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Extending cognitive development research to create more equitable science learning contexts

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This paper aims to examine how the field of cognitive development has shifted over the last 15 years or so to consider implications of basic research in the field for educational settings, specifically in science education. Focusing on informal learning contexts, we argue that cognitive development researchers have an opportunity to build upon the work of the last fifteen years in a few critical ways. The paper examines theoretical frameworks driving research at the intersection of cognitive development and science education and reviews current research related to early science learning. We then discuss future directions for researchers aimed at creating more equitable science learning contexts for young children, including diversifying samples, forging sustainable community partnerships, and rethinking science and science education. Taken together, this paper has the potential to provide new directions for researchers, practitioners, and policymakers at the intersection of cognitive development and science education.

KEYWORDS

science education, early science learning, cognitive development, interdisciplinary research, equitable science learning

Introduction

This paper aims to examine how the field of cognitive development has shifted over the last 15 years or so to consider implications of basic research in the field for educational settings, specifically in science education. A great deal of research over the past two decades has focused on fostering science learning and engagement in informal learning contexts such as museums and homes (e.g., Callanan et al., 2020; Callanan and Jipson, 2001; Crowley et al., 2001; Fender and Crowley, 2007; Gutwill and Allen, 2010; Haber et al., 2022; Haden et al., 2014; Hassinger-Das, 2024; Kurkul et al., 2021; Leech et al., 2019; Marcus et al., 2023; Tenenbaum and Callanan, 2008; Weisberg et al., 2023; Willard et al., 2019). This work suggests that adults can foster children's early STEM (Science Technology Engineering and Mathematics) learning by providing high-quality causal explanations that are related to increases in children's knowledge of causal mechanisms (Callanan et al., 2020; Crowley et al., 2001; Legare et al., 2017; Mills et al., 2017). Additionally, prior research shows that museum interventions increased caregivers' explanatory talk, question-asking behavior and children's science learning during the early and middle childhood years (Benjamin et al., 2010; Gutwill and Allen, 2010; Haden et al., 2014; Jant et al., 2014; Marcus et al., 2017).

Nevertheless, we argue in this paper that cognitive development researchers have an opportunity to take this work further to extend and build on the work of the last 15 years in two critical ways. We focus on informal learning environments (e.g., home, museum, library, zoo, aquarium, and park), as key spaces where young children spend most of their time and are developing their interest and engagement in science (Hassinger-Das et al., 2018). According to a recent report, women in the US are underrepresented in STEM at the bachelor's, master's, and doctoral levels [National Center for Science and Engineering Statistics (NCSES), 2023]. Additionally, the disparity depends on the STEM field; although women are well represented in agricultural and biological sciences (64% of bachelor's degrees earned in 2020 were award to women), they are underrepresented in physical and earth sciences (43% of bachelor's degrees earned), mathematical and computer sciences (26% of degrees earned), and engineering [24% of degrees earned; National Center for Science and Engineering Statistics (NCSES), 2023]. In addition to gender disparities, there also continue to be disparities by race and ethnicity, with Black students and American Indian or Alaska Native students underrepresented in STEM fields at the bachelor's level [National Center for Science and Engineering Statistics (NCSES), 2023]. We see these disparities in adulthood, but differences in children's early science beliefs, behaviors, and attitudes emerge as early as the preschool years, making early childhood a key time to intervene (Master, 2021). Given these disparities, it will be important to take an intersectional approach, understanding that children have multiple identities that may enhance or diminish their sense of belonging in STEM (e.g., Crenshaw, 1990; Lei and Rhodes, 2021). Taken together, this paper aims to provide key directions for researchers, practitioners, and policymakers at the intersection of cognitive development and science education.

The paper has three primary goals.

1. To present a new framework at the intersection of cognitive development and science education research that integrates current theories of constructivism and social-interactionism with ecological systems theory.
2. To highlight research findings examining science learning in formal and informal learning contexts over the last 15 years that have pushed the field of cognitive development forward.
3. To identify three future directions for researchers aiming to produce research that can be meaningfully incorporated into the lives of families in informal learning environments, along with actionable steps that researchers can take in those directions.

