# Unleashing the Power of Science in Early Childhood

## A Foundation for High-Quality Interactions and Learning

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**Abstract**
When science is integrated into early childhood learning experiences, it becomes a critical area supporting young children's development. Young children are natural scientists, curious about their world, and they engage in scientific practices to learn about and explore their world. This article describes how the K-12 Framework for Science Education can and should be tailored and applied to early childhood to align science learning from infancy through 12th grade. Further, the Framework provides a coherent structure for children to build the complexity of their understanding of science across the early years and beyond. The authors highlight the role that adults play, illustrate application of the framework, and demonstrate how high-quality science interactions not only build the foundation for later science learning but also support development across multiple readiness domains.

Supporting meaningful science education during early childhood, beginning in infancy, is at a critical tipping point. On the one hand, a national focus on the considerable advantages of science for young learners has included: (a) a National Research Council (NRC) task force report on the importance of introducing science to young children and the need to capitalize on cognitive research on how young children learn (Duschl, Schweingruber, & Shouse, 2007); (b) a position statement from the National Science Teachers Association endorsed by the National Association for the Education of Young Children's governing board on the importance of science education in early childhood (National Science Teachers Association, 2014); (c) a White House-hosted symposium for practitioners, funders, policymakers, and researchers on the need for a much greater focus on STEM (science, technology, engineering, and math) in early childhood (White House Symposium on Early STEM, 2016); and (d) two new major reports on why a focus on STEM in early childhood is critical as well as recommendations on what is needed to achieve these goals (McClure et al., 2017; Spaepen et al., 2017).

On the other hand, early childhood educators do not feel prepared for teaching science (Greenfield et al., 2009). Their own training in science largely focused on memorizing facts and teacher-demonstrated science activities that produced the "correct" answer. These experiences with science education have often resulted in early childhood teachers' concerns that their children will ask questions that they will not be able to correctly answer. There is also the widely held misperception that science is for a select group of students with aptitude and should not be introduced until students are much older (McClure et al., 2017; Spaepen et al., 2017) As a result, very little time is spent on science experiences in early childhood classrooms (Nayfeld, Brenneman, & Gelman, 2011). When science experiences do occur, they are mostly of low quality (Brenneman, Stevenson-Boyd, & Frede, 2009).

The purpose of this article is to introduce a conceptual framework for early childhood science education that will address the critical role of early science education and its promise to provide a strong foundation for high-quality teaching and learning for young children. We illustrate this framework for infants, toddlers, and preschoolers in the context of our ongoing project, the "Early Science Initiative," funded by the Buffett Early Childhood Fund (Greenfield, 2015). In addition to presenting and illustrating the framework, we also discuss the critical role that adults play when they use the framework to support science learning with young children.

## A Framework for Science Education

In 2012, the NRC's Committee on a Conceptual Framework for New K-12 Science Education Standards published a framework that articulated a broad set of expectations for students in science (NRC, 2012). This framework addressed the problems with the current ineffective approach that covered many science topics at a superficial level (characterized as a "mile wide and an inch deep"; NRC, 2012, p. 10) in a fragmented, disconnected way with little relevance for students' everyday lives. The new framework focuses on a small set of core ideas in four science disciplines and requires that students learn science by doing science. The three essential features of the framework, detailed in the next section, are integrated and revisited at deeper levels of understanding each year throughout K-12 science education (NRC, 2012). In a later section, we highlight the high degree of relevance and appropriateness of this approach in early childhood, and we illustrate the role of adults in using science to support high-quality interactions and development across important readiness domains througout early childhood.

### Description of the K-12 Science Framework

The K-12 Conceptual Framework is an integrated three-dimensional approach to science education. The dimensions of the framework are Practices, Crosscutting Concepts, and Disciplinary Core Ideas.

#### Practices

Practices are the behaviors that provide structure for children to engage in science experiences to explore and develop their knowledge of crosscutting concepts and core ideas (see next sections). These behaviors include: making observations; asking questions; making predictions; developing and using models; planning and carrying out investigations; using math and computational skills; documenting, analyzing, and interpreting data; constructing explanations; and communicating information.

