Volume 32, Number 3 | 2019

Social Policy Report

Leveraging Research on Informal Learning to Inform Policy on Promoting Early STEM

Michelle A. Hurst, University of Chicago
Naomi Polinsky, Northwestern University
Catherine A. Haden, Loyola University Chicago
Susan C. Levine, University of Chicago
David H. Uttal, Northwestern University

ABSTRACT

In recent decades, educators and policymakers in the United States have increased their focus on Science, Technology, Engineering, and Mathematics (STEM) learning opportunities both in school and in informal learning environments outside of school. Informal STEM learning can take place in varied settings and involves a variety of STEM domains (e.g., engaging in engineering practices in a construction exhibit at a museum; talking about math during book reading at home). Here we provide a selective review of the literature on informal STEM learning to illustrate how these educational experiences are crucial for efforts to increase early STEM learning even before children reach school age. Leveraging cognitive and learning science research to inform policy, we make three recommendations to advance the impact of informal STEM learning: 1) integrate cognitive and learning science–based learning practices into informal learning contexts, 2) increase accessibility and diversity of informal STEM experiences, and 3) create explicit connections and coherence between formal and informal STEM learning opportunities in early childhood education.

Corresponding author:
Michelle A. Hurst (hurstm@uchicago.edu; hurst.mich@gmail.com)

Social Policy Report

Volume 32, Number 3 | 2019
ISSN 1075-7031

Social Policy Report
is published three times a year
by the Society for Research in
Child Development.

FROM THE EDITOR

This *Social Policy Report* is situated in a particular contemporary context: as the authors make clear, since 2010 there has been federal-level interest in encouraging children's enthusiasm for science, technology, engineering, and math (STEM) to help ensure that our nation has an adequate supply of STEM workers in the future (an area where we have been lagging behind). Additionally, there are some real concerns about public education today; across the United States, this past year has seen teacher strikes, reduction of school to four days a week in some areas, and evidence of a halt in progress on student performance on national standardized achievement tests. Given the great stress that is already placed on teachers in formal school settings, the central idea of this SPR is that we look at how *informal* educational settings—such as museums, clubs and organizations, and simply the home environment—can enhance, augment, and provide a more comprehensive approach to encouraging STEM interest in young children. Furthermore, these informal settings provide opportunities to engage parents and caregivers in encouraging their children's interest in STEM.

Within this *SPR*, the authors, a team of cognitive and developmental scientists across three universities in the Chicago area, provide concrete evidence for the importance of informal settings as a way to promote STEM interest, engagement, and learning among preschool and early grade school children. As the authors note, informal settings are "nondidactic" and allow for more informal guidance by adults to engage children in activities that "build upon the child's own interests and initiatives." The authors also provide substantial evidence that early STEM experiences are important for later achievement. Exposing children to STEM early in life can not only encourage the child's interest in STEM, but also support the development of higher order thinking skills.

Given the importance of early informal STEM learning, three policy recommendations are offered here. First, that cognitive science based learning principles be incorporated in informal learning settings (and especially in museums). The authors argue persuasively that increasing children's STEM language and ability to articulate STEM activities is important for advancing higher order cognitive skill development and in turn will increase children's interest in STEM activities. Second, when museum workers or exhibits provide a wider diversity in workers and a wider range of cultural activities, more children will be engaged. Therefore, more diversity and greater accessibility should be incorporated into informal STEM settings, especially in underserved communities. Third, that connections between informal and formal (i.e., school) settings should be made more transparent, such as when schools develop family school partnerships to incorporate parents and caregivers into school-based STEM programs. This recommendation aligns well with the common theme in education today of finding home-to-school and school-to-home pathways and programs to traverse these environments. A logical and important next step is to incorporate other cultural institutions into these pathways as well.

This *SPR* notes as well that there is still much research needed in order to realize the potential for advancing children's interest in STEM. For instance, more research is needed on young children since the extant literature primarily has examined older children's STEM activities and learning. How should these activities be encouraged among younger children *before* they enter formal schooling? Second, more work is needed to develop best practices for creating strong connections among cultural institutions, schools, and families. This is especially the case for children living in non-urban and rural environments. Third, this SPR makes clear that social policy is set at many levels, not just within federal- or state-level institutions. It is important that we continue to find new ways of encouraging education outside of schools and outside of traditional policy quarters if we are to truly be effective at increasing our STEM capacity.

Leveraging Research on Informal Learning to Inform Policy on Promoting Early STEM

There is a critical need in the United States to increase the quantity, quality, and diversity of future professionals in the fields of Science, Technology, Engineering, and Mathematics (STEM). Although the percentage of US students pursuing STEM degrees in college is on the rise, it remains low in many STEM disciplines (National Science Board, 2018). Moreover, disparities in STEM achievement begin even before children enter the primary school classroom (Morgan, Farkas, Hillemeier, & Maczuga, 2016), making advancing STEM educational opportunities a national priority (e.g., "Educate to Innovate"; Obama Administration, 2010). There is also considerable consensus, however, that important efforts to enhance STEM education in schools are only part of the solution to the STEM problem. Indeed, meaningful informal STEM learning opportunities can add substantially to the experiences that children have in schools (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Stevens, Bransford, & Stevens, 2005) and are a critical objective of early childhood education even before the start of formal schooling. Informal STEM education is increasingly being targeted as part of a comprehensive effort to increase STEM engagement, stimulate and build interest, and support learning (Bell, Lewenstein, Shouse, & Feder, 2009).