Theoretical frameworks

At the intersection of cognitive development and science education in early childhood, research is often framed using one of three theoretical perspectives: constructivism, social-interactionist theory, and ecological systems theory. These frameworks allow researchers to investigate how children construct knowledge and learn about the world around them and focus on different aspects of early learning. Prior work has integrated constructivist theory with social-interactionist theories related to parent-child interactions (Callanan et al., 2020). We present a new framework integrating current theories of constructivism and social-interactionism with ecological systems theory. To the best of our knowledge, there is little empirical data examining this intersection, making it a ripe area for future cognitive development research in science education. Recognizing and considering the connections between these theories is critical to informing researchers' understanding of children's early STEM learning.

Within the constructivist framework, children are often conceived of as scientists, building knowledge via their direct, hands-on experiences with objects (e.g., Gopnik, 1996). Relatively recent research in cognitive development has demonstrated that young children can problem solve and engage in causal reasoning, key components of scientific thinking (e.g., Gopnik et al., 2004; Sobel and Legare, 2014; Weisberg and Sobel, 2022). Through these early experiments, children gain insight into the physics, biology, and chemistry of the world (e.g., Heyman et al., 2003; Gelman, 1989). Early learning can happen through free play as well as through guided play with an adult scaffolding the learning environment (e.g., Bonawitz et al., 2011). Prior work has examined how adult-child interactions during exploration can help children build their scientific understanding, but can also hinder their science learning (e.g., Bonawitz et al., 2011; Weisberg et al., 2023, 2016; Sobel and Stricker, 2022).

Social-interactionist theory posits that children learn about the world around them via conversations with more knowledgeable social others, including caregivers, teachers, and older siblings (Rogoff et al., 2005; Vygotsky, 1978). These conversations can be especially important in early science learning because many science concepts, such as electricity or natural selection, are not observable (Canfield and Ganea, 2014; Harris and Corriveau, 2011; Harris et al., 2018; Leech et al., 2019). For example, a child may observe that a light switch makes the light turn on and off, but they cannot observe the underlying mechanism, electricity, that is at work (e.g., Leech et al., 2019; Kurkul et al., 2021). However, conversations with parents or teachers about how electricity works can provide children with an understanding of this concept. The example of electricity also provides an opportunity to show how constructivism and social interactionism are not at odds but rather can strengthen and reinforce each other. For example, a conversation about electricity could be followed by an opportunity for a child to get hands on experience playing with a Snap Circuit. Additionally, the two frameworks can be integrated to develop a more nuanced understanding of how children learn. For example, a teacher's lesson on electricity might be followed by giving children the opportunity to explore snap circuits. With snap circuits, children can gain hands-on experience with circuits and see that placing the circuits, batteries, and lights in certain positions can result in a light or fan turning on.

Although prior research in cognitive development has considered the connection between constructivism and social-interactionism, we suggest integrating a third theory, ecological systems theory, which is often utilized in the field of education. There is little empirical work integrating ecological systems theory within cognitive development research, but it is an important and useful framework because it highlights how knowledge is not constructed in a vacuum (Bronfenbrenner, 1994; Rogoff et al., 2005). Additionally, this framework can allow researchers to gain a more nuanced understanding of diverse datasets. Whereas constructivism and social-interactionist theory focus on direct interactions between a child and an object or a child and another person, ecological systems theory emphasizes that the growing child is surrounded by complex and sometimes indirect systems that interact to shape the child's development (Bronfenbrenner, 1994). The ways in which adults talk to children about science in early childhood (examined through the lens of social interactionist theory) as well as the objects with which children interact with in early childhood (investigated via constructivism) may change depending on the children's culture, gender, and race, among other factors (e.g., Bang et al., 2007; Rogoff et al., 2005, 2003). Children's attitudes, beliefs, behaviors, and decision-making with respect to science are shaped by their environments (e.g., Gerde et al., 2021; Bang et al., 2007, 2013). Importantly, ecological systems theory provides context for why we see gender and racial gaps emerge and how these gaps may widen or narrow over time in science majors and careers [Cheryan et al., 2017; National Center for Science and Engineering Statistics (NCSES), 2023]. Returning to the example of electricity, an adult in the United States, influenced by the larger social mores (perhaps even unconsciously), might be more likely to provide detailed explanations of the mechanisms involved in a light turning on to a boy than to a girl. Further, given evidence that the toys children play with are highly gendered and that parents report gendered stereotypes about toy preferences (e.g., Eisen et al., 2021; Gerde et al., 2021; Liben, 2016), they might be more likely to gift a science toy like a Snap Circuit to a boy than to a girl. Thus, at a young age, children's science learning and motivation, particularly the ability for them to develop a sustained interest in science, is influenced by the larger social context. It is worth noting that ecological systems theory can also provide a framework for understanding why some of these gaps have closed over the years. For example, women now earn more than half of degrees award in agricultural and biological sciences, a shift from prior decades (NCSES). This shift may be attributed in part to changing gender stereotypes across time within the United States.