#### Crosscutting Concepts

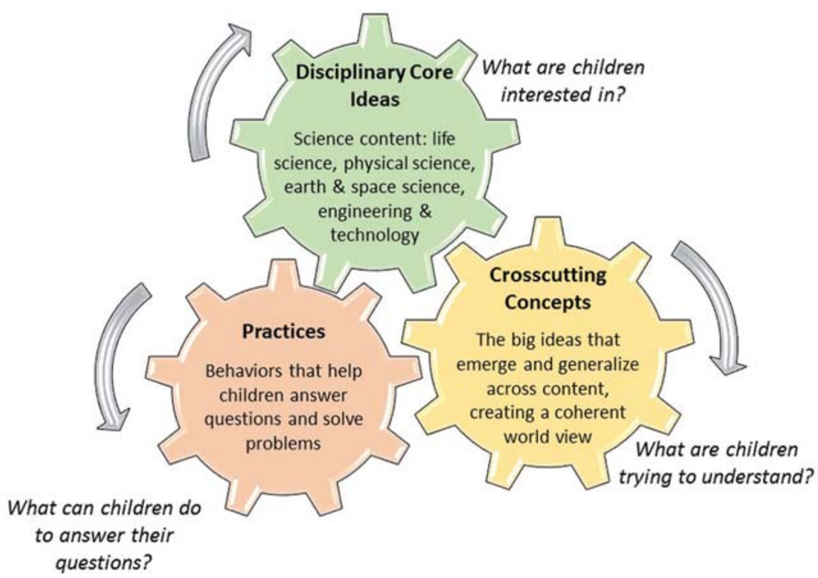
Crosscutting Concepts are big ideas that are relevant in many areas of children's lives and are applicable across all disciplines of science. These concepts include: patterns; cause and effect; scale, proportion, and quantity; systems and system models; structure and function; and stability and change. When children are challenged to think about crosscutting concepts during their engagement in scientific practices, the value of the experience is substantially deepened and enriched. The pursuit of understanding crosscutting concepts demands critical thinking. There is no room for rote memorization or shallow learning when crosscutting concepts are the intended learning goal.

#### Disciplinary Core Ideas

The four science disciplines include: life science; physical science; earth and space science; and engineering, technology, and the applications of science. Each discipline has from two to four core ideas that are designed to create high school graduates who are science literate in highly relevant topics. For example, physical science includes what things are made of and how materials interact with each other; life science investigates how living things interact and use their environments to survive; earth and space science describes the patterns, cycles, and movement of the earth, sun, moon, and stars; and engineering, technology, and the application of science explores how humans design and use tools to help answer questions and solve problems.

As children progress through the K-12 system, they are provided with multiple opportunities to engage more rigorously in scientific practices; develop a deep, sophisticated understanding of core ideas; and revisit crosscutting concepts to build a coherent, integrated view of the world (see Figure 1).

*Figure 1. Early Science Framework (Adapted from the K-12 Framework for Science Education)*



## Science Education in Early Childhood: It's Not Too Early—It's Just Right!

Although the new conceptual framework for K-12 science education was developed for older children, the application of the framework in early childhood is not a "push-down" approach. Similar to the approach of our colleagues in early math (Chen, Hynes-Berry, Abel, Sims, & Ginet, 2017, this issue, p. 23), we assert that science education is both foundational and developmentally appropriate for infants, toddlers, and preschoolers. Infants are primed to investigate and explore their world in ways similar to scientists (Gopnik, 2010; Gopnik, Meltzoff, & Kuhl, 1999), and their curiosity to understand their world intensifies throughout early childhood as they become more mobile and verbal. Research shows that very young children can engage in learning across all three dimensions of the science framework which sets the foundation for later scientific thinking (Gerde, Schachter, & Wasik, 2013; Gopnik, 2010; NRC, 2012; Shillady, 2013). Children are quite capable, highly curious, and motivated to engage in science experiences (French, 2004; Gelman, Brenneman, Macdonald, & Roman, 2010). As we illustrate in later sections, they benefit by using the framework's scientific practices, and, with adult help, acquire a beginning understanding of the crosscutting concepts, as they build their foundational knowledge of the four science disciplines.

### Questioning and Information Seeking

Questioning is a key mechanism through which children engage in science and is one of the scientific practices in the science framework. Even before they are verbal, infants ask questions about how their world works by pointing and gesturing (Chouinard, 2007). In a series of studies looking at children's questions, Chouinard (2007) documented that from the moment infants become verbal, the vast majority of their questions are information seeking (91%). All of the science disciplines are reflected in the questions children ask as they seek information about how their world works: "Why don't my shoes fit anymore?" (life science), "What will happen if I throw these mashed potatoes?" (physical science), "Where does the sun go at night?" (earth and space science), and "What can I use to reach the cookie jar?" (engineering and technology).

