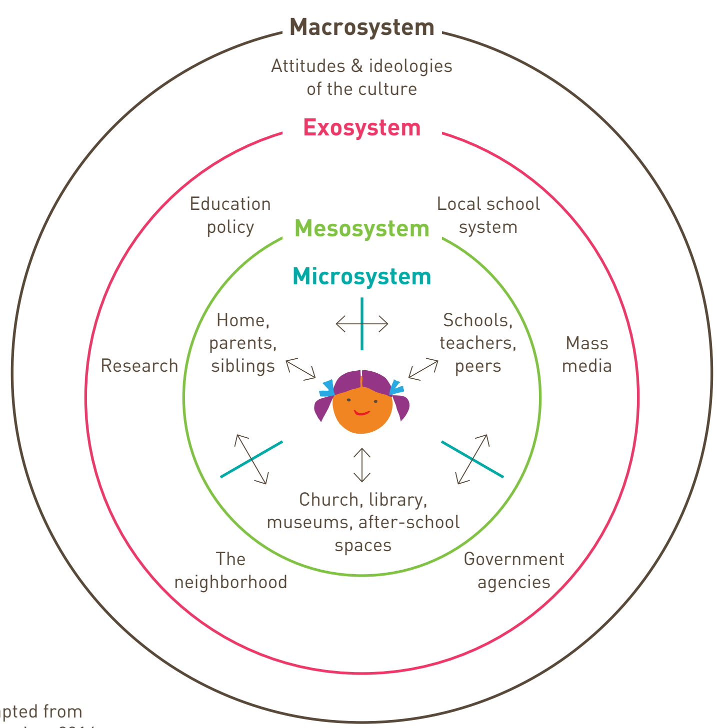
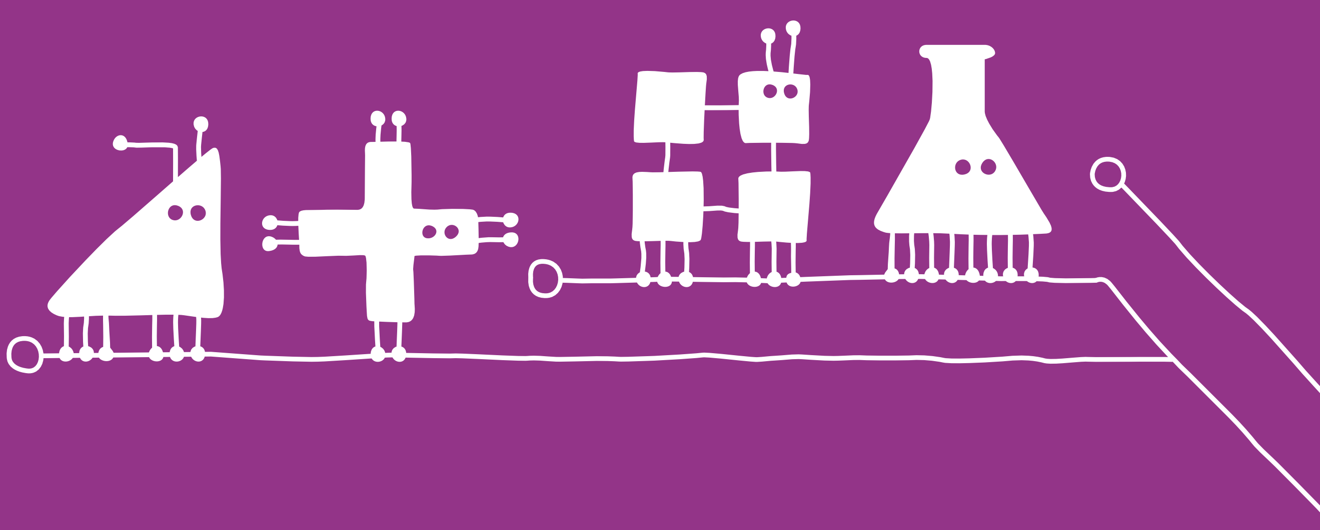


Diagram adapted from Takeuchi & Levine, 2014

III. the child at the center: what research tells us about children and STEM

Early math, science, technology, and engineering

Research shows that children can and should engage in STEM learning, even in the earliest years of life. We now know that very young children are much more capable of learning about STEM concepts and practices than originally thought, resulting in missed opportunities for early learning when we wait to start STEM education until later. In fact, a growing number of studies show a correlation between early experiences with STEM subjects and later success in those subjects or in school generally. The recent *Transforming the Workforce for Children Birth Through Age 8* report even warned that "without such education starting, and continuing, throughout the early years, many children will be on a trajectory in which they will have great difficulty catching up to their peers."[11] Research on each of the four STEM branches is demonstrating just how much is at stake in early exposure to these areas of learning.



Early mathematics has become an area of intense study over the past two decades, and the long-term effects of early exposure are now becoming clear. Math knowledge in preschool, for example, predicts math achievement even into the high school years,[12,13] and preschool math skills predict later academic achievement more consistently than early reading or attention skills.[14] Furthermore, some studies show math to be integral to how children learn to learn.[15] In other words, learning early math is about more than simply learning discrete skills such as naming numerals;[11] it is about reasoning and discovery. Yet many early childhood classrooms focus on extremely limited objectives—for example, fostering the memorization of the counting sequence, basic addition facts, and shape names by rote—and, as a result, have minimal impact on children's overall mathematical proficiency.[11] Instead, educators can foster this proficiency by providing children with opportunities to reason and talk about their mathematical thinking. For example, preschoolers can line up acorns on a table to take stock of what they have collected on the playground (say, eight big acorns and two small ones) and then determine whether they have more or fewer of a particular size. With guidance from a teacher, they can start solving problems using mathematical reasoning, such as how many more small acorns they would need in order to show equal numbers of small and big ones. Early introduction to this kind of math "talk" helps children build STEM vocabularies and acquire the knowledge necessary for deeper understanding of STEM topics later.[16]

In **early science**, as well, new research is shining a light on the impact of experiences and interactions in promoting children's conceptual learning and ability to engage in science inquiry. Children who engage in scientific activities from an early age develop positive attitudes toward science,[17,18] which also correlate with later science achievement,[19,20,21,22] and they are more likely to pursue STEM expertise and careers later on.[23,24,25] And there is now little doubt that young children can meaningfully participate in science activities. In 2014, the National Science Teachers Association (NSTA) summarized several national reports on science learning this way: "young children have the capacity for conceptual learning and the ability to use the skills of reasoning and inquiry as they investigate how the world works."[26] (For more on principles from the NSTA, see box below.) An emerging body of literature indicates that all children, regardless of background, have the capacity to learn science.[27] Multiple studies suggest that when young children enter school, they already have substantial knowledge of the natural world, can think both concretely and abstractly, use a range of reasoning processes that represent the underpinnings of scientific reasoning, and are eager, curious, and ready to learn.[9,27,28]

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Science: Guidance from NSTA drawn from the latest research

The board for the National Science Teachers Association voted in 2014 to adopt a position statement on science in early learning, defined in this case as age 3 up through preschool. The statement is based on findings from several large summative studies of science learning and endorsed by the National Association for the Education of Young Children. The statement identifies the following key principles to guide the learning of science among young children:[26]

- Children have the capacity to engage in scientific practices and develop understanding at a conceptual level.
- Adults play a central and important role in helping young children learn science.
- Young children need multiple and varied opportunities to engage in science exploration and discovery.
- Young children develop science skills and knowledge in both formal and informal settings.
- Young children develop science skills and knowledge over time.
- Young children develop science skills and learning by engaging in experiential learning.

Strengthening these abilities appears to be aided by early educators' use of and modeling of scientific and engineering practices (including inquiry-based teaching) while helping to guide children to ask questions, make observations, collect and record data, and generate explanations and ideas based on evidence. Consider, for example, the difference between using inquiry-based teaching in an exploration of how caterpillars turn into butterflies, compared to reading children a book about caterpillars and butterflies. The book may help teach new words and concepts; but if the book is used in coordination with an inquiry-based approach, children are introduced to new words and concepts *and* they can reflect on and make meaning of their own butterfly observations. This experience helps them understand the characteristics, needs, and life cycle of butterflies, and it prepares them to make predictions and generate ideas about new insects they find. An inquiry-based practice, according to the NSTA statement, gives children the basis for "seeing patterns, forming theories, considering alternate explanations, and building their knowledge."[26]

"Young children are quite capable of doing, at a developmentally informed level, all of the scientific practices that high schoolers can do: they can make observations and predictions, carry out simple experiments and investigations, collect data, and begin to make sense of what they found. Having a set of practices like these that become routinized and internalized is going to really help them learn about their world."

—Researcher

The realms of **early technology and engineering** are less well understood and have been called "the missing T & E" in early childhood STEM.[26] Technology as a subject area is complicated by the fact that many people assume that "technology in early childhood" means using digital or electronic technology, such as touch-screen tablets, in a classroom. There are many studies demonstrating the positive impact of well-designed digital media when used thoughtfully and intentionally to support early childhood learning.[29,30] However, it is important to remember that using a particular type of technology (whether a printed book, a chalkboard, or a tablet) is not the same as helping children gain *technology literacy* or teaching them that technology is used to expand our knowledge beyond what our senses can tell us, and to reflect on and share what we find out. By the same token, engineering is either missing or misunderstood in early childhood. "Exploring engineering ideas is rarely part of pre-K learning" and receives "short shrift" in K–3 grades, according to a brief published for the NSF's STEM Smart meeting in 2013.[31] But children are natural engineers, wanting to build things and design solutions, and this type of play can have beneficial effects in the long-term. For example, preschool block building predicts math achievement as far out as high school.[32]

And yet, while engineering and technology are less common as explicit subjects in the early years, instances of both have been part of early childhood classrooms for decades in the form of fort-building and block play, and in explanations of how to use tools as simple as spoons and scissors. Studies of *Ramps & Pathways*, a curriculum that encourages children to build structures of roller-coaster-like ramps using simple wood trim, balls, and other rolling objects, have shown that children are able to gain an understanding of relationships between the angle of the ramps and motion of the objects, as well as the need to test, analyze, and rework their designs.[33] Research is also beginning to explore whether and how young children should learn to use digital communications technology in pre-K and early-grade classrooms, including how tools such as Skype and other video-messaging programs, if used carefully, can introduce children to new ways of communicating and acquiring background knowledge.[34,35] In fact, some researchers are raising equity concerns regarding access to technologies, pointing out that children from low-income families who have less access to technology than their peers may be disadvantaged because they have "fewer opportunities to learn, explore, and communicate digitally."[36]

Interdisciplinary connections

Although our knowledge of the STEM disciplines is sometimes easiest to describe one topic at a time, research is now showing the importance of **interdisciplinary connections** for STEM learning. The STEM acronym is more than an easy-to-remember word; it also makes explicit that the subjects under the STEM moniker—science, technology, engineering, and math—are deeply interconnected and can be taught effectively in concert, with science and mathematics as anchors. In fact, the acronym was once "SMET," until Judith A. Ramaley, the former director of the NSF's Education and Human Resources Division, changed the acronym to STEM, justifying the change by explaining that science and mathematics are often the bookends and enablers for the applied subjects of technology and engineering.[37] When understood in this way, teaching STEM is different from teaching the individual topics of science, technology, engineering, and math because it emphasizes their potential for integration and mutual support. Research from the learning sciences has demonstrated that children benefit from contextualized, integrated lessons,[38,39] and integration often deepens understanding of relevant concepts, promotes problem-solving, and supports understanding of how concepts are applied in the real world. For example, physical science concepts like matter and force are brought to life for children when engineering design (e.g., building structures, creating systems to move water, rolling and sliding objects on ramps) is integrated into the lesson. Similarly, math learning can be enhanced when it is supported by well-designed, playful technologies (e.g., research-based computer games).[40] Total integration is not necessarily the answer, though—the integration of engineering design may not enhance many life sciences lessons, for example—and reviews of fully integrated curricula reveal little evidence that they are superior to traditional structures.[41]

In other words, educators must be intentional as they consider when and how the integration of the STEM topics will best support learning.

Some of the newest research in early STEM involves interdisciplinary connections between children's STEM skills and other important outcomes, like reading and executive function development. For example, a randomized study of the *Building Blocks* math curriculum showed that it led to higher scores on measures of early language and literacy, such as the ability to recognize letters and gain oral language skills like expressing one's knowledge and understanding spoken words.[42] Evidence also exists for the reverse: exposure to more spatial language during block play in infancy and early childhood increases children's spatial abilities when they are older.[43] A longitudinal study of children ages 6 to 9 found that language ability was associated with how they performed three years later in geometry, as well as data analysis and probability (though not in arithmetic or algebra).[44] Learning scientists are now grappling with questions of which comes first, what causes what, and what mechanisms are at work. Experts have long recognized that the practices associated with STEM invite children to engage in many forms of literacy, not just the learning of scientific vocabulary. STEM provides a context for learning across the four English-Language Arts strands identified in the Common Core state standards: reading, writing, speaking and listening, and language. Oral language in particular is a strong part of STEM learning as children gain skills to ask questions, describe observations, identify problems, and generate and share solutions.[45,46,47]

Researchers are also examining the interplay between children's executive function or self-regulation skills (e.g., self-control, sustained attention, cognitive flexibility) and their abilities in STEM subjects. Executive function and mathematics performance are strongly related to one another; in fact, it has been suggested that high-quality early math education may have the dual benefit of both supporting the math content area and encouraging the development of executive function.[48] Furthermore, executive functioning skills, particularly the ability to revise predictions based on observations, both contribute to and are supported by high-quality and facilitated early science experiences.[49]

Specific populations

Questions of how girls and boys perceive STEM subjects have been the focus of intense study in the later grades and at the postsecondary level for years, and they are becoming more routinely asked in elementary school settings as well. For example, a recent study of children in Singapore showed that the more that young girls identified with the stereotype that girls are not good at math, the less well they performed on math tests.[50] Similar research in the U.S. has found that girls internalize the stereotype as early as preschool.[51] These perceptions may affect many of the *educators* of these young students as well, since the majority of early childhood educators are women.