Current research

Over the last 15 years, cognitive development researchers have taken a multi-pronged approach to understanding and boosting children's science learning and motivation. In this paper, we focus on informal learning contexts rather than formal classroom settings. The reason for this is twofold. First, in early childhood, children spend around 80% of their waking hours outside of formal classroom settings, giving informal learning environments a key role to play in early learning (Hassinger-Das et al., 2018). Early science learning occurs not just in the classroom, but also in informal contexts like museums, parks, and homes (e.g., Hassinger-Das et al., 2018; Callanan et al., 2020; Westerberg et al., 2022). Second, in early childhood, families are already engaging in activities that are rich in science content, such as baking, going to the grocery store, reading storybooks, and playing board games together (e.g., Callanan et al., 2013; Haber et al., 2022; Hadani et al., 2021; Swirbul and Melzi, 2024). Researchers recognize that scientific learning is embedded in activities at the playground or in a science museum (e.g., Bustamante et al., 2020). Researchers therefore have an opportunity to work with families to build on existing science learning practices. In this paper, we focus on three contexts in which researchers have conducted a great deal of research on children's science learning and motivation: the home learning environment, museum settings, and community spaces. Across these contexts, children learn not through formal, direct instruction, but through science activities with caregivers (e.g., Hurst et al., 2019).

Parent-child science interactions at home

The home learning environment provides natural opportunities for caregivers and children to engage in early learning and relates to later academic ability (Tamis-LeMonda et al., 2019). In the case of science, opportunities for early science learning abound in the home learning environment. Prior work has found that doing science with children at home predicts children's scientific knowledge in early childhood (Junge et al., 2021; Westerberg et al., 2022). The home science environment (HSE) is thus part of setting the foundation for children's early and long-term academic success in science (e.g., Junge et al., 2021; Varnell et al., 2025). The HSE encompasses adult-guided interactions like talking about science content and engaging in scientific practices and processes at home. Some of these activities include reading science storybooks, watching science television, or talking about science together. Prior work has found differences in the HSE by gender and culture, although findings are mixed (Alexander et al., 2012; Crowley et al., 2001; Gerde et al., 2021; Varnell et al., 2025). Later gender and racial differences that emerge in science interest and decision making may be attributed in part to these early differences in the HSE, although more work needs to be done in this area.

Recent work has begun to recognize that many families are already engaging with their children in ways that support science learning (e.g., Hassinger-Das, 2024; Leech, 2024; Swirbul and Melzi, 2024). Thus, there is now a focus on building upon these existing practices and on engaging with parents as collaborators who have specialized knowledge of their children's interests and knowledge (e.g., Bae et al., 2023). Some work on parent-child interactions in the home science environment have found differences by SES, which is often measured based on parent education level, annual income, or a combination of the two (e.g., Dominke and Steffensky, 2025; Junge et al., 2021). More recent work has measured science capital as a way to examine the value families place on scientific knowledge (e.g., Archer et al., 2015; Leech, 2024). Measuring science capital can capture more nuance and variation in beliefs about the role of science in everyday life than measuring SES as a proxy for these beliefs.