In the current report, we characterize the powerful learning opportunities that informal STEM experiences can provide to young children and make policy recommendations that harness the potential of early informal STEM learning opportunities to bolster science education. Our recommendations are based on cognitive science research, leverage this research for use in a variety of informal settings, and aim to support STEM educational policy.

Early STEM in Informal Educational Settings

Informal learning opportunities occur in a broad array of settings, including at museums and other cultural institutions, within clubs that focus on STEM, and at home during everyday activities, such as gardening or playing with blocks and puzzles (Bell et al., 2009). Despite the variation in opportunities for STEM learning across informal learning contexts, informal STEM education is characterized as social, playful, and engaging in ways that foster children's natural tendency to ask questions, explore, and experiment (Bell et al., 2009). This type of active STEM engagement can supply substantial high-quality learning opportunities for young children (Fisher, Hirsh-Pasek, Golinkoff, Singer, & Berk, 2010; Hassinger-Das, Bustamante, Hirsh-Pasek, & Golinkoff, 2018; Hirsh-Pasek et al., 2015; Ramani & Eason, 2015; Schulz & Bonawitz, 2007; Weisberg, Hirsh-Pasek, & Golinkoff, 2013). Although designed environments, such as museum exhibits, may be particularly well suited for both fostering and studying these informal learning opportunities, the recommendations and principles of informal

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STEM learning discussed in this report can be used in a variety of settings, including in the home, where children spend much of their time (Meltzoff et al., 2009). Thus, we draw on a range of examples of informal STEM learning from libraries, museums, and observations of parent–child interactions more generally.

Regardless of the particular informal learning context one important feature of informal learning is that it is nondidactic (Rogoff, Callanan, Gutiérrez, & Erickson, 2016). That is, the learner freely chooses how and what they engage with and the adults do not fully control the flow of the activity or constrain the environment with their own prescribed learning goals (Toub, Rajan, Golinkoff, & Hirsh-Pasek, 2016). The nondidactic nature of informal environments is beneficial for children's learning in a variety of ways. First, it allows children to choose the content with which they want to engage, allowing them to fulfill their own learning needs, motivated by their curiosity. This is the essence of free choice learning, which contributes to a majority of the public's science knowledge (Falk, Storksdieck, & Dierking, 2007). Furthermore, the free choice aspect of informal contexts facilitates a variety of entry points to learning for children with diverse backgrounds, interests, and levels of expertise (Falk & Dierking, 2010). Finally, free choice within informal contexts can contribute substantially to children's meaningful exploration and engagement with objects. Although children sometimes benefit from engaging in free exploration independently (e.g., Bonawitz et al., 2011), adults can provide guidance and facilitation that expands upon a particular experience without limiting or constraining it. By providing this guidance, adults can help structure the environment, so that children are actively engaged in the learning process (Weisberg et al., 2013). Importantly, however, this active guidance is distinct from the explicit instruction often used in formal STEM learning and is especially good at facilitating opportunities for children's exploration and discovery without the constraints of formal instruction.

A second cornerstone of informal learning is that the experiences build upon the child's own interests and initiatives (Haden, 2010; Hirsh-Pasek et al., 2015; Rogoff et al., 2016; Toub et al., 2016). When the relations between STEM content and children's experiences and interests are made explicit, children more readily understand and make sense of new content, remember information, and engage in sustained learning (Ornstein, Haden, & Hedrick, 2004; Valle & Callanan, 2006). For instance, Valle and Callanan (2006) found that children in early elementary school learn most from science activities when parents relate the content of this homework to more familiar and relevant subject matter—subject matter that engages children's interests.

Lastly, children may benefit most when informal learning is social and involves other peers or adults. Social interactions often require that children explain their thinking, ideas, and problem-solving process. Providing these explanations can help children to deepen their own understanding of the problem, which can enhance their learning (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chiu & Chi, 2014; Hirsh-Pasek et al., 2015; Rau, Aleven, & Rummel, 2015). Furthermore, social interactions within informal environments help highlight what children can learn, as well as when and how they can learn it (Meltzoff et al., 2009). In turn, social interactions can facilitate children's focus on potentially valuable information or experiences that may otherwise go unnoticed in environments that are less structured then the typical classroom (Haden, 2010).