### High-Quality Adult–Child Interactions

Children's engagement in science naturally aligns with their curiosities about the world and has been shown to improve interactions between children and adults (Fuccillo & Greenfield, 2017). When adults engage with children in science experiences, adults are prone to use highly effective teaching practices such as asking the right questions at the right time (Elstgeest, 1985). These teaching practices include attention-focusing questions, measuring and counting questions, comparison questions, action questions, problem-posting questions, and open-ended how and why questions that encourage children to observe, count, predict, and compare.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Infants are primed to investigate and explore their world in ways similar to scientists.

Adults also introduce advanced and relevant vocabulary, and they help scaffold children's planning and communicating. These teaching practices are especially important because the quality of early adult–child interactions is a predictor of later developmental outcomes (Xu, 2011). Research has also demonstrated that positive, engaging relationships in childhood predict later cognitive and social development (Poehlmann & Fiese, 2001). Furthermore, the combination of high-quality infant, toddler, and preschool care and education produces the largest effects for academic achievement (Li et al., 2011).

### School Readiness

The benefits of science learning for young children go well beyond developing a foundation in science. When children are engaged in high-quality science experiences, they draw upon multiple school readiness areas, including language, math, social–emotional, and fine motor skills (Greenfield et al., 2009). They acquire new vocabulary that provides meaning for what they are trying to understand and allows them to engage in rich, real-world conversations (French, 2004; Peterson & French, 2008). As they develop the ability to use measurement tools they strengthen their mathematical thinking (Nayfeld et al., 2011).

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Executive functioning (i.e., working memory, inhibition, and cognitive flexibility; Blair & Razza, 2007) and approaches to learning (i.e., curiosity, persistence, initiative, and preference for challenge; McDermott et al., 2011) are two foundational areas of development that may benefit from a focus on science education. For example, as a young toddler explores the properties of objects by rolling various items down a ramp, she must focus on the task at hand and inhibit the desire to engage with other children at a different center (inhibition). When confronted with a cylinder, she may need to think flexibly about the different ways the cylinder can be oriented so that it can roll down the ramp (cognitive flexibility). Finally, the motivation to enact her planned experiments with each of the shapes will help her persist, even when the ramp falls down multiple times (approaches to learning). Research linking science education to both executive functioning (Nayfeld, Fuccillo, & Greenfield, 2013) and approaches to learning (Bustamante, White, & Greenfield, 2016) in young children provides additional weight for promoting a greater focus on high-quality science experiences in early childhood.

## The Critical Support That Adults Provide

As we noted earlier, infants are primed to investigate and explore their world, and they do so like scientists (Gopnik, 2010; National Research Council & Institute of Medicine, 2000). For example, a young child learns life science knowledge when she notices ants crawl toward a piece of cracker on the floor and carry it to off to their "house." The young child uses the scientific practices of observing when watching the ants and predicting when she speculates that the ants plan on eating the cracker for dinner.

Despite this curiosity and desire to make sense of their immediate world, children's exploration can only go so far without support from adults (McClure et al., 2017; Spaepen et al., 2017). Vygotsky's sociocultural theory of development (Vygotsky, 1978a, 1978b) in early childhood education provided strong theoretical support for the important role that the adult plays in children's learning. According to Vygotsky, children learn best when an adult is present to help scaffold children to the next level of learning just beyond their reach (referred to as the "zone of proximal development").

Following are two examples to illustrate the critical role that adults play in young children's learning and the role of the science framework in facilitating this role. Each example focuses on the physical science discipline and the core idea of the properties and attributes of materials, the crosscutting concept of structure and function, and involves engaging the children in a variety of scientific practices. Although life science is the more common discipline adults select when they do engage young children in science learning, physical science has the advantage of providing immediate feedback to the child (as will be illustrated in these two examples). These examples also demonstrate how the same core idea in physical science (properties and attributes of materials) can be experienced in multiple contexts that all draw upon the ever-present structure and function crosscutting concept.