Parent-child interactions in informal learning environments

Museum settings

In museum settings, science activities are often crafted by museum professionals with knowledge and training in child development allowing researchers to examine how children's science is embedded in family conversations and interactions (e.g., Callanan and Jipson, 2001; Callanan et al., 2020; Sobel and Jipson, 2015; Sobel et al., 2021; Sobel, 2023; Thorson et al., 2024; Weisberg et al., 2023). Indeed, findings from the past two decades highlight that brief museum interventions can foster parent-child talk and children's science learning, exploration and engagement during the early childhood years (e.g., Benjamin et al., 2010; Callanan et al., 2017, 2021, 2020; Crowley et al., 2001; Gutwill and Allen, 2010; Haden, 2010; Haden et al., 2014; Jant et al., 2014; Marcus et al., 2023; Medina and Sobel, 2020; Tare et al., 2011; Umansky and Callanan, 2024; Willard et al., 2019). Much of the work on museum-based interventions has focused on two key approaches design to enhance caregiver-child scientific talk and great exploration in museum exhibits: conversational cards (text-based guidance; see Fender and Crowley, 2007; Jant et al., 2014) and modeling from museum experts (Marcus et al., 2017). For the first strategy, researchers have utilized interactive displays and exhibit labels to encourage caregivers to ask scientific questions and provide high-quality scientific explanations when engaging in the exhibit with their children (e.g., Callanan et al., 2020; Fender and Crowley, 2007; Jant et al., 2014; Willard et al., 2019). By providing caregivers with text-based guidance as well as detailed instructions for how to engage in the exhibit with their children, caregivers have asked a greater number of wh-questions (what, where, when, why, how questions, e.g., Benjamin et al., 2010), engaged in more inquiry-based exploration (e.g., Gutwill and Allen, 2010; Gutwill et al., 2015) and produced more causal talk (e.g., Willard et al., 2019). For the second strategy, researchers have provided guidance through the use of museum experts and educators (e.g., Marcus et al., 2017). For example, caregiver-child dyads who received engineering explanations from museum experts were more likely to transfer knowledge to a novel building task (Marcus et al., 2017). Such findings suggest that museum settings are one key informal learning space that can enhance family scientific conversation and interactions during the early childhood years.

Importantly, a great deal of research on children's science learning and motivation in museum settings focuses on WEIRD (Western, Educated, Industrialized, Rich, and Democratic; Henrich et al., 2010; Nielsen et al., 2017) populations, demonstrating little diversity in the study findings. As a result, we are unable to understand if the results are generalizable to a more diverse population. One plausible explanation for why the museum context appears to attract a more middle class, White group of individuals is that the cost and access (or lack thereof) that families have to museums may provide a barrier (e.g., Dawson, 2014). First, the price of museum admission is quite high, which places children from a lower socioeconomic status at a disadvantage. Second, cultural and language differences may be another barrier for some families (i.e., families may not understand exhibits in English if it is not their first language). Third, years of schooling (Siegel et al., 2007) and level of comfort in this novel context may inform whether parents decide to bring children to museums. Taken together, there are many factors that may limit families' access to museums. The focus of this paper is not to criticize research in museum settings, but rather, to highlight that these research findings are based on a small, WEIRD sample.

Community spaces

One of the biggest shifts in cognitive development research over the past 10 to 15 years has been toward partnering with community members and local governments to develop public spaces that encourage parents and children to talk about science together. Much of this work falls under the body of research on Playful Learning Landscapes (PLLs). PLLs encourage play, learning, and, importantly, rich opportunities for adult-child interaction (Bustamante et al., 2019; Hassinger-Das et al., 2018). PLLs targeting science learning have typically involved higher cost and more permanent changes to public infrastructure. For example, for Urban Thinkscape, researchers developed science-related activities that families could do together while waiting for the bus (Hassinger-Das et al., 2020). Another example, Parkopolis, is a playful STEM learning landscape exhibit in a local science museum (Bustamante et al., 2020). When compared to another group, it had mixed benefits compared to an active comparison exhibit (Bustamante et al., 2020). These structures are great examples of the benefits of cognitive development researchers collaborating with community members and local officials. Some PLLs require a large amount of community buy-in and resources (Hassinger-Das, 2024). For researchers interested in working with community members on designing and fabricating PLLs, it may be useful to consider smaller, less expensive, and potentially less permanent interventions as a starting point (e.g., Hanner et al., 2019).