Language learners are another important population to consider when building quality STEM experiences in the U.S. STEM explorations offer opportunities for communication and complex reasoning, thus providing students a concrete context for using language for a variety of purposes and supporting their language development.[53] However, teachers may not automatically recognize the significance of, nor have training in, integrating language learning with STEM learning. In fact, in many schools, STEM and English-language learning are kept separate from each other because of the misconception that children should learn English prior to being exposed to STEM lessons.[54] Several initiatives are working to explore or change that dynamic. One example, among many others, is the *Language Acquisition through Science Education in Rural Schools* (LASERS) project in California, which is examining teachers' beliefs about the connections between STEM and language learning.[55] Both the Exploratorium's *Institute for Inquiry*[53] and the Hartford-based project *Literacy and Academic Success for English Learners through Science* (similarly named LASErS), work with educators and families to integrate STEM and language learning for young children.[56]

IV. the microsystem: teachers and parents as the gateway to STEM

Microsystem: the environments in which the child is directly involved, usually on a daily basis

As the most frequently and consistently present adults in a child's microsystem, educators and parents (or the other adults who raise them) are the most direct gateway to STEM learning for very young children. Many of them, however, experience anxiety about STEM topics and believe that STEM is only for older children, boys, and certain "types of kids," attitudes and beliefs that are often transferred to their children. Furthermore, many Americans believe that STEM topics can only be taught successfully in formal settings like schools (see Appendix B).

The importance of teachers

Teachers do play a critical role in the development of STEM engagement for young learners. Teachers who are confident and enthusiastic about STEM topics, and who engage their students in developmentally tailored STEM activities, pass that excitement to their students. However, many early childhood teachers are not eager and prepared to engage children in rich experiences in domains other than literacy.[27,57,58] In fact, there is widespread anxiety about topics like mathematics among teachers of young children, which correlates with the achievement of their students, particularly girls.[59] Furthermore, many teachers do not know how to adapt STEM instruction to suit the needs of their students.

> "We need to change habits of mind for teachers, not just for kids."
>
> —Teacher Educator

Teacher confidence

Many teachers, who are unlikely to have experienced engaging, inquiry-based STEM learning in their own early and K–12 education, may begin their training with negative dispositions toward STEM and the persistent science misconceptions common in our culture, even among the highly educated.[60] In fact, education has been called the most "STEM-phobic" of any college major,[61] and many education majors gravitate to early childhood or special education at least partially because there are minimal STEM course requirements and little perceived demand for teaching STEM. Many continue to hold negative feelings about math and science even after graduation. In mathematics, for example, these feelings lead to undervaluing the teaching of math, avoiding or minimizing math instruction, and teaching math in ineffective ways.[62,63,64] Similar trends appear for science. One report, which drew from a 2013 national survey of science teachers, showed that only 19% of K–2 classes receive science instruction on a daily or almost daily basis.[65] Furthermore, the strongest predictor of preschoolers' learning of mathematics is their teachers' belief that math education was appropriate for that age.[66] Fortunately, we can effectively increase teachers' STEM content knowledge, as well as change negative dispositions and beliefs, with high-quality pre-service and professional development.

Child development and pedagogy

Even teachers who are confident STEM leaders must also know how to gauge the understanding and developing skills of their students, and use this knowledge to plan and modify instruction using research-based instructional strategies.[67] However, many early childhood educators lack sufficiently detailed knowledge of what experts call *learning trajectories* or *progressions*, the paths children take when learning STEM topics. Understanding how to support children requires an understanding of the three elements of a learning trajectory: the learning goal (i.e., the STEM content), the developmental progression that enables children to reach that goal (i.e., a sequence of levels of thinking), and the instructional activities and strategies that aid this progression.[68]

Consider the skill set for measuring length, critical to all STEM topics. A typical goal is for children to learn, by the end of second grade, to measure the length of an object using appropriate tools, relate the size of the object to the number of units, and determine how much longer one object is than another. Between pre-K and second grade, children go through a series of levels of thinking as they work up to achieving that measurement goal.[69,70] A developmental progression for measurement and length comparison looks like this: around age 4, children tend to be able to make gross comparisons between objects. For example, in pre-K settings children can line up by height, making comparisons among themselves. Eventually they can compare two or more objects, lining up the endpoints themselves. Next, they are able to compare the length of two objects indirectly by using a third object. For example, they might cut a ribbon the length of their arm and find things in the classroom that are the same length. Then they begin to measure length by laying down multiple objects, or physical units, end-to-end to fill the entire length.

By age 7, they are typically able to measure by repeatedly and carefully laying down a single unit. Finally, they have mastered these basics when they can measure and compare items, accurately and with full understanding, by using either physical units or a ruler.[71]

> "We need pedagogical approaches that are responsive to children."
>
> —Researcher

When teachers are aware of children's developmental progressions in a topic area, they are responsive to their students' needs. The activities demonstrated above, like lining up by height in preschool or using ribbon to indirectly measure length, offer a "sketch" of a curriculum, a sequence of activities. The understanding of learning trajectories also supports teachers' use of *formative assessment*, the ongoing monitoring of student learning to inform and guide instruction. In other words, teachers who understand learning trajectories can adapt their instructional activities to meet the needs of both the class and of individuals or groups of students who may be at different levels in the developmental progression. Teachers who observe their students for evidence of progressing ideas and thinking, and then iterate their activities based on that data, build effective learning environments.[68]

The power of family engagement in STEM learning

While school is the place most Americans naturally associate with STEM learning, research has demonstrated that there are ample opportunities for STEM learning well before child care, preschool, and kindergarten. In fact, children are literally *born* scientists.[72,73] Even before one year of age, babies have been shown to systematically test physical hypotheses when they observe objects behaving in unexpected ways.[74] For example, when an 11-month-old sees a toy car go off the side of a table and appear to float, that infant is likely to look longer at that car and also try exploring and dropping the car to see if it will continue to float.[74] Parents watch their toddlers push sippy cups, food, and utensils off the edge of their high chairs—over and over and over again—testing the limits of gravity. Children's curiosity about their surroundings becomes clearer as they get older: preschoolers are eager to understand why their clothes no longer fit (life sciences) and are obsessed with the fair distribution of communal snacks (math). Children are curious about and capable of learning STEM starting the day they are born. Parents, who have an earlier and more sustained presence in their children's lives than teachers (even once they begin to attend school, children only spend about 10% of their time there[75]), consequently have an enormous opportunity to help encourage, support, and normalize early STEM learning.

Family engagement (i.e., when a child's parents or family are actively involved in their learning) is a powerful force. Across the research literature, family engagement in the math and literacy education of young children (3–8 years) has a consistently positive effect on children's learning in those areas, and this relation is strongest when that engagement takes place outside of school—for example, when playing with shapes, puzzles, or blocks together at home.[76] When parents are actively involved, their children become more successful learners, regardless of race, parental education, or socioeconomic status, with greater parent involvement resulting in greater confidence and engagement in their children.[77] Furthermore, parents from diverse backgrounds are capable of becoming more engaged with their children in these areas when they are given instruction, and this increased engagement results in better child outcomes.[76] As parents support their children's learning in this way, schools are able to be more effective in building the knowledge, confidence, and skills of children,[77] creating a ripple of positive effects. Parental and family engagement, therefore, is a critical pivot point for changing the educational trajectory of under-resourced young children.

Yet parents are subject to many of the same gaps in knowledge, beliefs, and attitudes about STEM that teachers are. Many of them may have missed opportunities to learn STEM in a playful,

engaging way in early childhood, and may need both knowledge and support to encourage this exploration in their children. Furthermore, many Americans believe that STEM is for older children and is best taught formally in classrooms (see Appendix B). Parents simply may not notice their children's early STEM curiosity, rendering it difficult for them to support or encourage these important moments. Even those parents who are aware of their child's ability to learn STEM at home may not know how to provide developmentally informed support for them. For example, such parents may buy formal "STEM kits" or flashcards for their babies and toddlers, rather than engaging in developmentally appropriate activities like stacking blocks together, playing with water in the bathtub, or routinely counting snack items as they hit the tray. As Allison Gopnick, a scientist who studies early experimentation among infants, aptly put it:

> Everyday playing is a kind of experimentation—it's a way of experimenting with the world, getting data the way that scientists do and then using that data to draw new conclusions. What we need to do to encourage these children to learn is not to put them in the equivalent of school, tell them things, or give them reading drills or flash cards or so forth. What we need to do is put them in a safe, rich environment where these natural capacities for exploration, for testing, for science, can get free rein.[73]

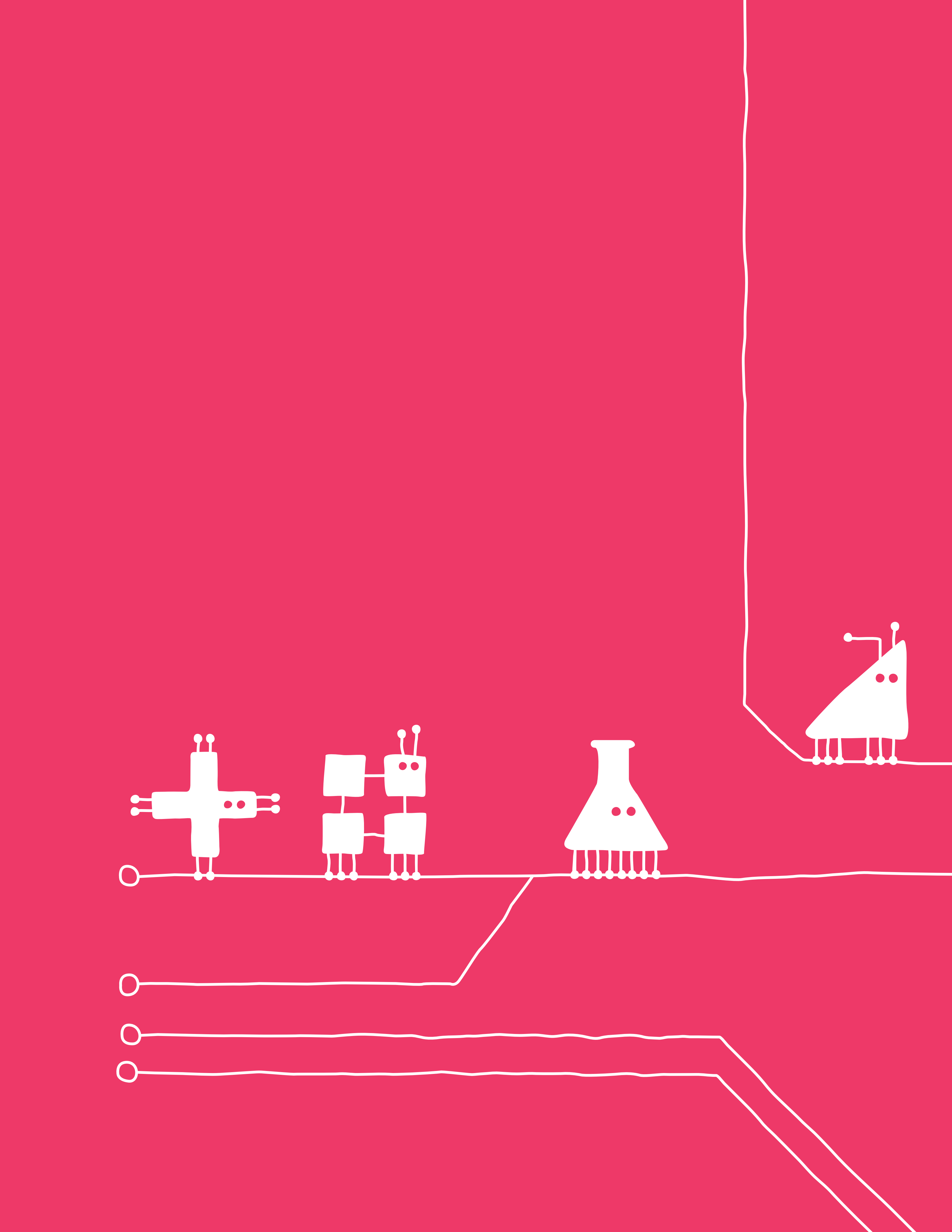
Parents, like teachers, need to be supported as they encourage the abilities of their young children so they can help scaffold their learning in developmentally appropriate ways.

A second potential limitation for parents is the belief that math is more important for boys than girls.[51] While the effect of parent perceptions has not been well studied among very young children, it has been strongly documented among children generally. According to a 2012 literature review in the journal *Sex Roles*, parents tend to expect that their boys are more gifted in STEM than their girls, even when their achievement levels do not differ objectively,[51] and those beliefs are passed along to their children in both implicit and explicit ways. For example, parents are three times more likely to explain science exhibits to their preschool boys than girls when they visit a museum.[78] Low-income mothers have been shown to use a higher proportion of science process talk with their boy than their girl children during magnet play at 5 years of age, which was associated with their later science reading comprehension scores.[79] More explicitly, parents' gendered attitudes toward math and science can be communicated through the opportunities they provide and the activities they encourage. For example, they tend to purchase more math and science toys for boys than for girls, one of several parental math- and science-promoting behaviors that have been linked to children's math and science involvement several years later.[80]

A third potential limitation is a lack of parental confidence in the ability to support STEM learning. According to a recent report by the National Parent Teacher Association, even though parents believe that they themselves play the biggest role in inspiring their child's interest in science, almost one-third of them do not feel confident enough in their own scientific knowledge to support hands-on science activities,[81] and only 18% of families with preschool-aged children report having recently done a science activity at home.[82] While a great deal of research on parental support in STEM has been conducted among older children,[51] very little has been done during the early childhood period, perhaps because of the belief that the parents' role in promoting early literacy and reading is more important than promoting early STEM learning.[51] More work is necessary in this important area.