### Making Science Visible: Cleaning Up

For the first example, a young child is cleaning up a spill using a paper towel. The paper towel isn't sufficient to absorb all the water, but the child continues to push the water around, trying to clean up the spill. The child is frustrated that her effort is not working, and she doesn't understand why she is not being successful. This situation provides the opportunity for the adult to turn this frustration into a quality learning experience by using the science framework to make the science visible to the child. The adult focuses the experience on the concept of absorption (properties and attributes of materials) and highlights the crosscutting concept of the structure and function of materials (the paper towel is soft and fibrous so it can absorb). The adult begins by asking the child to draw upon her past experience and think about what other objects could "absorb" the water while providing a definition of this new word. Strategically, the adult provides a small set of materials to choose from, including things that will absorb (e.g., a cloth towel) and things that will not absorb (e.g., wax paper). The adult asks the child to brainstorm which materials might work best and why (making predictions). As the child then tries out different materials (planning and carrying out investigations), the adult engages the child in a conversation about absorption, asking the child to observe and report on how well each material absorbed the water (documenting, analyzing, and interpreting data). With the help of the adult, the child compares the materials. Together, they squeeze the water from each material back into identical-size glasses and see which held more water (using math and computational skills). Reflecting on the activity (constructing explanations), the adult discusses with the child how the material's structure (what it is made of) relates to the material's function (how much water the material could absorb or not absorb).

## Making Science Visible: Building

A second example takes place in a classroom block center or in a toddler or preschool child's home play area. The child is building a tower with blocks, motivated to make the tower as tall as possible by stacking long blocks on their smallest end. Her tower falls down because she has built it too tall and with a narrow, unstable base. This young engineer has not yet discovered how to build a stable structure. An adult who is knowledgeable about the science framework would scaffold this child-initiated activity by guiding the child through a series of scientific practices. For example, observing her unstable tower, asking questions about why it might be falling down, eliciting predictions about how to make the structure more stable, and planning and carrying out investigations to test alternative solutions would result in much more than just engaging in a fun adult–child interaction. The young child would be learning core content in physical science (properties and attributes of materials), attending to the crosscutting concept (structure and function) and developing important problem-solving skills through the use of a number of scientific practices. This intentional focus of engaging the child in a series of scientific practices, a core idea in physical science and the crosscutting concept of structure and function, can also help children apply this science knowledge to relevant engineering problems. To further strengthen this connection of the application of science principles to engineering design problems, the adult can discuss relevant engineering concepts; for example, how to use these same blocks to create a more stable foundation and structure, and challenging the child to do so.

These two examples clearly demonstrate the presence of science in children's everyday activities and the critical role of the adult in making the science visible. Although these examples are written with preschoolers and toddlers in mind, infants experience similar opportunities that align with the scientific principles:

- The infant in his high chair carefully watching an adult (a parent or teacher) cleaning up his spill with a paper towel or cloth.
- The infant crawling from one object to the next (a tower of blocks and the box that holds them) and pushing to see what will fall down or remain stable.

These moments of "hidden" science need a knowledgeable adult to make the science visible. By making the science visible, the adult facilitates the child's engagement, introduces new vocabulary in context, and provides the foundation of science practices, crosscutting concepts, and core ideas as pivotal tools with which to understand and explore the world. Engaging in science allows adults to implement high-quality practices that support children's critical thinking skills. As adults reframe thinking about young children as scientists and encourage children to explore science, the emotional relationships between children and adults may increase as well.

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Moments of "hidden" science need a knowledgeable adult to make the science visible.

Consider the following typical example during breakfast from two different perspectives:

A moment of frustration:

> *Owen is 9 months old. He loves to lean over the edge of his high chair, reach out his hand, and drop his spoon. And he does this repeatedly during breakfast. Frustrated with having to pick up the spoon, his dad says, "OK, no more spoon for you!" Owen starts to cry when his dad takes away his spoon.*

A moment of learning:

> *Owen is 9 months old. He loves to lean over the edge of his high chair, reach out his hand, and drop his spoon. He does this repeatedly during breakfast. His dad notices that Owen is carefully observing what happens when the spoon is let go. "Wow!" says Owen's dad, "that makes a loud noise when you drop it. Do you think the napkin will make a loud noise too?" Owen's dad hands him a napkin and then looks at the floor to prompt him to test out this new material. Owen smiles, takes the napkin, and drops it.*

Notice in the second example how the emotional climate remains positive. Because the adult has a focused lens for science, and sees his infant engaging in science exploration, he is able to reframe this potentially frustrating situation into a learning opportunity. Seeing the science in young children's play helps adults value and respect children's curiosity and inquiry.