Future directions

We have identified 3 key future directions for cognitive development researchers who want to produce research that can be meaningfully incorporated into the lives of families in informal learning environments, along with actionable steps that researchers can take in those directions. These points are interrelated and not exhaustive. First, there is a critical need to increase the participation of underrepresented groups in science (e.g., children of color, children from lower-SES backgrounds, multilingual children) in research on children's early science learning. Although many researchers are actively working to diversify samples, often this topic is relegated to the "Future Directions and Limitations" sections of manuscripts. Second, researchers should take steps to forge mutually beneficial and sustainable long-term community partnerships. Third, researchers should unpack what *science* and *science education* mean within the context of early childhood.

Diversifying samples

One of the biggest problems facing the United States is the lack of representation of women, people of color, and people from lower socio-economic status (SES) backgrounds in the STEM workforce [National Center for Science and Engineering Statistics (NCSES), 2023]. Broadening and diversifying the STEM workforce has historically been one of the primary missions of the National Science Foundation. This mission is critical to creating a country on the cutting edge of science and that is engaging in sustainable, humane science practices. Disparities in children's science interest begin emerging in early childhood, making early childhood a key time to intervene and demonstrating why the intersection of cognitive development and science education is of particular importance (see Master, 2021 for a review on gender differences; Curran and Kellogg, 2016).

For the last decade, researchers in psychology as a whole and in the developmental subfield have been grappling with the field's focus on WEIRD (Henrich et al., 2010; Nielsen et al., 2017) populations. Historically, most research in psychology has been done with this "WEIRD" slice of humanity, with findings then incorrectly generalized to all people (Henrich et al., 2010). Within cognitive development, there has been a positive shift toward diversifying samples and, if samples are not representative, acknowledging this in the manuscript. Indeed, the journal *Child Development* now requires a statement on the generalizability of the findings. In the realm of science and science education, diversifying samples is important because of the inequity that continues to exist in sciences like computer science, chemistry, physics, and engineering [National Center for Science and Engineering Statistics (NCSES), 2023].

One goal of this research should be to increase the participation of children from underrepresented groups in research on early science learning, including children of color and children from lower-SES backgrounds. In cognitive development research, there is a growing and meaningful body of work examining the development of gender differences in science and math (e.g., Bagès and Martinot, 2011; Bagès et al., 2016; Beyer et al., 2005; Bian et al., 2017, 2018; Cheryan et al., 2015, 2017; Chestnut et al., 2018; Cvencek et al., 2011; Master, 2021; Master et al., 2016, 2021; Rhodes et al., 2019; Shu, 2020; Stoet and Geary, 2018; Tang et al., 2024). A greater push toward including race, ethnicity, SES, and the intersections of these factors would allow a more nuanced and comprehensive understanding of children's early science learning and motivation. There have been a few key intertwined issues here. First, in some work on this topic, people of color are lumped into one category and compared to White participants, despite the fact that Asians are overrepresented in the STEM workforce [National Center for Science and Engineering Statistics (NCSES), 2023]. It would be more useful to group participants into overrepresented in STEM or underrepresented in STEM categories. Even this approach may be somewhat lacking in nuance as racial groups are sometimes treated as monoliths despite large amounts of variation. For example, the group Asian is not a monolith and Asians from Vietnam or the Philippines are underrepresented in STEM whereas Asians from India or China are overrepresented in STEM (Loi, 2024). Researchers should therefore think carefully and with nuance about the racial and ethnic demographics of their samples when interpreting and reporting findings.

When working with children, the issue of racial categorization also emerges when we ask children to draw pictures of scientists, a commonly used task intended to measure children's implicit stereotypes of scientists (Miller et al., 2018). Although a widely used measure and one that is useful when measuring scientist gender, measures of race have been less successful (Miller et al., 2018). For example, some papers have asked children to draw pictures on white sheets of paper, making white the default. A recent critique on this topic notes that although researchers commonly cite that children view scientists as "White men," consistent data on the race of scientists in drawings does not exist (Walls, 2022).