Parental perceptions like the ones reviewed here are of critical importance. In fact, parent beliefs about a child's math ability are a stronger predictor of the child's self-perception in math than the child's own previous math performance.[51] So when parents believe that STEM is not for very young children, that it is not learned well outside of formal schooling environments, that it is more important for boys than girls, or that they themselves are underqualified to share in STEM activities, there may be a very real and persistent intergenerational problem for early STEM education.

Some organizations, including the U.S. Department of Education (ED)[83] and the NSTA,[77] have begun to support children's STEM learning at home by offering recommendations and tip sheets for parents. More needs to be done to reach parents where they are in effective and engaging ways. For example, these tips could be delivered via daily text messages, an approach that is currently being tested. Many of the tips and programs available still need to be adapted for younger children and STEM specifically. Furthermore, simply providing parents with information may not be enough. For example, some family engagement interventions that only offer *suggestions* to parents for increasing natural parent-child math interactions have not found positive effects on children's math learning. However, interventions that include comprehensive, long-term training for parents on the same issues have demonstrated improvements in children's math skills.[76] It appears that many parents are willing and able to make these important changes, but they need both knowledge and formal support to do so.



V. the mesosystem: interactions between home and school environments

Mesosystem: the connections between the child's microsystem environments; and the experiences or people that directly affect the adult-child relationship

Just as we cannot consider the child in a vacuum, we also cannot consider the child's everyday environments, like home and school, as though they exist independently of one another. Experiences in each of his or her microsystem environments affect the ways in which the child engages in his or her other environments. For example, a child who experiences high degrees of stress or support at home may behave differently as a student; and a child who experiences bullying from peers or strong support from a teacher may behave differently at home.

In addition, cross-environment interactions can include what Bronfenbrenner called "higher-order effects," such as the experiences or people that directly affect the adult-child relationship within the microsystem. For example, a stressful work environment can lead parents to vent frustrations or behave in negative ways when speaking with their children, leading children to feel stress in ways that affect their capacity to learn and explore. Alternatively, children experience positive interactions with adults when those adults have been given high-quality training that prepares them to carefully observe children, to recognize learning progressions, and to engage in ways that enhance growth and learning.

Higher order effects: Workforce development

To teach STEM effectively, early childhood teachers need to understand: (a) the content they are teaching, (b) the nature of children's STEM thinking/knowledge and how it develops, and (c) best practices for ensuring that STEM instruction meshes with children's developmental needs and level.[84] Yet many teachers of early STEM have fundamental training needs in all three of these critical areas. Much of this is related to systemic issues, many of which are beyond their control, including weaknesses in their own education; ineffective professional development; and a complex daily work environment that can include diverse sets of learners and a lack of resources and support.

Much is expected of early childhood teachers today. The Early Childhood Generalist Standards, for example, specify that an accomplished early childhood teacher should be familiar with the major concepts of life, earth, and physical sciences, and should be capable of unifying themes across them.[85] Yet teachers rarely receive adequate STEM education when they are initially trained. A report from the National Academy of Science found that only "36% of elementary science teachers reported having completed courses in all three of those areas, 38% had completed courses in two of the three areas, and 20% had completed courses in one area. At the other end of the spectrum, 6% of elementary science teachers indicated that they had taken no college science courses."[86]

> "Our main role is to teach kids how to learn. That's not going to look the same in my classroom as in another classroom, and we need support to make that happen."
>
> —Pre-K Teacher

Furthermore, few teachers receive intensive, sustained, and content-focused professional development in STEM.[87] Despite the existence of learning standards and increased curricular attention to mathematics and science, professional development frequently does not focus on scientific or mathematical content, development, or pedagogy.[88,89] When it does, the focus is often on simple facts or uncoordinated activities without a clear rationale: there is a focus on how but not *why*.[90] Inadequate training and professional development produce few pre-service and in-service teachers who have themselves achieved proficiency with elementary-level STEM content, and who are consequently ill-equipped to foster proficiency in others.[13]

However, simply increasing the *quantity* of courses and training sessions available to early childhood pre- and in-service teachers is insufficient.[12,91] Prospective and current teachers need to experience substantive, connected instruction regarding early childhood STEM learning, including content, child development, and pedagogy. In current pre-service education, this is rarely the case. There is a lack of interdisciplinary connection within teacher preparation programs and the higher education institutions that house them. For example, separate faculty members from different departments often teach STEM content, educational/developmental psychology, and instructional methods independently as distinct, uncoordinated courses. This leaves teachers without an understanding of critical developmental trajectories related to STEM content knowledge, including the learning sequences that come before and after the age or grade they teach.[92] Teachers need to understand common learning goals across grades, such as those laid out by the Common Core, the Next Generation Science Standards, and, in pre-K, their states' early learning standards and guidelines.[93]

Furthermore, the STEM teaching method courses that prospective teachers take are not, themselves, a good example of best practices in pedagogy. They are taught primarily in a lecture format, and sometimes fail to focus on the rationale for the best practices they teach. This approach does not ultimately support teachers in the classroom, where new teachers tend to adopt the methods by which they were taught throughout their lives as students.[94] In this way, there is an "intergenerational" transmission of ineffective practices across cohorts of teachers. Instead, all teacher education and training should be grounded in classroom practice. Pre-service teachers gain substantially more from frequent and high-quality opportunities to acquire hands-on experience, explore teaching methods, practice with curricula, and encounter situations and challenges they are likely to see in the classroom. In-service teachers benefit from one-on-one coaching, which situates training in the classroom, evaluates fidelity of implementation, and provides timely feedback and support.[95,96]

> "The teacher should be a learner, and learning in the same way that the child is learning."
>
> —Researcher

Ultimately, pre- and in-service teachers need (and deserve) the very same hands-on, engaging learning environments and practices in their own education as we hope to see for America's young children. When they feel intrinsic curiosity and joy about STEM in their own learning, and when their own instructors demonstrate sensitivity to learning trajectories and best practices, teachers see a model they can use. Just as for child learners, STEM content courses for teachers need to focus on fostering a *deep* understanding of STEM knowledge, fostering engagement through guided inquiry-based learning. They should also emphasize the relation of this understanding to teaching practices by including coordinated instruction across the domains of content, child development, and pedagogy, taught by instructors who have competence in all three areas and have experience teaching young children STEM. High-quality, specific teacher preparation and development has been shown to be an effective way to improve the knowledge and skills in the workforce. It is also a strong predictor of student achievement.[68]

Family, friend, and neighbor child care providers

While our report focuses on early childhood educators who work in schools and care centers, it is also prudent to consider the education and development of those who are sometimes called the *family, friend, and neighbor* (FFN) child care providers. These critical members of the early childhood community make up half of the workforce and yet are a silent and often unseen community within education reform discussions. FFN providers have extremely diverse backgrounds, and more research is desperately needed to explore which training programs can effectively reach and positively affect providers in this community. Researchers and funders should work with organizations like *All Our Kin*, which provides training to FFN providers, to explore this important and understudied population.[97]

Connections between microsystem environments: parents and technology as bridges

Many Americans view school learning as separate and more important than out-of-school learning (see Appendix B), yet learning is supported and enriched when children's formal learning is meaningfully connected to experiences outside school, in visits to libraries and museums, in group activities with other children, and in other moments in their everyday lives.[38,98] To bridge informal and formal learning, educators and caregivers can make use of two powerful tools: parents and technology.

Parents, as long-term influences in children's lives, can help them make connections between in-school and out-of-school STEM learning, as well as their learning experiences over time. Parents can activate a child's in-school learning by engaging in related activities at home or outside the home,[10] like taking trips to a STEM museum or to a library with STEM resources, or enrolling the child in STEM-relevant after-school activities (e.g., Boy/Girl Scouts, Coding Club).

This kind of parental support has a strong, positive effect on children's participation in math and science activities.[99]

In supporting their children's involvement in these activities, parents expose them to the important influence of informal learning environments, which have been shown to encourage excitement and motivation to learn STEM, as well as to promote children's identification as STEM learners.[100] Experiences like these not only encourage science learning outside of school, they also enrich science learning when children return to school.[101] Institutions of informal learning like museums and libraries also play a crucial role in providing high-quality, engaging, and socially supportive professional development for STEM teachers, thus influencing children via multiple direct and indirect pathways.[101] More research is needed on how informal spaces, especially libraries, can act as "hybrid spaces" to pollinate young children's STEM learning, connecting their nascent STEM curiosity in out-school settings to more formal learning programs.[102] But it is evident from observing interactions in these spaces that even a short visit to a museum exhibit has the opportunity to engage not only the child, but also the parent in STEM learning. In one study at a museum, giving families brief instruction in how to spark STEM conversations resulted in parents asking double the number of "Wh" questions (who, what, when, where, why) to their children at a STEM exhibit, and the effect did not differ by ethnic background.[103]

Technology, too, can be a bridge between learning environments in a child's life.[10] Digital media are advancing into nearly every aspect of children's lives, even in their earliest years, and with the help of informed adults, they can provide opportunities for deeply connected learning.[10] For example, the Bedtime Math Foundation, using the familiar model of a bedtime story, offers an app to encourage families to incorporate fun nightly math activities into their bedtime routine. The presence of this app at home had an impact at school: first graders who used the app with their parents (even as little as once a week) during the school year were three months ahead of their peers in math achievement by the end of the year. The app was most effective for children whose parents had greater math anxiety.[104]

Some programs, like the PBS Ready to Learn initiative, have used trans-media content (i.e., content that crosses multiple platforms, like a Peg + Cat app that uses games to enhance the content of the *Peg + Cat* television show) to support and extend teacher-led workshops for parents about preschool math engagement. Teachers spent time each week discussing a new math concept and providing activities that parents could incorporate at home to support learning with the help of the PBS app. This intervention resulted in greater math knowledge, understanding, and ability among students.[105]

The mesosystem structure reminds us that teachers in the classroom (including the pre- and in-service training they receive), parents at home, and educators of all kinds in out-of-school settings mutually influence one another and the children they nurture together. Using parents and technology as a bridge, each of these learning environments—and the adults in them—can support one another in the common effort to encourage STEM interest and growth in children.

VI. the exosystem: the importance of research and policy in early STEM education

Exosystem: the societal structures and institutions that do not directly contain the child but indirectly affect him or her

Shifts in both research and policy play a critical role in the presence and quality of STEM learning in young children's lives. This role must not be overlooked, especially in light of the latest international test scores, which show that students in the U.S. continue to be outperformed in science and mathematics by their peers around the world.[106] Yet, even though differences in math performance between Americans and their international counterparts begin to surface as early as age 4 or 5,[107,108] the insights from publicly funded research on how to help young children learn do not often find their way into early childhood programs and practices. Richard Elmore, of the Harvard Graduate School of Education, writes of the "deep, systemic incapacity of U.S. schools…to develop, incorporate, and extend new ideas about teaching and learning in anything but a small fraction of schools and classrooms."

Education policy

While experts may disagree about the specific educational policies that are most effective for young learners, one important element is clear: when policies for early learners and elementary school children are not thoughtfully integrated, they can work against one another. Studies show a need to recognize the extent to which there is policy **alignment** (the coherence of policy expectations and instruments) and **continuity** (connections across grade levels) in the early grades. There is some evidence that lack of alignment and continuity is at least partially responsible for the "catching up" that happens between children who do and do not experience high-quality pre-K (a phenomenon sometimes characterized as "fade out" of early gains from pre-K).[110,111,112,113] Pre-K through third grade teachers often use different curricular materials and instructional strategies, and repeat material that students already know.[114] Although much is known about early learning and curricula,[11,115] disconnects between pre-K and early elementary school can lead to uneven instructional practices, which compromise student learning.

Many state and district policy makers are working toward creating greater alignment and continuity in elements of policy affecting pre-K and elementary schools.[116] Policy efforts intended to foster *alignment* typically attempt to ensure that different elements of the instructional guidance infrastructure—standards, curricula, assessment, and professional development—promote similar instructional approaches. Policies promoting *continuity* seek to create more seamless pathways from pre-K to elementary.[117] For example, efforts may be made to ensure that (developmentally adapted and appropriate) common curricula or assessments are used in pre-K and elementary classrooms, that the same administrator has responsibility for both pre-K and elementary levels, or that pre-K teachers are included in professional development alongside elementary school teachers. These efforts are well-founded: professional development supporting curricular continuity results in better induction experiences for new teachers,[118] shared goals and instructional strategies, and increased student performance.[120,121]

Furthermore, the concept of learning trajectories appears to be gaining attention in education policy arenas. Several recent reports from large-scale panels have stressed the importance of teaching educators about them. For example, the National Research Council report on early mathematics[115] is subtitled "Learning Paths Toward Excellence and Equity;" the Early Numeracy Research Project (ENRP) in Victoria, Australia, was built around using "growth points" to inform planning and teaching;[122] the Next Generation Science Standards are built on the notion of learning as a developmental progression;[123] and the authors of the Common Core State Standards started by writing learning trajectories for each major topic. With the support of thoughtful education policies and thoughtful teacher education, there is hope that the important frameworks of learning trajectories, policy alignment, and curricular continuity can be used to support early childhood STEM education.