## Learning Across Domains

It is also evident in these examples that science provides a rich context for the development of other important learning domains. Complex vocabulary is introduced and applied to hands-on experiences (e.g., absorb, materials, stable, structure, model) wherein children are hearing and seeing these new words and are motivated to start using this language to talk about what they are doing. Experiences like the ones described previously help create an environment where children can develop critical social and emotional skills (e.g., they must work together, share materials, challenge each other's thinking, and cooperate to achieve a desired goal). Skills that promote all types of development are used and strengthened during adult-scaffolded experiences described here. For example, when children's towers continue to fall, children can be encouraged to persist, creatively problem solve, flexibly think about the structures they can design, inhibit potential distractions going on in the classroom, and capitalize on the learning that results from failures.

## Developing Guidelines for Infants, Toddlers, and Preschoolers

A set of nationally recognized Next Generation Science Standards (NGSS Lead States, 2013) were developed to guide the implementation of the new K-12 conceptual framework for science education (NRC, 2012). The Next Generation Science Standards, however, do not extend below kindergarten, and very little research has focused on the development of science learning for children under 5 years old. Creating a similar guide to implement the framework starting in infancy that progresses through toddlerhood and the preschool years is still an ongoing, evolving process and will require considerable efforts with researchers and practitioners working in collaboration (Spaepen et al., 2017). We have begun such collaborations in the context of our "Early Science Initiative," funded through our Buffett Early Childhood Fund Acceleration Grant (Greenfield, 2015). We next illustrate what such a guide might start to look like with respect to another key crosscutting concept: "cause and effect."

Children from a very early age are capable of recognizing the crosscutting concept of "cause and effect" as it unfolds before them in their daily interactions with their world (Bonawitz et al., 2010; Waismeyer, Meltzoff, & Gopnik, 2015). In Table 1, we contrast three young children—an infant, a toddler, and a preschooler—as they experience "cause and effect" with respect to causing an object to make a sound. In comparing these three vignettes, one should notice that as children move from infancy to toddlerhood to preschool, their understanding of "cause and effect" becomes more sophisticated and nuanced. We also highlight the critical role of the adult in supporting the understanding of this crosscutting concept early on in infancy, as it serves to help set a foundation to build on this understanding more easily as infants develop through toddlerhood and the preschool years.

## Reframing Early Science Education

When adults use the early science framework to "see the science" and make it visible to children, learning flourishes and the interactions between children and adults articulate the wonder and joy of science, filling the hearts and minds of both children and the adults who are privileged to learn alongside them. The following contrasting learning experiences further highlight the advantage of this reframing of early science education.

### Paper Flowers as Art

The teacher in a preschool classroom is sitting in a small group with five children. She has pipe cleaners, construction paper, and colored tissue paper in baskets on the table. "We are going to make flowers like this one" the teacher says to the children and shows them her premade paper flower. "First, we are going to take the pipe cleaner and use it to make a stem" she says, and hands each child a pipe cleaner. Then, she gives each child a piece of construction paper and explains that they are going to use this to make leaves. She continues to help the children assemble their flowers by giving each of them one of the materials and showing them how to use it to make their flower. At the close of the lesson the teacher comments on how pretty the flowers look. She checks this off as having completed a science activity with her children.

*Table 1. Examples of Learning About Cause and Effect*

| Infants | Toddlers | Preschoolers |
|---|---|---|
| Six-month-old Callie is laying in her crib eying the mobile that hangs within hand and foot reach. Her mom notices that Callie both reaches with her hand to swat and kicks with her foot to move the shiny bird hanging from the mobile. She smiles every time she is successful in causing the bird to produce its chirping sound. As Callie swats and kicks the bird, her mom says, "Look Callie, when you cause the bird to move it makes its chirping sound. You are the cause of this delightful effect!" | Bailey, an 18-month-old, is playing with musical instruments in her classroom. She is alternating between hitting the drums with her hands and shaking a maraca. Bailey's teacher notices Bailey doing this, points to the drum, and asks her, "Can you make the drum make a sound?" Bailey hits the drum and her teacher praises her and says, "It made the sound when you hit it. Can you make the maraca make a sound?" as she hands her the maraca. Bailey shakes the maraca and again her teacher praises her and says, "Look, when you hit the drum and shake the maraca they each make a sound. Your actions are causing these effects!" | Fernando is in his preschool classroom playing with the musical instruments. He notices that when he hits the drums with his hands, the top of the drum vibrates. He hits the drum again really hard and notices that the drum vibrates even more. "Look Ms. Carrie!" he exclaims, "When I hit the drum it moves." "Good thinking," responds Ms. Carrie. "Can you show me?" she asks, and he hits the drum again. "You're right, Fernando, when you hit the drum, you cause it to move and vibrate. I wonder what would happen if you hit the drum very softly?" Fernando lightly taps the drum, "It doesn't move as much," he says. "Good observation, Fernando! When you hit the drum hard you cause it to vibrate a lot, but when you tap it softly you cause it to vibrate just a little." |