The process of diversifying samples means that researchers are more and more frequently working with families and children from racial and ethnic minorities and from lower-SES backgrounds. Moving away from primarily focusing on White, middle-class families is a good thing from a research perspective because it means that we are building a more accurate picture of the development of science learning and motivation. However, this change also comes with a responsibility to engage respectfully and collaboratively with families who might be different from us or who might bring different perspectives or needs to the process of research. Key to engaging respectfully and collaboratively with families (which we will talk more about in the next section) is that researchers should recognize the existing practices that families are already engaging and should not make assumptions or use White, middle-class families as a baseline or automatic comparison group. One way to pause assumptions is to recognize that there is variation *within groups*, not only between groups (e.g., Loi, 2024). Understanding these within group variations may provide greater insight into how to boost children's science learning and motivation within that group. Thus, future work might focus specifically on samples of participants from an underrepresented group in STEM (rather than including a comparison group of, e.g., White participants), such as focusing on Black or Hispanic families in order to tease out best practices for participants from those groups.

Another area for more work is considering the SES of participants in a sample. One possibility is for researchers to collect measures of science capital in addition to measures of SES. Science capital provides a measure of adults' science knowledge, beliefs about science, and interest and engagement in science (DeWitt et al., 2016). This measure pulls from the cultural funds model in education research (e.g., Yosso, 2005) and in some ways cuts across typical measures of SES like education or income. For example, caregivers may value science and see science learning as important for their child's development even if they are not high-income earners (and by contrast, may see science as unimportant even if they are high-income earners). Some research has recently examined the relation between science capital and parent-child interactions, finding that science capital moderated gender differences in science talk during a parent-child science activity (Leech, 2024).

A related suggestion is to focus more on intersectional identities in research (Crenshaw, 1990; Lei et al., 2020). Researchers should design and interpret studies through an intersectional lens and recognize that children's multiple identities can impact both how they are perceived and how they perceive science. Some cognitive developmentalists have put out this call but there is still little work examining findings intersectionally and specifically in the context of science learning (Lei et al., 2020; Jaxon et al., 2019; Perszyk et al., 2019). In the study of early science learning, there has been a large focus on gender. This focus on gender makes sense because of the large and sustained gender gap in the STEM workforce. Working with pools of participants that are gender balanced may be accessible to researchers with little effort, whereas it may require more forethought, effort, and resources to work with pools of participants that include many different races or socioeconomic statuses (especially depending on geographic location). One way to ensure that participant pools are representative is to build strong and lasting partnerships with local communities. The next section provides suggestions for how to initiate and sustain meaningful community partnerships in the process of conducting cognitive development research and provides more context for why this is particularly important when researching early science learning.

Forging sustainable partnerships

Working with community partners is critical to creating high-quality, research-based science interventions, but forging and sustaining these partnerships can come with challenges that many researchers are not trained for. The focus of this paper is on informal learning environments, but many cognitive development researchers also work closely with and even develop partnerships with schools, principals, directors, and teachers and already have experience with forging and sustaining these partnerships. It is worth turning to work on how these partnerships can be strengthened through a focus on respecting educators as experts in their classrooms who often have years of experience to back up their teaching practices, integrating feedback from educators when conducting research in schools, and ensuring that the relationship is tangibly and mutually beneficial (Shusterman et al., 2019). These guidelines can provide insights into working with educators but also into working with parents, families, and community members who may be invested in increasing learning opportunities for children.

Indeed, recent reviews have highlighted clear pathways for building partnerships informal learning environments and inviting families in the community to participate in this research (see Callanan, 2012; Sobel and Jipson, 2015 for review). There are sometimes pathways for researchers to talk to museum educators and parents about the importance of our research findings to experiences in early childhood. These conversations can occur via formal professional development courses or more informal conversations during data collection. These conversations are also often mutually beneficial, with museum educators and parents providing their insights into our research in addition to learning more about the research they and their children are participating in. In the case of informal conversations, it would be useful to build them into the process, concluding studies with a space like an online form or a 15-min conversation to discuss the research and solicit feedback.