Informing research funding priorities

When researchers conduct studies to determine what is applicable and scalable in real-world classrooms, they provide policymakers with the evidence they need to implement more effective policies.[124] However, it is rare that STEM researchers develop a research program to inform or influence policy and practice in the pre-K through third grade years. In fact, many conduct their studies at a remove from the classroom, preferring clean, controlled lab trials to explore learning and development. This approach is critical to scientific theory and progress, but it can also produce results that are difficult to translate into effective policy or, worse, not relevant to the needs of teachers. One alternative is to involve teachers as consultants and allies in the research process. Several experts interviewed for this report pointed to successes that arise when teachers are seen as research partners and long-term collaborators *as early as the design stage*. These research-practice partnerships take advantage of the wisdom and expertise of both educators and scholars, and can play an essential role in supporting the iterative process of education reform.[125] The NSF has been praised as particularly supportive of research projects that require the additional time and funding to include this upfront collaboration and exploration.[126]

> "Teachers and children (who they are; how they learn; what supports they need) ought to be where we start, not where we end up!"
>
> —Teacher Educator

Funding organizations, both governmental and non-governmental, play an important role in influencing education policy.[127] The NSF is an especially good example of this influence: it accounts for about 20% of federal support to academic institutions for basic research,[128] has an annual $7 billion research budget, and spends almost three times as much as the largest philanthropy in the U.S.,[129] culling through tens of thousands of research proposals each year.[130] The NSF, then, plays a very powerful role in helping to set research, policy, and reform agendas by steering funding toward particular topics.[131] Furthermore, the NSF has made the largest financial investment in STEM education of all the government agencies,[149] so its funding priorities are of vital importance to the future of early STEM learning.

In what ways do the priorities of funding organizations support or hinder the development of effective STEM learning in early childhood? There is little research exploring this question, so we performed a systematic (albeit limited) search of NSF's publicly available online award abstracts database[132] to document its current major[c] funding commitments to early STEM learning. The detailed methods and findings of this analysis are available in Appendix A, but briefly, among the major research awards associated with STEM education for children between the ages of 0 and 10, we found that:

1. Younger children are not studied as often as older children.
2. Support for the individual STEM topics is distributed differently among younger and older children.
3. There is a greater focus on *children* (e.g., assessing the development of math concepts in 4-year-olds) in pre-K, and *teachers* (e.g., teacher training, professional development) in K–5 classrooms.

The imbalances observed here signal where there may be room for growth in research support for early STEM learning.

It is, of course, unclear from this analysis whether these imbalances are due to priority-setting by the agency, the composition of its applicant pool, or other reasons. We also recognize that a perfect balance of studies and funding across all areas may not be strategically wise or the intent of the NSF. The agency awards grants to the proposals with the greatest intellectual merit and potential for broad impact. These observations do, however, offer an opportunity to reflect on the nature and cause of each imbalance and to consider whether they may be related to features of the *macrosystem*, the broader cultural frames, paradigms, values, and models about early STEM learning that shape the child's experience within all the other systems.

[c] "Major" is defined here as awards of $500,000 or more. For more information, see Appendix A.

VII. the macrosystem: pivoting cultural frameworks to support early childhood STEM

Macrosystem: the broader cultural frames, paradigms, values, and models that shape the child's engagement and relationships in all the other systems

To understand how our culture is inhibiting the uptake of STEM instruction, we need to understand the *macrosystem*, a place where values and cultural frames can hold sway. This is critical to consider because, as journalist Walter Lippmann put it, "the pictures in people's heads do not always correspond with the world outside."[133] In the macrosystem, policymakers and the public alike often hold assumptions that run counter to efforts that would improve children's STEM opportunities. This situation is even more fraught in early learning settings, where American cultural models—deeply held understandings of what children can learn and are able to do—have not caught up with scientific discoveries about the critical importance of early childhood development.

In fact, despite plentiful research documenting the crucial importance of supportive early childhood and family policies, the U.S. continues to lag behind other developed countries. For example, it is the only country out of 41 in the OECD[d] database that does not have national policies that mandate paid maternity leave.[134] While many other countries supplement or pay entirely for the cost of child care, the annual cost of child care in 28 states and the District of Columbia is greater than a year's tuition at a four-year public college.[135] And while the majority of early child care educators want to make a long-term career of it, they see low pay as the greatest challenge they face to staying in the profession.[139] The median salary for a preschool teacher is $28,570, compared to $51,640 for kindergarten teachers,[136] and annual teacher turnover in many child care settings remains high.[137] Libby Doggett, a noted expert on early childhood programs and policy development, remarks that "a teacher's salary level reflects how the work is valued by society."[138]

Views about early childhood have begun to change in recent years. According to current polls, most Americans (62%) recognize the period from birth to age 5 as the most important time for developing a child's capacity to learn.[139] Voters overwhelmingly support greater affordability and access to high-quality early childhood education, and it is a relatively non-partisan issue.[140] Furthermore, about three quarters of voters support investing in voluntary home visiting and parent education programs to help first-time parents support their child's early learning, health, and emotional development.[139]

As public support begins to grow around new investments in early learning programs and policies, it may be time to use the mounting scientific consensus about early exposure to the STEM disciplines to expand the national conversation. However, a strategic communications effort will be needed to ensure that an accurate understanding of that science is conveyed when it reaches the public, rather than reinforcing problematic ways of thinking. Communications work of this kind is testable, and the FrameWorks Institute has taken up the mission of understanding the intersection of research communications and public support for effective policies, using social science methods. The institute's recent work on the public's perceptions of STEM in early childhood (see Appendix B for a detailed report) provides the foundation for an effective communications plan to support meaningful policy change around early STEM learning.

The key elements of a national public engagement strategy based on the FrameWorks Institute research appear in the accompanying box (page 36). Clearly all of the pivotal sectors—research, practice, policy, and other key leaders—will need to embrace a new set of assumptions and values about the enduring benefits of seeding STEM learning in the early years.

[d] The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental economic body with 35 member countries. The OECD Family Database includes all OECD countries as well as members of the European Union, for a total of 41 countries.

!

Using effective STEM communication to frame national dialogue

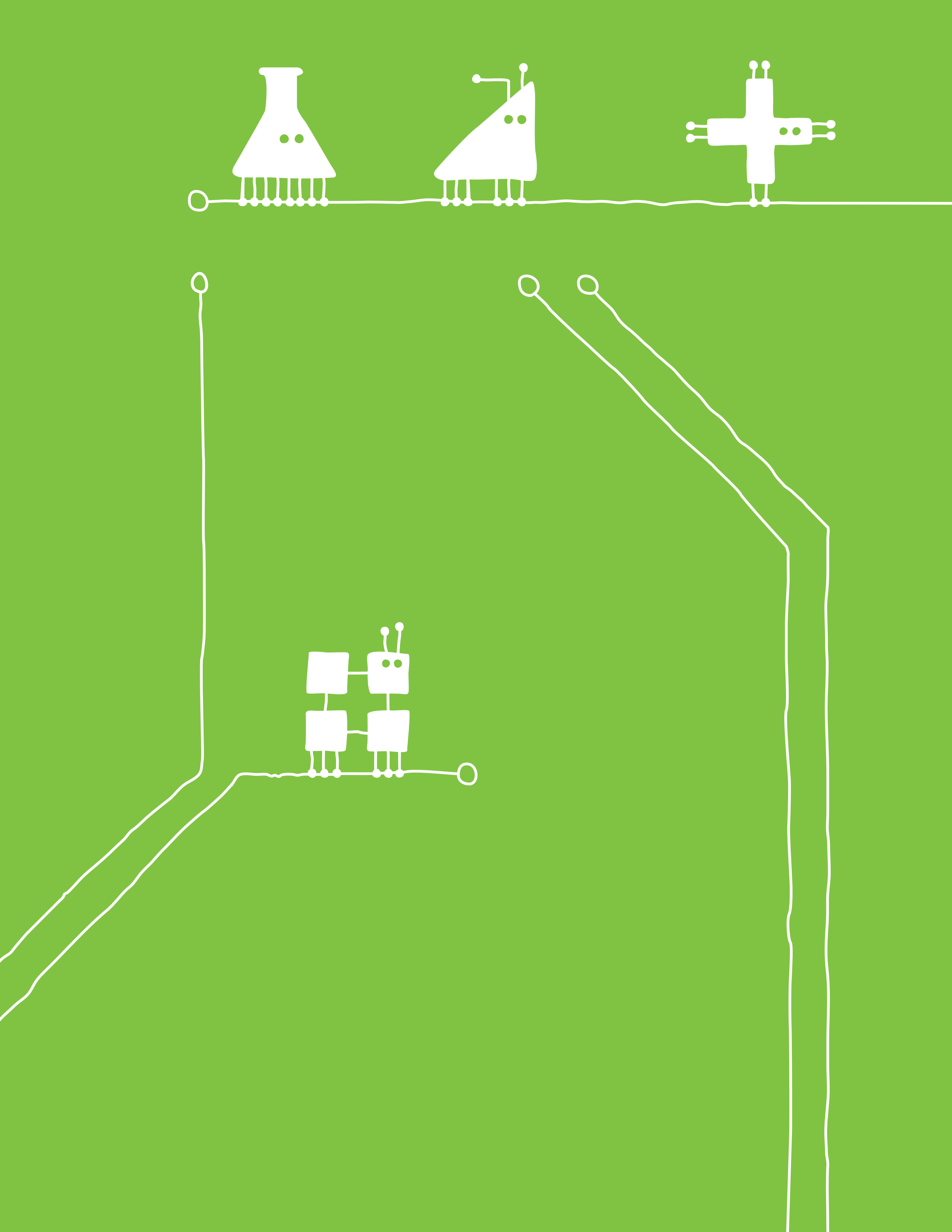
According to a series of qualitative and quantitative research studies completed by the FrameWorks Institute, many discrepancies exist between what the public thinks and what research says about early STEM. Strategies based in communication science can help to change the pictures in people's heads and enable them to see the value of research-based approaches. Here are some examples of how communications science can help galvanize public engagement and policy action to promote a shared commitment to investing in early STEM learning. See Appendix B for the detailed report.

Research says: Children are born scientists.
The public says: Some children are born scientists, and others not. And then some are encouraged or discouraged to pursue science by their family cultures. Not every child can learn STEM subjects, nor do they need to. Not every kid needs to be a math or science kid.
Communications science suggests: Watch a group of very young children who are engaged in planning and planting a community garden. What are they learning? The beginnings of environmental science and plant biology, critical thinking skills, problem solving, trial and error, and more. All young children can be engaged at this level and can begin to think of themselves as "math and science kids" who can use their skills and knowledge to put food on the lunch table.

Research says: Children who engage in scientific activities from an early age develop positive attitudes toward science.
The public says: Children need to learn the "basics" first, before they are able to address more complex STEM subjects. First come reading, writing, and arithmetic. Then kids can decide whether they are ready for STEM.
Communications science suggests: STEM learning opportunities are like charging stations that power up kids' learning. Some kids live in charging systems with lots of opportunities for learning, while other kids have very few. If we increase the number of STEM charging stations in kids' environments, we will see more interest and fluency in STEM. Our current system is patchy; this explains why some children never develop STEM fluency, which has significant consequences for their overall learning.

Research says: Early introduction to science and math "talk" helps children build STEM vocabularies and acquire the background or prior knowledge they need for deeper understanding of STEM topics.
The public says: Children need to wait until they can understand complicated scientific concepts. Little kids should be focusing on learning their ABCs.
Communications science suggests: Just as people need to be immersed in a language in order to become fluent, children, too, need to be given many opportunities in many different settings to become fluent in STEM subjects. They need real-world exposures to STEM activities, like planning a community garden. These types of activities help whet kids' appetites for STEM learning and build their skills. When we give *all* children STEM opportunities, they learn to speak fluent STEM.

Research says: Preschool math skills predict later academic achievement more consistently than early reading or attention skills.
The public says: Children who are motivated will achieve. Not everyone can be good at math. But everyone can read.
Communications science suggests: Developing STEM skills is an integral part of weaving strong skills ropes. As we learn new skills, our brain weaves skill strands into ropes that we can use to solve problems, meet challenges and, in turn, acquire new skills. STEM skills are vital in many different kinds of skills ropes. When kids have opportunities to collect evidence and solve scientific problems, they build strong ropes that can be used in many ways later in life.



VIII. recommendations

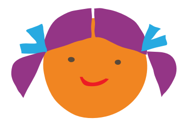
Today's preschoolers are tomorrow's inventors and problem solvers. In high-quality early learning environments, we can find these children playing with blocks and experimenting at the water table. Yet by the time they leave high school, a large percentage will have lost the confidence and motivation to engage in STEM subjects as adults (or worse, never had sustained opportunities to deepen their skills in the first place). This represents not only a loss for individual students; it is also a loss for our nation.

As the research here shows, advancing educational outcomes for young children more generally, and for the STEM disciplines specifically, will require urgent, well-coordinated, cross-sector work. Fortunately, fertile groundwork has already been laid. Important efforts are already underway to improve STEM learning in public schools up through twelfth grade. Other efforts are underway to build a more coherent, high-quality, and sustainable system of early education from birth through age 8.

STEM starts early: Key recommendations

use communications science to build public will and understanding

support parents to be STEM guides



expand the availability of STEM "charging stations"

improve how research is funded and conducted

improve teacher professional learning on STEM

build a sustainable and aligned system of high-quality early learning from birth through age 8

In the six recommendations below, which start in the child's most proximate environments and move outward to broader frameworks and structures, we have borrowed from both streams of work to create an action plan that brings high-quality STEM education together with early learning. We recommend providing stronger support and education for parents and teachers; a more aligned strategy across grade-levels and between formal and informal learning environments; a redoubling of efforts to improve the early education system in general; a new emphasis and direction for research and development, and a new approach to communicating and disseminating research findings. We recognize the need to engage multi-sector actions across and within the complex ecosystems in which children grow up.