### Paper Flowers as Science

The teacher in a preschool classroom is sitting in a small group with five children. She has pipe cleaners, construction paper, colored tissue paper, and cut sections of brown string in baskets on the table. That morning, the children picked daisies from the perimeter of the playground. Many of them still had their roots attached. The teacher collected these flowers from the children and is now handing them out to each child. "We are going to make models of flowers," the teacher says to the children. They have discussions about what a model is. The teacher then directs children to look at their flowers. They pick them up and examine them. She says, "Let's talk about the parts of the flower. What do you see?" One of the children says that she sees a long green string part. The teacher says that this is the stem and asks the children which material would make a good stem and why? One child responds, "The green pipe cleaner—it is long just like the stem." Another child points to the dirt-covered roots on his flower. "What did you find, Reggie?" Asks the teacher. Reggie is quiet. "Those are the roots," says the teacher. "The roots go in the ground and help the plant get nutrients and water. Which one of our art materials can we use to model the root?" The teacher and children continue to explore the daisy, talking about the names of the parts, their function, and what materials would be best to model each part and why.

### Comparing the Experiences

The differences between the two experiences are stark, yet the physical product is the same: both experiences result in paper flowers. Because the teacher in the second vignette uses the science framework to drive her interactions, there is more child engagement and critical thinking. She is motivated to engage the children in modeling and is asking them intentional questions to help them critically observe the flower and model it (scientific practices). Furthermore, she is engaging them in conversations about the functions of different parts (structure and function crosscutting concept; life science core idea knowledge). Overall, application of the science framework has elevated this flower-building experience from a rote, teacher-driven art lesson, couched as science, to an experience in which children are critically thinking, engaging in scientific practices, and developing an understanding of crosscutting concepts and core ideas.

## Conclusion

The most effective way to jumpstart a greater focus on science in early childhood education is for adults to start using the science framework to help them "see the science" that produces young children's wonderment and joy in learning about the world in which they live. Although this conceptual framework for early science education had its roots in K-12 science education, it can be adapted and applied naturally and developmentally from infancy through the beginning of formal schooling. The continuity and coherency of learning experiences for infants, toddlers, and preschoolers is important for optimal child development and learning (Institute of Medicine & National Research Council, 2015). It is not only important that young children are exposed to science early, but also that the framework for this science learning is aligned with the K-12 system. Effective alignment must be more than simplifying content for younger children. Instead, as we have demonstrated, it involves engaging young children in using scientific practices to build foundational knowledge of crosscutting concepts and core ideas in the four science disciplines. The promise of this approach is that young learners will transition out of preschool eager to learn, full of curiosity, and equipped with a strong foundation in science practices, crosscutting concepts, and science content. With this foundation, children can ask and answer questions about their world and find joy and understanding in lifelong learning.

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### Learn More

*Infants and Toddlers: Young Scientists Exploring the World Around Them*
D. B. Greenfield (2015)
https://earlyeducatorcentral.acf.hhs.gov/teaching-supports

*Lens on Science and Enfoque En Ciencia: Preschool Science Assessments*
https://youtu.be/2pxs3xjEKMI

*Science in the Preschool Classroom: Why and How This Can Be a Teacher's Best Friend*
D. B. Greenfield
https://eclkc.ohs.acf.hhs.gov/hslc/tta-system/teaching/practice/fp/fpArchive2015.html

*Everyday Fun With Science: Let's Talk About STEM Video*
https://www.zerotothree.org/resources/1573-everyday-fun-with-science-let-s-talk-about-stem-video

The RISE Project: Readiness through Integrative Science and Engineering
http://rise.as.tufts.edu

assessments for both English- and Spanish-speaking young children. He serves as an advisor on multiple national, state, and local panels, advisory boards, and work groups for issues related to research, policy, and practice in early science. He was the invited speaker on early science at the 2016 White House summit on STEM in early childhood.

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