Where many developmental researchers may be lacking in experience is in engaging with community members and families who are not White and middle class. These partnerships are possible through intentional, respectful community building that takes a long view of community relationships rather than aiming for short-term or one-off interactions with community partners (Shusterman et al., 2019). Researchers in cognitive development should continue to work to bring research on science learning out of lab settings and into local communities where the research can then continue to be shaped by parents, caregivers, and other community members on the ground. We suggest two concrete strategies for how to begin. First, researchers might conduct interventions like PLLs. For example, the Playful Learning Landscapes Action Network can provide a starting point and guidance (Playful Learning Landscapes Action Network, 2019) for collaborating with community partners. Researchers may also consider interventions that are smaller scale but still impactful and designed with community collaboration. Community partners can provide input throughout the research process, including research questions, best measures to use, recruitment, data collection, and interpretation. Second, researchers can utilize online data collection platforms such as Zoom to recruit and collect data from more diverse communities, including families from across the country. These strategies are a step toward forging lasting connections with the local and national community that in turn can all children can feel a sense of belonging in science.

Unpacking and rethinking science and science education

What is science? As researchers, sometimes in studying children's science learning, we reinforce a Western construct of science. This science is based on objectivity, on classification and taxonomy, on the idea of science as being for brilliant people, and on the idea that there is a single right or wrong answer to a question (Bang et al., 2018; Kimmerer, 2013). Often, Western science is thought of as something that happens in a lab, that involves direct experimentation, and that requires question asking to succeed (e.g., Kimmerer, 2013; Kurkul, 2015; Rogoff et al., 2003). However, a growing body of research, especially by indigenous scholars, suggests science as relational and subjective, as something that anyone can do and that can benefit communities, and as a process rather than an identity (Bang et al., 2007, 2013, 2018; Bang, 2020; Hassinger-Das et al., 2018; Kimmerer, 2013; Bustamante et al., 2020; Marin and Bang, 2018; Swirbul and Melzi, 2024). In one study, Bang et al. (2013) illustrates how students, especially those from underrepresented groups in STEM, can become disenfranchised in formal science education settings. In the study, a middle grades class is classifying natural phenomena as either living or nonliving. A Black male student, Jonathan, suggests that the Sun could be classified as living since without it, no other living organisms could survive. A White female peer disagrees, arguing that the Sun does not meet the criteria for life that the class had learned earlier. This moment created an opportunity in the classroom for critical discussion and learning about what it means to be living or non-living. The authors note that Jonathan's argument "suggest[ed] a different, more dynamic way of seeing the sun and its connection to life on Earth [...] moving toward a view of the system as living," a way of thinking that was "arguably [...] closer to contemporary scientific thinking" (Bang et al., 2013, p. 305). By thinking outside of the living and nonliving binary of categorization, Jonathan was arguing from a non-normative perspective which, after class discussion, was set aside in favor of a more normative, binary view. This example emphasizes the often rigid boundaries of Western science in school contexts and the emphasis placed on ultimately conforming to a certain way of thinking. Although understanding foundational science concepts is important to science learning, equally as important is learning how to think like a scientist; in other words, learning how to think critically, to problem solve, to work as a team, and to learn how to think through and utilize data and evidence. Often in cognitive development, we focus on science as something that happens in a lab, that involves direct experimentation, and that requires question-asking to succeed. This view of science is reflected in how we conduct research (e.g., in lab settings) as well as in how we design studies examining children's science knowledge and understanding. We suggest that researchers can learn a lot from expanding their view of what science is, especially through engaging with work from indigenous researchers and communities during every stage of the research process.

The above anecdote occurred in the middle grades, when most students are fully embedded in formal schooling. By this stage in the US, families may be less involved in science education and educators may be beholden to high stakes testing standards that lead them to prioritize correct answers rather than engaging in critical discussion with students. In the context of science learning in early childhood, shifting our way of thinking to create an expansive and inclusive definition of science is not only important but also intuitive. Early childhood educators and parents engage children in science learning often. For example, families taking a nature walk in the fall might have conversations about how the leaves are changing color. These informal discussions are ripe for scientific talk that can be fun for children and parents alike. They may lead families down paths such as discussing the seasons, the impact of the Sun on plant life, the Earth's rotation, the distinction between evergreens and other trees, the importance of native plants, and more. This type of informal engagement goes beyond learning to find the "right" answer and pushes students to problem solve and learn how to think through and utilize data and evidence. It also demonstrates science as something accessible and enjoyable for families.