Related reports and recommendations

Our recommendations draw from authoritative work from scientific panels and professional associations, as well as our practitioner focus groups and key informant surveys. They are also informed by the April 2016 White House Symposium on Early STEM and the June 2016 convening that the Joan Ganz Cooney Center and New America led to draw together a national action plan. Many of the recommendations are adapted from reports published by the Institute for Medicine and the National Research Council, the U.S. Department of Education (including the new STEM 2026 report), the American Institutes for Research, the National Science Foundation, the National Mathematics Advisory Panel, the National Science Teachers Association, the National Association of Elementary School Principals Foundation, and recent reviews of digital innovation and professional development by New America and the Joan Ganz Cooney Center.

+ Engage parents: Support parent confidence and efficacy as their children's first and most important STEM guides.

When parents have the understanding and confidence to support their children's STEM learning, they can have a powerful and lasting impact. Parents are willing and able to skillfully engage with their young children, but they need both knowledge and formal support to do so.

- Parent educators, advocates, and researchers should reach out to parents about early STEM learning *where they are* in engaging ways, through blogs, child care centers, pediatricians, parenting magazines, and publications like *Zero-to-Three* and *Young Children*.
- Communicators should emphasize what early STEM learning actually looks like, providing a variety of clear and accessible examples of early STEM exploration (e.g., participating in a community garden, testing which bath toys float and sink) that make it clear that STEM learning can happen anytime, anywhere, even with minimal resources.
- Resources for parents do not have to be limited to simple early STEM tip sheets; policy makers, community leaders, and media producers should work to make comprehensive, long-term training on early STEM learning and support more accessible to parents using mobile technology.

+ Support teachers: Improve training and institutional support for teaching early STEM.

STEM learning must be incorporated skillfully into early learning environments. This is not about simply adding in a new mathematics curriculum or asking children to memorize scientific vocabulary; it will take a concerted effort to integrate STEM in ways that reflect the latest science on how children learn, how teachers and early learning programs can improve, and what families need. Teachers will need high-quality preparation to do so successfully.

- Education leaders should ensure that efforts to improve the workforce include interconnected and ongoing STEM training and support, which is meaningfully woven into teachers' existing classroom practices.
- Teacher preparation and training programs—both pre- and in-service—should include, in interconnected and meaningful ways: STEM content, training in children's developmental learning progressions in STEM, and well-modeled and practiced pedagogy situated in the classroom.
- Preparation and training programs should be designed to allow teachers to experience STEM learning in the same ways that children will. Teacher education should be driven by curiosity, allow for tinkering and exploration, and help teachers weave a holistic understanding of STEM topic areas so they can empathize and model this learning for their students.
- Researchers should disseminate findings in formats accessible to teachers, addressing teacher concerns (for an excellent example, see the new report *Early STEM Matters*). Demonstrations of successful early STEM teaching should be made more accessible, enabling educators to easily find, understand, and apply the lessons in their work.

+ Connect learning: Support and expand the web of STEM learning "charging stations" available to children.

Parents, teachers, technology, museums, and libraries create a web of charging stations where children can power up and extend their STEM learning. Immersion in this web of STEM learning leads to STEM fluency. Leaders must act together to broaden this web of charging stations to ensure that *all* children are capable of powering up their STEM exposure and becoming fluent STEM learners.

- Leaders in museums, libraries, and community organizations should prioritize early STEM in informal learning environments. Exhibits and interactive features should engage children, and also provide direct instruction to parents on how to engage with their children around STEM features and continue their learning beyond that environment. The Every Student Succeeds Act (ESSA) authorizes new funds that can be deployed in these efforts, and national networks of 21st Century Community Learning Centers can provide other significant community program opportunities and funding for wider adoption of early STEM programming.
- Education and technology leaders should ensure digital equity by providing access to high-speed internet and other digital age infrastructure for all families with young children and the professionals who work with them.
- The president and cabinet should activate the executive agencies, partnering with states and cities to ensure that early STEM educators have access to the internet to collaborate, take professional-development courses, update lessons, conduct assessments that inform teaching, and provide age-appropriate digital tools for documentation and analysis in the classroom. Early educators and parents also need access to the growing cadre of professionals known as *media mentors*, librarians and others trained in the use of educational media with children, who can ably promote the use of interactive media for higher level STEM learning by working directly with parents and caregivers.
- Public and private funders should continue to fund initiatives like Ready to Learn, which support family engagement in STEM learning.
- Media officials should undertake projects that build public interest in early STEM and form a bridge for home-school learning connections.

+ Transform early childhood education: Build a sustainable and aligned system of high quality early learning through age 8

Strong STEM teaching in early childhood must be integrated with efforts to support and expand more effective public commitments to early childhood teaching *in general*. All levels of government, along with state and community leaders, should apply existing and new resources to improve teaching.

- All levels of government, along with state and community leaders, should apply existing and new funding resources to improve *general* early childhood teaching and quality.
- Frameworks produced by the National Mathematics Panel Report on Preschool–Grade 12 and by the National Science Teachers Association are foundational documents for states and districts to adopt and use to build professional development systems. The NSF Math and Science Partnership (MSP) program, a collaboration among institutions of higher education and school districts, is one model for further study and broader adoption.
- Special attention should be paid to address professional preparation, staff development, and continuing education, with attention to the vast disparities in compensation, benefits, and work conditions that exist between K–12 educators and their counterparts in early learning settings.
- Federal and state policy leaders should look to the recent report from the Institutes of Medicine and the National Research Council, *Transforming the Workforce for Children Birth Through Age 8*, for 13 important recommendations for creating the professional standards to support high quality early learning.[11] It calls for the creation of higher education professional preparation programs to incorporate "an interdisciplinary foundation in higher education for child development," which can clearly be aligned with a new commitment to teaching STEM.

+ Reprioritize research: Improve the way early STEM research is funded and conducted.

Research agencies are not yet prioritizing early STEM learning. Our review and others[143] suggest that agencies currently prioritize investment in older children and in training undergraduates and graduate school students at a later stage of the STEM pipeline (see Appendix A). Some early STEM research is underway in the private sector through product launches, such as apps and educational products like Goldie Blox, Wonder Workshop, Motion Math, and Bedtime Math. In addition, significant commitments to early learning research come from the U.S. Department of Education (ED), National Institutes of Health (NIH), the Department of Defense, and the NSF, and interagency mechanisms such as CoSTEM (the White House-led Committee on Science, Technology, Engineering, and Math) have helped to promote cohesion in STEM initiatives. But efforts are fragmented and lack mechanisms to foster inter-agency coordination and collaboration. We suggest:

- CoSTEM and the White House Office of Science and Technology Policy should take stock of what research is being funded on early learning and STEM across the federal agencies and research organizations. The information gathered would allow the identification of knowledge gaps and form the basis for a government-wide strategy to support early STEM learning R&D. A similar effort should be initiated by governors and chief state school officers at the state level.
- Program designers should encourage studies that enable a two-way street between research and practice. For example, ED's Institute for Education Sciences (IES) recently announced funds for a network of interdisciplinary research teams exploring how early elementary school science teaching can improve education outcomes for children, especially those from low-income backgrounds and from communities underrepresented in science professions. An expanded effort could focus attention on the T, E, and M in STEM and use teacher researchers to inform future study designs.
- Research agency leaders should establish an interagency and interdisciplinary research program with emphasis on early learning and STEM. Such a program could collect and synthesize evidence of effective pedagogy and program designs to encourage early STEM learning. Actors could include the NSF, IES, and NIH, as well as ED, the U.S. Department of Health and Human Services, and the Institute for Museum and Library Services. One powerful blueprint for modernizing research-agency activities, the NSF-developed report *Fostering Learning in a Networked World: the Cyberlearning Opportunity and Challenge*, outlines directions that could help focus related activities at other research agencies.
- Philanthropic organizations should continue to use their research grants and convening power to engage policymakers, community leaders, and private investors in early STEM efforts. Current commitments focused on early STEM learning are coming from leaders such as the Heising-Simons Foundation, which is funding a particularly promising interdisciplinary initiative called the Development and Research in Early Math Education (DREME) Network. Other forward-thinking funders include the Overdeck Family Foundation, the Bezos Family Foundation, and PNC Bank. Organizations supporting STEM innovation and equitable opportunities for older learners should consider reframing grant-making portfolios to include early learning.

! **Spotlight on the role of the National Science Foundation**

The differences between the U.S. and other countries' performance in math and science remain significant on international assessments measures such as TIMSS (Trends in International Mathematics and Science Study) and PISA (Program for International Student Assessment). As the research on the potency of "learning trajectories" is better understood, there is great interest among practitioners, researchers, and policymakers in expanding NSF's investments in the early years. NSF, already a major catalyst in this area, has a vital leadership role to play in encouraging early STEM learning R&D: already, we embrace the foundation's priorities to drive equity for underrepresented populations and to promote human-centered research innovation as shown in its five-year strategic plan.[144] Drawing from key informant interviews and focus groups, as well as the meetings held in April 2016 at the White House and in June 2016 at New America, we recommend that the NSF:

1. Increase funding in early learning STEM:
- Direct 25% to 50% of Discovery Research PreK–12 program funding to studies that include at least one of the early childhood years (birth through age 8). Those nine years represent half of children's lives before they graduate from high school and the percentage of research dollars should be commensurate.
- Invest new resources to promote a more equitable balance of studies and funding between research on early childhood and research on older age groups across all funding streams.

2. Make cross-disciplinary research and dissemination on early learning a priority:
- Prioritize research that spans the pre-K to elementary school transition.
- Change the acronym of the Discovery Research PreK–12 funding program from DRK–12 to DRPK–12.
- Require projects in the Division of Research on Learning in Formal and Informal Environments to include the target age range in research abstracts and to include tags for types of settings (home, museum, preschool, etc.).
- Fund longitudinal research that tracks student outcomes and the quality of instructional settings from pre-K (and before pre-K where applicable) through at least the third grade.
- Continue to encourage educator-scholar research partnerships in early childhood through regular meetings and dissemination events.

3. Reward innovation in design and expand project funding for applied work:
- Include new measures of project impact the NSF's awards RFPs and online database.
- Encourage a wide range of dissemination methods from grantees.
- Expand support for projects with flexible and/or innovative research designs and those based in researcher-practitioner partnerships.
- Support an expansion of research and curriculum-based intervention programs that can be scaled up.
- Partner with other executive agencies to promote the research-to-practice pipeline.

+ Communicate clearly: Use insights from communications science to build public will for integrating STEM learning in early education.

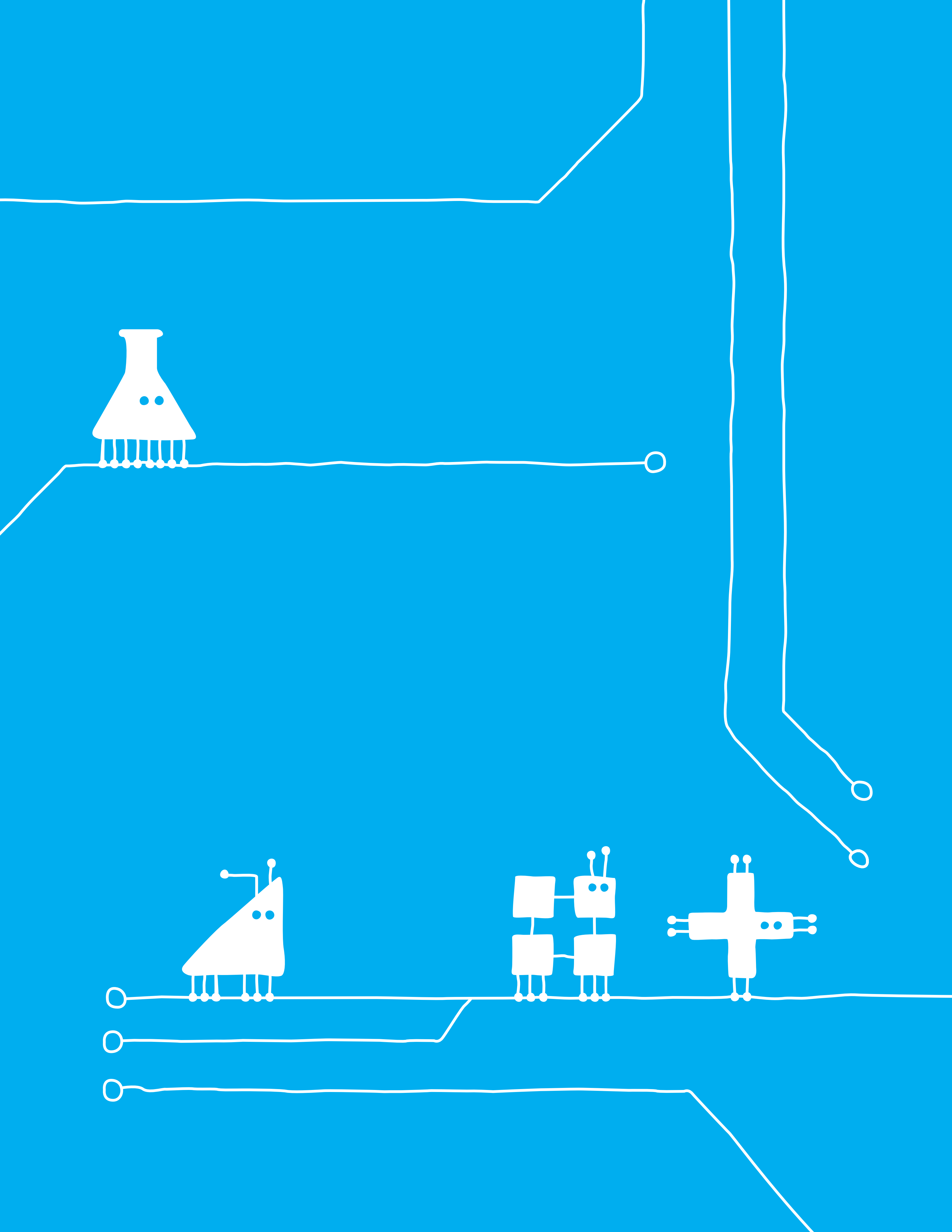
Current agendas for action are misaligned with the emerging scientific consensus on early STEM learning: they are geared towards preparing older children for careers with the goal of making the national economy more competitive, and in imparting specialty knowledge on a smaller population of "capable" youth. What is more, potential advocates for early STEM—such as parents and even many educators—are often wary of STEM in the early years, as shown by the FrameWorks Institute analysis (see Appendix B). However, many concerns fall away once early

STEM is explained in terms that accentuate the benefits of children as active, curious learners, or when couched in terms of authentic learning experiences. The FrameWorks Institute's emphasis on "two sciences"—communications science and policy science—is a helpful guide to the public engagement work needed to inform new investments in early childhood learning. To help launch a national conversation on the benefits of early learning and STEM using this two-science approach, we recommend the following action steps:

- All stakeholders and advocates of early STEM, across all the child's environments, should use a unified communications plan to ensure that they do not activate negative pre-existing cultural misconceptions about early STEM. A brief Communications Guide is provided on page 36 and is detailed further in Appendix B.
- National, state, and local leaders should convene summits on the future of Early Learning and STEM. The first White House Summit on Early Learning and STEM[e] in April 2016 should be followed up on and expanded by the next administration. The White House, ED, governors, chief state school officers, and business groups should organize follow-up meetings to focus attention on R&D priorities for early learning, and to recommend new public and private investments by the government and private sources, such as non-profit organizations and market investors.
- Public media officials should undertake projects that build public interest in early STEM and form a bridge for home-school learning connections. Media assets developed by highly trusted, research-based educational media distribution organizations, such as PBS, Sesame Workshop, WGBH, and WNET, are often untapped and are no-cost resources for parents, libraries, early educators, family child care providers, and elementary schools. ED's Ready to Learn program, which creates, distributes, and conducts research on the impact of "trans-media" content for children ages 3–8, is a valuable model.

To effectively seed STEM development for young children, we must mobilize leaders from every pivotal sector—research, practice, industry, philanthropy, and policy—to work together.[11] Only then will America's most precious asset—its youngest children—grow and bloom in a world where STEM learning is no longer a luxury but a necessity.

[e] For that convening, the White House and ED received over 200 submissions of innovative STEM work from leaders across the country, representing state and local entities, foundations, non-profits, media organizations, technology companies, research institutions, and museums. Many examples were rooted in stories of children's exploration and confidence-building that the FrameWorks analysis shows to be effective with the public. (https://www.whitehouse.gov/the-press-office/2016/04/21/fact-sheet-advancing-active-stem-education-our-youngest-learners)



appendix a:
STEM in early childhood: an analysis of NSF grant awards

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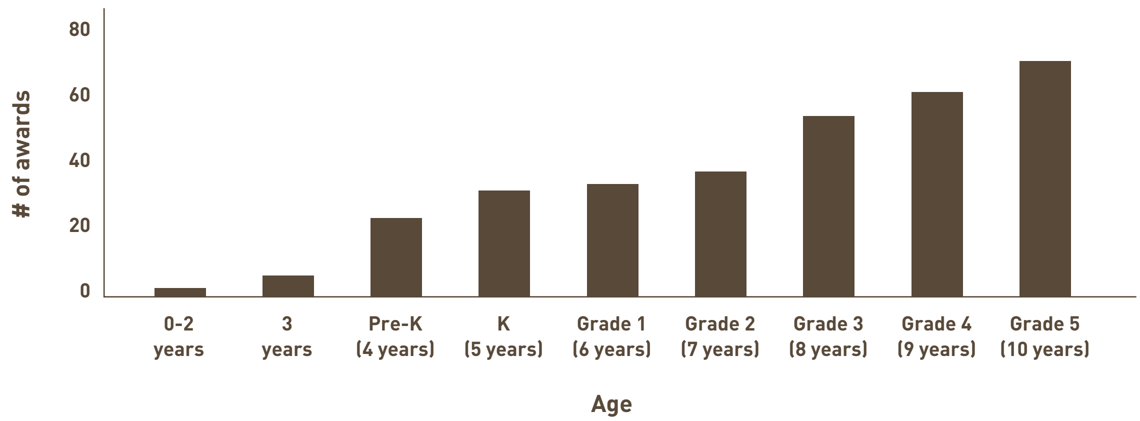
Introduction
Funding organizations, both governmental and non-governmental, play an important role in influencing education policy.[145] The National Science Foundation (NSF), which accounts for about 20% of federal support to academic institutions for basic research,[146] has an annual $7 billion research budget and spends almost three times as much as the largest philanthropy in the U.S.,[147] culling through tens of thousands of research proposals each year.[148] The NSF has a powerful role to play in helping to set the research, policy, and reform agendas by targeting funding toward particular topics.[149] Furthermore, the NSF has made the largest financial investment in STEM education of all the government agencies,[149] so its funding priorities are of vital importance to the future of early STEM learning.

Not only is the NSF one of the largest funders of STEM research in the United States, it is also seen as having a model system and infrastructure for supporting the kind of research that can be most useful for the advancement of early STEM. In our interviews with policy makers, researchers, and teacher educators, the NSF was consistently cited as being both a primary funder of early STEM work, and also an ideal venue for support that is flexible enough to sustain innovative research designs and long-term researcher-practitioner partnership development. For this reason too, then, an investigation of the NSF's current funding of projects related to early STEM is useful for determining both where our national priorities fall and where there are opportunities for growth.

Method
To document the NSF's present funding commitment to the topic, we performed a systematic search of its publicly available online award abstracts database.[150] The database contains hundreds of thousands of records of projects funded since 1989, so it was necessary to set certain boundaries on our search terms. We limited our search to the Division for Research on Learning in Formal and Informal Environments (DRL), under which the Discovery Research PreK–12 (DRK–12) program—which specifically targets STEM teaching and learning[149]—is housed. Because there was no age filter available for the database and abstracts did not consistently include typical age range language, we used the search terms "STEM early learning" and "STEM early childhood," combining all the resulting abstracts and removing duplicates. Since child age and learning topic were not catalogued in the database, it was necessary to code these characteristics manually by reading each individual abstract; in order to control the size of the field, the search was further limited to only major grants of $500,000 or more, as an indicator of agency priority. All awards were current (i.e., not expired) and awarded between January 1, 2010, and December 31, 2015.

Under these conditions, the search returned 512 unique award abstracts. We then discarded 409 awards from the analysis because they were, in most cases, intended for research on students outside the age range of interest (i.e., they were for research on students in middle school or older) or because they did not specify the children's ages. The remaining 103 award abstracts described research associated with science, technology, engineering, and math education for children between the ages of 0 and 10. We manually coded the age of the children who were studied (or, alternately, the age of the children being taught by the teachers who were studied); the learning topic (science, technology, engineering, and/or math, as described in the abstracts); whether the research was focused on teachers/staff, students, or the overall school/organization; whether the research had an emphasis on a special population (e.g., low-income or minority ethnicities); and whether the learning context was a formal (e.g., school) or informal (e.g., zoo, television) environment.

Number of awards by age



Results
The average award amount across all age groups and topic areas was $2,219,468.[f] There were seven outliers (those whose awards were more than two standard deviations greater than the mean award), and when these were removed the average award amount became $1,787,405. Here are our five main findings:

1. Younger children are not studied as often as older children.

Of the 103 awards we coded and reviewed, 23 included children in pre-kindergarten (pre-K) or were described as being 4 years of age. The number of awards that included each grade level increased with age. It is important to note that many of these awards fell into multiple age categories. For example, if an award studied kindergarten (K) through second grade students, it was coded as falling into three age categories: K, first grade, and second grade.

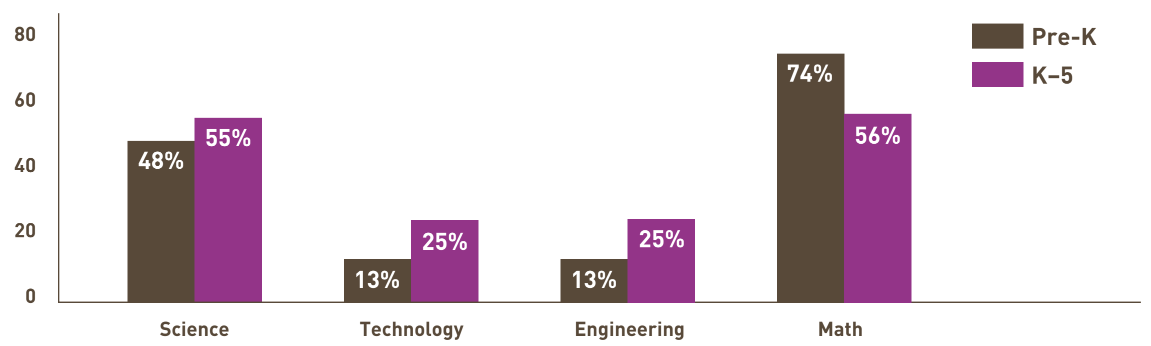
- 48% of the grants that included pre-K children also included kindergarten children, while 94% of the grants that included kindergarten children also included first grade children. In other words, projects that study children across the transition between pre-K and kindergarten are not being funded as often as those covering the transition from kindergarten to first grade.
- 20% of the awards cover the range of K to fifth grade, while only 3% of them cover the entire range of pre-K to fifth grade. 27% included K through second grade, and 50% included third through fifth grade.
- Only two awards were given to projects including children between 0 and 2 years of age, and only six awards included 3-year-olds. All eight of these awards studying children between 0 and 3 also included 4-year-olds. In other words, no awards were for the purpose of studying babies and toddlers *exclusively*; they were included in broader age ranges.
- Of the seven outliers in award amount (those awarded more than $6,125,615), only one included pre-K, and two included kindergarten. All others started with third grade or above.
- Award amounts and durations (see table below) were about the same for all awards that included pre-K versus those that only included children in kindergarten through fifth grade.

Average award amount and duration by age

	Amount	Amount w/o outliers	Duration (yrs.)
Pre-K	$2,300,434	$1,950,454	4.35
K–5	$2,196,191	$1,738,931	4

[f] Only major awards, defined here as those granted $500,000 or more, were reviewed in this analysis.

STEM distribution by age group



2. Individual STEM topics are distributed differently among younger and older children.

Both the number of projects devoted to each topic and the amounts awarded for each topic differ among older and younger children. Only six of the awards for the K–5 group did not include third grade or older, so here the awards are separated by whether they included pre-K in their studied age range or whether they studied a kindergarten and older group exclusively.

A. Number of projects: Math favored in pre-K
Technology and engineering appear equally often, both in the pre-K group and the K–5 group of awards; however, they both occur less often than the science and mathematics topics, especially among preschoolers. While math and science occur equally among K–5 awards, among preschoolers math is very clearly the priority: it is included in awarded projects 26% more often than science.

B. Topic integration: Topics studied in greater isolation among older children
The degree to which individual awards focused on multiple topics was different across the pre-K and the K–5 awards, with studies including pre-K children being more likely to include math and science together and technology and engineering together in the same awards.

For the awards that included ***pre-K****:*
Technology and engineering were *never* studied in isolation: all awards that included technology or engineering included *both* topics.

- **Technology:** No awards that included technology studied it in isolation from the other topics. It was most likely to be studied with engineering (100%), but was often studied with science (67%) and/or math (33%).
- **Engineering:** No awards that included engineering studied it in isolation from the other topics. It was most likely to be studied with technology (100%), but was often studied with science (67%) and/or math (33%).

Science and math were more likely to be studied in isolation than technology and engineering, with math dominating as an isolated topic of study.

- **Math:** 65% of all awards that included math studied it in isolation from the other topics. When it was studied with other topics, it was most likely to be studied with science (35%). It was very rarely studied with technology (6%) and/or engineering (6%).
- **Science:** 36% of all awards that included science studied it in isolation from the other topics. It was most likely to be studied with math (55%), engineering (18%), and/or technology (18%).

3% of all awards covered all four topics together.

For the awards that only included **K–5**:
Technology and engineering were more likely to be studied in isolation for the older children, but were still lumped together with other topics most of the time.

- **Technology:** 25% of all awards that included technology studied it in isolation from the other topics. It was most likely to be studied with science (75%), but was often studied with math (60%) and/or engineering (60%).
- **Engineering:** 10% of all awards that included engineering studied it in isolation from the other topics. It was most likely to be studied with science (85%), but was often studied with math (65%) and/or technology (60%).
- Science and math continued to be more likely to be studied in isolation than technology and engineering, with math continuing to dominate as an isolated topic of study.
- **Math:** 62% of all awards that included math studied it in isolation from the other topics. When it was studied with other topics, it was most likely to be studied with science (36%), but was sometimes studied with technology (27%), and/or engineering (29%).
- **Science:** 48% of all awards that included science studied it in isolation from the other topics. It was almost equally likely to be studied with engineering (39%), math (36%), and/or technology (34%).

14% of all awards covered all four topics together.