The example of leaves changing color also shows how science and the ways that we can learn and know about the world are culturally dependent. For example, a child living near the equator might not experience seasons in the same way as a child living further north or south. In those places, the leaves may never change color. A nature walk in that context would involve different plant life and different ways of discussing the natural systems at play. In a desert environment, families might also discuss topics of import to the community such as drought and irrigation.

Best practices in science education

In the United States, the Framework for K-12 Science Education Practices, provides eight key practices to science learning, emphasizing learning strategies such as asking questions and defining problems, developing and using models, and constructing arguments (National Research Council et al., 2012). The development of these strategies has been well studied in cognitive development research. This is a good thing as it is important to understand how children are learning science. However, it is also important to consider how these types of best practices are developed within the specific cultural context of the United States. For example, some indigenous cultures prioritize learning via observation rather than question asking (Rogoff et al., 2003). Thus, researchers might begin to expand our idea of best practices in science education.

To date, the practices for the framework for science education and cognitive development research on children's early science learning primarily focus on asking questions, constructing explanations. Although it is important to convey scientific information about concepts and processes to young children, it is also important to engage young children in the process of science. Arguably, some key strategies for success in STEM, especially in early childhood, are not touched on in the Framework for K-12 Science Education Practices. These strategies primarily involve social-emotional skills that highlight the process of science and are critical to science success, such as persisting in the face of a challenge or being curious about failure rather than frustrated. Examining the social-emotional components of science learning is also an important and understudied area for future research. Additionally, policymakers may want to consider updating the framework to include these social-emotional skills as part of the process of science learning.

In early childhood, we argue everything that a child experiences is a cross-domain learning opportunity. For example, a child reading about a scientist whose experiment failed is learning (a) literacy and vocabulary building (b) the scientific method and (c) how to respond to failure (social-emotional skills related to persistence, motivations, beliefs about the relation between intelligence, hard work and effort). For example, recent findings indicate that when preschoolers (aged 4–5) hear a story about a famous scientist who faced challenges along the pathway to success (rather than achieving success without any emotion of failure), children persisted longer on a scientific task (Haber et al., 2022, 2024), were more like to endorse more of a growth rather than a fixed mindset (Haber et al., 2024) and viewed hard work and effort (rather than innate intelligence) as the key to success in STEM (Haber et al., 2024). Arguably, hearing about famous scientists who struggled along the pathway to success creates an opportunity to encourage preschoolers to make connections between their own experiences and the scientist in a story or exhibit. It also teaches children that learning from our mistakes and viewing setbacks as an opportunity to grow are critical constructs of the learning process, especially in the science domain. In turn, when children experience challenges in their own science learning, they continue to persist (Haber et al., 2022, 2024).

By focusing on the *process* of science learning (e.g., critical thinking skills that integrate science, literacy and social-emotional learning) rather than the outcome ("getting the right answers"), we can integrate scientific content with foundational social-emotional learning areas including *growth mindset* (believing that intelligence can change or grow over time, Dweck, 2006), *self-efficacy* (beliefs about your ability to succeed, Bandura, 1994; CASEL, 2023) and *self-management* (preserving through challenges). Such experiences can also impact children's interest and motivation to persist during science activities and emphasize inclusivity in STEM, encouraging greater participation of children from unrepresented groups in science activities Future work should focus on the social-emotional learning component of early science learning and consider how science learning is not only knowledge acquisition but is also integrated with other domains of learning. Importantly, is critical for cognitive developmentalists to consider the personal narratives that are used in study designs. For example, if we focus only on the narratives of White male scientists, this sends a strong messages to young children about who belongs in the science field, reinforcing gender and racial stereotypes in STEM (Gladstone and Cimpian, 2021). In contrast, focusing on the personal narratives of individuals in STEM who reflect groups that are underrepresented in STEM fields broadens the image of who can be a successful scientist. These experiences during early childhood can impact children's early motivation, persistence and interest in science learning and their later decision to pursue a career in STEM.

Conclusion

Taken together, the aim of this paper is to provide cognitive developmentalists with potential future directions for the field. We recognize that over the past 15 years, many researchers in the field have been conducting high caliber research on children's early science learning. This paper provides food for thought and a push toward future directions for research centering diversifying samples, forging sustainable partnerships in the community, and rethinking what science is and can be, especially in early childhood.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SK: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing. AH: Conceptualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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