C. Funding Distribution: Science Favored in Pre-K, Engineering in K–5

The funding distribution across topic areas appeared to differ by age group.[f] Among the pre-K awards, science was the most "valuable" topic to include in a project: when studied in isolation, it received more than twice the award amount ($4.37 million) as math studied in isolation ($1.98 million), and awards that included science among other topics of study had the highest award amounts (almost $1 million more than the next runner up, math).

Among K–5 awards, the topics were valued more equally; however, of these, engineering appeared to be the most "valuable" topic to include in a project: it received the highest award amount when studied in isolation (by $788,000) and it also produced the highest award amounts when included on a project among other topics. This is particularly striking when you consider that engineering was very unlikely to be studied in isolation, and was a less common topic of study overall (25% of awards) than science (55%) and math (56%). This contrast between the high award value of engineering and the small number of studies including it suggests that there may be a stronger demand from the NSF for K–5 engineering research than there are projects studying it.

Average awards amounts across topics studied in isolation

	Science	Technology	Engineering	Mathematics
Pre-K	$4,370,328	—	—	$1,977,728
K–5	$2,361,902	$1,440,199	$3,150,059	$1,834,759

In the following tables, recall that for pre-K awards, technology and engineering always fall under the same grants, so their awards amounts will be the same. Engineering is almost always studied along with other topics (particularly at the K–5 level), especially science and math.

Average award amounts across topics overall

	Science	Technology	Engineering	Mathematics
Pre-K	$2,783,829	$1,154,481	$1,154,481	$1,927,313
K–5	$2,484,567	$1,939,022	$2,719,522	$2,165,642

Of the seven outliers for award amount (those awarded more than $6,125,615) in the sample, six included science, five included math, four included engineering, and two included technology. When these are removed, the distribution looks as follows:

Average award amounts across topic areas, without outliers

	Science	Technology	Engineering	Mathematics
Pre-K	$2,062,212	$1,154,481	$1,154,481	$1,927,313
K–5	$1,797,170	$1,105,544	$1,367,656	$1,430,834

[f] Only major awards, defined here as those granted $500,000 or more, were reviewed in this analysis.

3. There is an emphasis on children in pre-K and on teachers in K–5.

The distribution of teacher/staff-focused (e.g., teacher training, professional development) and child-focused (e.g., assessment of the development of math concepts in 4-year-olds) differed for all awards that included pre-K versus those that only looked at K–5. In pre-K, the emphasis is heavily on children, and in K–5, the emphasis is on professional development and curricular design. When interpreting these results, recall that some awards focus on both teacher *and* child development.

Child vs. teacher emphasis across age groups

	Teacher/Staff-focused	Child-focused
Pre-K	43%	70%
K–5	66%	44%

4. There is a greater emphasis on formal learning in K–5 than in pre-K.

The distribution of awards that focused on formal versus informal learning environments looks somewhat different for all awards that include pre-K versus those that only look at K–5. Both emphasize formal over informal learning, but to different degrees. For awards that included pre-K, looking at formal learning environments was about twice as common as looking at informal environments, whereas for awards that only included K–5, formal learning was examined more than three times as often. When interpreting these results, recall that some awards look at both formal *and* informal learning.

Formal vs. informal emphasis across age groups

	Formal learning environment	Informal learning environment
Pre-K	65%	30%
K–5	86%	25%

5. The distribution of awards across regions, institutions, and PI sex differed across age groups.

A. Geographical Regions: South largely absent in pre-K research

The geographical distribution of the awards, as defined by the U.S. Census Bureau's regional divisions,[151] differed for awards that included pre-K and those that did not include pre-K. Those that included pre-K were based in the Northeast, Midwest, and West, with only one in a Southern state. Eleven unique states were represented, with Massachusetts and California leading the way: five in Massachusetts; four in California; three in Illinois; two each in Pennsylvania, Colorado, and Michigan; and one each in New Jersey, Ohio, Missouri, Virginia, and Wisconsin.

Those that only considered K–5 were much more evenly distributed across regions; however, Massachusetts and California still represented the highest number of awards by far. Twenty-nine unique states were represented, but 13 awards were from California and 11 were from Massachusetts, which is more than double the awards from the next highest ranking state (North Carolina, with five awards).

Regional distribution of awards by age group

	Northeast	Midwest	South	West
Pre-K	8	8	1	6
K–5	20	16	22	22

B. Institutions: A third of K–5 awards granted to the same institutions

Across both age groups, there were many institutions that received multiple awards for STEM in early childhood education. The institutions that received the most awards were: TERC (Technical Education Resource Centers) (5), North Carolina State University (4), Tufts University (4), Michigan State University (4), and Vanderbilt University (3).

The degree of duplication differed across age groups. Among the 23 awards that included pre-K, there were 18 unique organizations represented; four organizations (20%) received more than one award. All four of the duplicate organizations received two awards. They were: Tufts University, Michigan State University, University of Denver, and the Fred Rogers Company.

Among the 80 awards that included K–5 only, there were 62 unique organizations represented; 18 organizations (29%) received more than one award. They were: TERC (5), North Carolina State (4), Vanderbilt University (3), Tufts University (2), Michigan State University (2), Franklin Institute Science Museum (2), University of Arizona (2), University of California-Irvine (2), Northwestern University (2), University of Missouri-Columbia (2), New York University (2), and Stanford University (2).

C. Sex of principal investigator: More female than male

Overall, there were slightly more female than male PIs among all the early childhood awards. The distribution of PI sex was similar across age groups, favoring females in awards that included pre-K. Awards that included pre-K had a 65% female to 35% male ratio, while those that only considered K through fifth had a 59% female to 41% male ratio.

Limitations

This awards analysis is meant to provide a rough sketch of the NSF's recent and current funding priorities in the area of early childhood STEM research. To accomplish this, we analyzed a small sample of publicly available abstracts describing awards related to STEM in early childhood. When interpreting the results, it is important to recall that we only considered a very limited sample of the projects the NSF is supporting in this area: major awards (those in excess of $500,000), within a single division of the agency. This analysis did not consider the potential impact of each project, and it did not include the *many* significant STEM projects and activities that the NSF is supporting outside of its grant program, of which there are many.

It is unclear from this analysis whether the observed imbalances are due to priority-setting by the agency, the composition of its applicant pool, or some other reason. We also recognize that a perfect balance of studies and funding across all areas may not be strategically wise or the intent of the NSF. The agency awards grants to the proposals with the greatest intellectual merit and potential for broad impact.

Finally, this analysis did not use inferential statistical techniques. As with all research conducted on samples, these results must be considered with caution. However, they do provide a preliminary survey of the current funding landscape and may provide nascent ideas for how the NSF can continue to model and improve its excellent support of STEM in early childhood.

appendix b: how reframing research can enhance STEM support: a two-science approach

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A strong body of evidence shows that young learners benefit tremendously from instruction in the fields of science, technology, engineering, and math (STEM). Yet Americans are reluctant to back education reforms that favor innovative STEM learning. Why the disconnect? One key reason is a complex web of education policies that inhibit the widespread adoption of STEM instruction into pre-K and primary schools. Culture is largely to blame. Policies are the product of politics, and politics is the product of culture, as ex-Sen. Jim DeMint said. “Politics,” he quipped, “follows the culture.”[152]

To understand how our culture is inhibiting the uptake of STEM instruction, and preventing the next generation from fully contributing to our nation’s prosperity, we need to understand what journalist Walter Lippmann once called the “pseudo-environment”—the place where “the pictures in people’s heads do not always correspond with the world outside.” In this pseudo-environment, legislators and civic leaders who promote STEM learning often find themselves at odds with the public, as parents inadvertently argue for approaches to learning that undermine children’s ability to engage and achieve in STEM subjects. This situation is even more fraught in early learning settings, where the public’s cultural models—deeply held ideas about what children need and how learning takes place—have not caught up with scientific discoveries about early childhood development.

This paper will argue that efforts to delineate the obstacles to full integration of STEM into early childhood learning, and to devise evidence-based approaches to overcome those obstacles, must take into account the perceptions that people hold about STEM and early learning. Doing so requires a “two-science approach,” in which policy science is coupled with communications science. This approach, used in the collaboration between the Harvard Center on the Developing Child and the FrameWorks Institute,[153] emphasizes using social science to understand where ordinary Americans part ways with experts, what this means for public support of STEM policies, and what kinds of narratives help people engage, reconsider, and endorse meaningful policies.

The two-science approach promises to prepare STEM proponents to infuse better narratives into the public discourse. As psychologist Howard Gardner has written, “over time and cultures, the most robust and most effective form of communication is the creation of a powerful narrative.”[154] Importantly, this requires the recognition that what we say matters to what we ultimately do about any given policy issue. This is more than media spin; it gets at the heart of how ideas are encoded in our public lives.

Determining the narrative needed to engage the public in the range of education reforms required to foster STEM learning requires research. A coherent narrative can only be developed by mapping the cognitive terrain so that communicators know which “pictures in people’s heads” they wish to evoke and which to bypass. To revisit DeMint’s observation, we use “talk” as the audible manifestation of culture, allowing us to predict what policy prescriptions are likely to “fit” people’s operative cultural models. When people say, for example, that very young children need to “learn the basics” before they “graduate” to STEM subjects, they are articulating a deep but widespread belief about hierarchies of learning, a cultural model that, if unaddressed by communicators, will marginalize active early STEM learning and experimentation in favor of rote memorization of basic content and concepts.

To map this terrain and determine how to navigate it, FrameWorks uses a multi-method, multi-disciplinary approach called Strategic Frame Analysis. First, we use interviewing and analysis techniques adapted from cognitive anthropology to map the deeply held, patterned ways of thinking that members of a culture widely share. Understanding these default patterns of thinking allows us to develop messaging recommendations that prevent communicators from triggering problematic ways of thinking and help them target productive thought patterns instead. We then use techniques from experimental psychology and linguistics to test potential reframes with thousands of research informants against a set of specific dependent variables, policies that experts and advocates want enacted.

Since its founding in 1999, FrameWorks has used these techniques to understand how Americans think about early child development, and we have more than 75,000 participants in our database on this issue.[155] We reprise the relevant research[156] here to share with those operating at the crossroads of early child learning and STEM. In 2010, FrameWorks began a large, multi-faceted project to create a Core Story of Education[155] to explain concepts such as assessment, teacher quality, skills acquisition, digital learning, and disparities. For this project, we queried more than 28,000 participants about these and other aspects of education. While this body of research is too voluminous to address here, it is fundamental to understanding how STEM is understood within a broader cultural context and how specific education reform proposals are heard and interpreted by the public. We recommend it to communicators.[157]

We wrote a new chapter to this Core Story beginning in 2013, when the Noyce Foundation supported an inquiry into how Americans think about STEM education specifically. During this project, we added 6,350 participants to our database and were able to dig deeply into public thinking and framing strategies around STEM and informal STEM learning. The ideas presented here, therefore, reflect patterns observed by researchers across time and space and method. As such, they are more reliable and durable than recommendations gleaned from isolated polls or focus groups, which, unfortunately, are often used to drive communications recommendations.

I. Navigating "the pictures in people's heads"

There are many ways that Americans think about STEM and early learning. We describe four below that present major communications challenges or opportunities, and we compare the public assessment with that of experts in the field.[158]

1. STEM is hands-on science…or maybe it is just basic math. Americans are confused about the full meaning of the acronym. People equate STEM primarily with science, which they view as best learned through active experimentation. Math learning, which was somewhat less top-of-mind, was understood to be learned most effectively by rote memorization in traditional, book-based classroom settings. When asked to think about technology and engineering, people drew on a cultural model that is both linear and hierarchical (i.e., that math learning precedes science learning, which, in turn, precedes technology and engineering learning). These latter subjects were viewed as appropriate for older students, and not accessible to early learners. Experts, by contrast, emphasize the importance of exposing students to STEM subjects at an early age. Moreover, experts emphasize that even young learners can and should use hands-on approaches to all STEM subjects.

2. STEM is not for everyone; it is only for certain "kinds" of kids. Experts maintain that *all* children benefit from STEM programs—regardless of their innate abilities or background. But members of the public assume that advanced education should be targeted at only those students who are naturally gifted or driven in STEM subjects. This cultural model infects debates about early learning with questions about interest and aptitude rather than exposure and access.
It also assigns STEM learning to later grades, after children have had a chance to express their preferences. Proponents of early STEM education note that this learning promotes the kind of critical thinking skills that are foundational to higher-level learning. But the public sees STEM

as a set of discrete subjects that are disconnected from other areas of learning. Americans do not necessarily believe that STEM fosters higher-level, transferable skills to students of any age, young or old. At the same time, STEM skills are often seen as innate, or held only by certain kinds of kids. The public strongly believes that "every child is different." Disparities in STEM learning, by extension, are accounted for by a child's genetic or cultural predisposition or by his or her intrinsic motivation, rather than by structural inequities in the distribution of educational benefits.

3. The benefits of strong STEM educational programs accrue to individuals. The public believes that STEM skills are important primarily because they help individual students get "good" jobs and achieve financial success. When Americans consider the collective benefits of STEM education, they tend to talk about global competition. This way of thinking, though, actually *depresses* support for addressing disparities in education within the U.S.[159] Moreover, Americans are far less likely to think about future career preferences for 3- and 4-year-olds than they are for older children; thus, the public's focus on individual careers further "ages up" the STEM conversation. Again, the public's inability to connect STEM learning to foundational critical thinking skills impedes appreciation for STEM's contribution to the nation's overall workforce productivity and our collective prosperity.

4. STEM in informal settings is not as important as learning in formal settings. While experts are eager to see young children exposed to STEM in multiple settings, from science museums to summer camps, Americans are largely ambivalent about these options. For very young children, they are likely to dismiss the importance of mere "play" as an important learning process. Real learning, they assert, happens through formal classroom instruction. At the same time, many adults hold a "rechargeable battery" model of learning, which posits that children have only so much attention they can give to learning before they need to recharge by relaxing. Applied to very young children, this cultural model is likely to make people resistant to multiple STEM exposures and sites of learning within communities. Too much exposure to STEM activities, people might think, will leave young children drained and spent and thus unable to fully focus in the formal settings that they see as being more important for effective learning.

These strongly held, widely observed cultural models about STEM learning for young children pose important communications challenges. Experts and advocates must overcome them to build public and policymaker support for early learning reforms that are consistent with STEM education research.

II. Pushing and pulling concepts about STEM

The framing literature over the past two decades is clear: understanding is frame-dependent. That is, when communicators change the way a problem of judgment is presented, they signal what cultural model should be used to formulate a response. As anthropologist Bradd Shore has said, "the competition for the hearts and minds of people in policy work is the competition for restructuring salience by changing what cultural models are in the foreground."[160]

Put another way, when you tell the STEM story in different ways, you get different outcomes: more or less comprehension, more or less support for policies, more or less engagement with the issue. FrameWorks uses a number of frame cues to inform its narratives: values, metaphors, explanatory chains, exemplars, etc. Here we focus on two elements—metaphor and exemplar—as our research has shown that they significantly change the way people think about STEM and early learning.

A. Metaphors for Rechanneling Thinking

Metaphors hold great promise for changing the STEM conversation. By comparing an unfamiliar concept or idea to a common and familiar one, metaphors act as translation devices, making complex ideas more accessible. FrameWorks researchers designed a series of metaphors to address specific aspects of the expert story about

STEM that was not transmitting to the public. We then tested these metaphors, both qualitatively and quantitatively, to verify and improve their effects on policy preferences. Metaphors proved particularly effective in getting people to see:

- how children acquire skills, or the process of learning;
- how skills interconnect and are reinforced in various learning environments and
- why children need multiple exposures over time and place.

Here we focus on the three metaphors that helped in rechanneling thinking:

1. How do children learn? By weaving skills.

When it comes to STEM and other education-related issues, Americans mistakenly think of learning as a passive process and believe that "real learning" does not happen until children reach school age. Misperceptions like these have implications for people's support for education policies that foster hands-on learning programs and support early learning, including an early introduction to STEM subjects. A metaphor comparing the process of learning to that of weaving a strong rope can help correct these misperceptions. The metaphor can be conceived as follows:

> Learning is a process of weaving skills together: no single strand can do all the work and all need to be present, strong, and integrated. As we learn new skills, our brains weave these strands together into braided skill ropes. We use these ropes to do all the complex things that we need to be able to do to function well in school and in life: solve problems, work with others, formulate and express our ideas, and make and learn from mistakes as we grow. Solving problems using data, and experimenting in science, technology, engineering, and math, help us develop strong strands that we can then use in weaving many different kinds of skill ropes. At every age, children need opportunities to practice and learn how to weave these STEM strands into different ropes, depending on the needs of a given task or situation. When kids have strong STEM strands, they can use them for all kinds of things that they will need to be able to do throughout their lives.

This metaphor prevents people from defaulting to their baseline cultural models about learning as a passive process. It also counters unproductive cultural models about hierarchies of learning and of disciplines.[161] In addition, it illustrates the interplay between cognitive, emotional, and social development, which opens the door for conversations about how even young children can benefit from exposure to STEM learning opportunities. It also demonstrates how learning, like weaving a rope, is an active process that demands engaged participation.

2. How are skills reinforced in various learning environments? By providing opportunities to practice STEM fluency.

Dominant public default thinking about STEM education harbors a disconnect between, on the one hand, the kind of interactive, hands-on learning that people expect from extracurricular programs, and, on the other, the rote, "back-to-basics" pedagogical practices they equate with classroom learning. The perception is that informal learning environments are a nice but unnecessary supplement to "real" (i.e., classroom) learning. To strengthen communications about the need for applied, real-world STEM learning opportunities, FrameWorks tested the following metaphor, which compares hands-on STEM education to foreign-language immersion:

> Out-of-school learning helps children and youth become fluent in science, technology, engineering, and math—the subjects called "STEM." Just as people need to be immersed in real-world situations to best acquire a language, when children and youth explore STEM in their lives outside of the classroom, they can master these subjects. Giving students the chance to practice what they have learned in the classroom in contexts like libraries, community centers, museums, and afterschool programs builds understanding, develops confidence, and inspires a greater willingness to take on challenges and even

> risk the possibility of failure. This helps children develop cognitive agility, which will help them manage challenges throughout their lives.

This metaphor proved potent. It generated statistically significant increases in public support for out-of-school STEM programs; the recognition that children can and should learn all four STEM subjects at an early age; the acknowledgement that *all* children can learn STEM; and the attribution of responsibility for STEM learning to society rather than to individuals.[162]

Regardless of their level of educational attainment or their foreign-language fluency, Americans recognize that immersion is the best way to learn a language. Comparing STEM learning to language acquisition invigorates their understanding of the complimentary role that formal and informal STEM experiences play in improving students' STEM learning outcomes and skill development. This, in turn augments support for policies and initiatives that support immersive out-of-school STEM programming.

3. How can we improve the way that children learn? By giving them access to multiple charging stations.

When reasoning about why some children pursue and excel at STEM subjects and others do not, the public attributes differences to innate talent, motivation level, the degree of a family's commitment to education, cultural differences, and other preconceived biases about specific groups, rather than to disparities in access and opportunity. To counter this dominant, individual-focused narrative, FrameWorks researchers recommend comparing access to STEM learning opportunities to charging stations where children can "charge up" their skills, brains, and engagement, as exemplified here:

> STEM learning opportunities are like charging stations that power up kids' learning. Some students are in environments with lots of opportunities to charge up STEM learning. Everywhere they go, they can access and benefit from powerful charging stations, such as libraries, museums, science centers, and afterschool programs—places where they can apply abstract concepts and turn knowledge into skills. But other students are in charging dead zones, places without many high-quality learning opportunities they can plug into. Our current system is patchy; it provides fewer charging opportunities for some of our nation's children, leaving them without access to multiple opportunities and ways to interact with content necessary to master STEM subjects. We need to build a better charging system so that all students, no matter where they are, have high-quality opportunities to engage with STEM subjects.

The charging stations metaphor works by steering people's focus toward structural problems within our education system that can be fixed by repairing the system. Because the metaphor pertains to very young children, it affords a narrative slot for discussing how to provide more STEM instruction in pre-K programs. It also debunks the belief that very young children get "drained down" quickly and therefore cannot endure the kind of exposure and engagement that STEM subjects require. Finally, the metaphor's associations, such as the idea of replenishing (or "powering up") children's learning, have the added value of helping the public understand that learning is a constant process that requires resources beyond the classroom.[163]

One additional frame element—powerful examples —deserves discussion in this context. Confusion over what STEM is and its utility can be powerfully addressed by choosing the right examples.

B. What exactly is STEM? Provide an example.

Research suggests that Americans simply do not have much exposure to STEM learning and therefore struggle to understand why it matters and how it works. Providing a clear illustration of a STEM learning program—what participants learn and how they learn it, with what goals and outcomes—sketches a memorable picture that can fill in cognitive gaps. FrameWorks tested several concrete examples for their ability to move people's policy preferences. One especially effective example was that of the community garden. We have adapted the tested version to address young children, as follows:

> One way that very young children can be engaged in STEM learning is in community gardens. In these programs, children from all backgrounds learn STEM by growing their own fruits and vegetables. In doing this, children are exposed to environmental science and plant biology and begin to develop critical thinking skills. When these programs are in science centers or after-school programs, they give children the opportunity to meet STEM professionals from local universities and botanic gardens. Working in teams with these STEM experts, even very young children can begin to develop growing strategies, solve problems, and learn to adjust their approach when things do not go as expected. These programs lay the foundation for later success in STEM, helping children think of themselves as "math and science kids" early on. The fruits and vegetables that the children grow are used in preparing school lunches, so they can see the real-world benefits of STEM skills and knowledge.

This example, along with a number of others that proved effective, had a dramatic impact on various aspects of people's STEM thinking. The community garden example greatly enhanced public recognition that STEM is for all kids. It elevated support for applied learning and informal STEM programs. And it also helped people prioritize exploration and experimentation in learning (as opposed to prioritizing only "the basics") and to support early introductions to STEM.[164]

In sum, our communications research conducted for the Core Story of Education and for specific STEM projects yields numerous insights that can be used to enhance communications practices relating to STEM learning. Communications science offers STEM experts and advocates an important new perspective on what they are up against in moving public support, and how they can begin to mobilize this support.

III. How STEM communicators can use the two-science approach

The public conversation rarely transforms overnight. Most often, it requires the relentless, orchestrated efforts of dedicated communicators who are willing to become frame sponsors. As political scientist Sanford Schram wrote in his 1995 book *Words of Welfare*, "postmodern policy analysis…may be defined as those approaches to examining policy that emphasize how the initiation, contestation, adoption, implementation, and evaluation of any policy are shaped in good part by the discursive, narrative, symbolic, and other socially constructed practices that structure our understanding of that policy."[165] These efforts require a two-science approach: we must know what will make a difference in advancing effective STEM pedagogy for early learners and also how to translate the vision and needed education reforms so that ordinary people can get on board.

To determine if this approach might aid your efforts, consider this thought experiment: imagine that you are addressing a group of teachers, parents, or policymakers. Your job is to explain why very young children should be involved in STEM learning. Now, try to anticipate the questions you will be asked and think about how you might answer them.

> *Policy science says:* Children are born scientists. *The public says:* Some children are born scientists, and others not. And then some are encouraged or discouraged to pursue science by their family cultures. Not every child can learn STEM subjects, nor do they need to do so. Not every kid needs to be a math or science kid. *Communications science suggests:* Watch a group of very young children who are engaged in planning and planting a community garden. What are they learning? The beginnings of environmental science and plant biology, critical thinking skills, problem solving, trial and error, and more. Every young child can be engaged at this level and can begin to think of herself as a "math and science kid" who can use her skills and knowledge to put food on the lunch table.

Policy science says: Children who engage in scientific activities from an early age develop positive attitudes toward science.
The public says: Children need to learn the "basics" first, before they are able to address more complex STEM subjects. First come reading, writing, and arithmetic. Then kids can decide whether they are ready for STEM.
Communications science suggests: Learning opportunities are like charging stations that power up kids' learning. Some kids live in charging systems with lots of opportunities for learning, while other kids have very few. If we increase the number of STEM charging stations in kids' environments, we will see more interest and fluency in STEM. Our current system is patchy; this explains why some children never develop STEM fluency, which has significant consequences for their overall learning.

Policy science says: Early introduction to science and math "talk" helps children build STEM vocabularies and acquire the background or knowledge they need for deeper understanding of STEM topics.
The public says: Children need to wait until they can understand complicated scientific concepts. Little kids should be focusing on learning their ABCs.
Communications science suggests: Just as people need to be immersed in a language in order to become fluent, children, too, need to be given many opportunities in many different settings to become fluent in STEM subjects. They need real-world exposure to STEM activities, like working in a community garden. These types of activities help whet kids' appetites for STEM learning and build their skills. When we give *all* children STEM opportunities, they learn to speak fluent STEM.

Policy science says: Preschool math skills predict later academic achievement more consistently than early reading or attention skills.
The public says: Children who are motivated will achieve. Not everyone can be good at math. But everyone can read.
Communications science suggests: As we learn new skills, our brain weaves skill strands into ropes that we can use to solve problems, meet challenges and, in turn, acquire new skills. STEM skills are vital in many different kinds of skill ropes. When kids have opportunities to collect evidence and solve scientific problems, they add strands to these ropes, strengthening them to be used in many ways later in life.

Without a two-science approach, STEM communicators may lack the tools they need to shape public opinion and build support for their goals. They might have only a limited understanding of widespread thought patterns about STEM learning, and they might not have the skills they need to avoid triggering unproductive ways of thinking. Communicators who blast their rhetorical horns—without first understanding the science behind their messages—often achieve little more than personal satisfaction. We cannot allow support for STEM policies and programs to languish. The science of communications gives advocates the instruments they need to cultivate public support for rooting STEM deep in the early years, thus nurturing children's growth and strengthening our society.

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Acknowledgments
This work was a team effort. We are grateful to our current and former colleagues at the National Science Foundation, especially our program officers, Catherine Eberbach and Andrés Henríquez. Our colleague Lori Takeuchi, senior director and learning scientist at the Cooney Center, conceptualized this project, wrote the grant proposal, and served as an important adviser throughout. Our national advisory team, which included Susan Bales, Doug Clements, Sharon Lynn Kagan, Deborah Phillips, Russ Shilling, Marshall (Mike) Smith, and Vivien Stewart provided instrumental guidance and support. We would also like to thank the many researchers, teachers, teacher educators, and policy makers who were interviewed for the report as well as the research, event, and communications teams at New America and the Cooney Center for their tireless dedication to quality. Special thanks to educators at the Child and Family Network Centers in Alexandria, VA and Laurel Ridge Elementary School in Fairfax, VA, where we conducted focus groups. Finally, we owe a special debt to Janice Earle, a true pioneer in promoting STEM capabilities for America's youth. She passed away in March. Janice encouraged and seeded our early learning and STEM work: we dedicate this report to her, in honor of her remarkable legacy.

Managing Editor: Catherine Jhee
Copy Editor: Sabrina Detlef
Design: Jeff Jarvis
Illustrator: Marybeth Nelson

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