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These qualities of informal learning—free choice, being individually meaningful, and occurring within a social context—contribute to making informal learning especially unique and valuable. Early informal learning experiences have the potential to enhance children's readiness to engage in science learning in school and encourage lifelong STEM pursuits. In the following sections, we review evidence that supports the importance of early STEM for promoting children's STEM learning and development in three ways: 1) predicting academic learning, 2) fostering positive attitudes and interest surrounding STEM, and 3) developing higher order and critical thinking skills.

Informal Experiences Support STEM Achievement

Early STEM experiences are associated with higher achievement in math, spatial reasoning, and engineering (Casey et al., 2008; Grissmer et al., 2013; Gunderson & Levine, 2011; Jirout & Newcombe, 2015; Levine, Ratliff, Huttenlocher, & Cannon, 2012; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010; Pruden, Levine, & Huttenlocher, 2011; Ramani & Siegler, 2014; Tõugu, Marcus, Haden, & Uttal, 2017; Verdine et al., 2014). For example, experimental evidence shows that playing linear number board games can improve number knowledge (Siegler & Ramani, 2009) and when parents and children engage with an instructional and playful mathematics app at home, even just once a week, children's math achievement improves (Berkowitz et al., 2015). Similarly, early experiences with block building and puzzle play can improve children's spatial abilities (Casey et al., 2008; Grissmer et al., 2013; Levine et al., 2012; Verdine et al., 2014). Early experiences may be particularly powerful for providing children with the skills that are needed for *continued and sustained* STEM learning. Tõugu et al. (2017) found that children who engaged in more spatial play at home benefited more from instruction on how to solve engineering problems in a museum, suggesting that these home experiences may allow children to make better use of informal learning opportunities in educational settings. Taken together, this research suggests that informal experiences engaging with STEM at an early age may provide children with critical skills for subsequent learning and support later STEM achievement.

Informal Experiences Promote Positive Attitudes and Interest

A second critical benefit of informal STEM experiences is the potential for supporting positive attitudes and interests about STEM and combating negative stereotypes, which may be particularly important for fostering inclusivity and diversifying representation in STEM fields (e.g., Cheryan, Ziegler, Montoya, & Jiang, 2017). Children's participation in out-of-school activities is related to interest in STEM throughout K-12 education, highlighting the role of informal learning (Young et al., 2016). Additionally, scientists often report that their interest in STEM-related fields became evident before they entered middle school (Maltese & Tai, 2010) and many anecdotes cite the importance of early experiences in particular. For example, scholarly essays about the life of Frank Lloyd Wright, an early 19th-century American architect, highlight the role of playing with building blocks in his early childhood (McCarter, 2005). Thus, early and informal experiences may play a unique role in contributing to long-term STEM interests.

In addition to STEM interest, fostering positive attitudes toward STEM fields is particularly critical given that even early elementary school–age students (e.g., first graders) can experience math anxiety (Maloney & Beilock, 2012; Ramirez, Gunderson, Levine, & Beilock, 2013) and hold stereotypes about STEM fields (e.g., that computer science is for boys), which can impact self-efficacy and motivation (Cvencek, Meltzoff, & Greenwald, 2011; Master, Cheryan, Moscatelli, & Meltzoff, 2017). Furthermore, negative attitudes and self-efficacy are often reported as a major contributing factor to not continuing with formal STEM education (e.g., Cheryan et al., 2017; Hurst & Cordes, 2017; Hyde, Fennema, Ryan, Frost, & Hopp, 1990; Master et al., 2017). Providing children with experiences that encourage positive engagement in informal STEM learning can be particularly useful for promoting positive attitudes and sustained interest. For example, Master and colleagues found that when 6-year-old girls were provided a robotic learning experience outside of school they no longer showed differences in STEM interests or self-efficacy compared to their male peers (Master et al., 2017).

Informal Experiences Support Higher Order Thinking

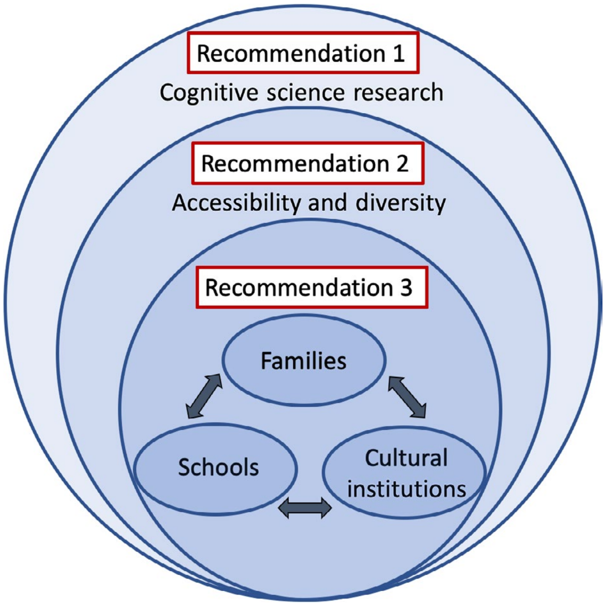
With the growth of technology and the ease of information access, curricula in formal STEM education are beginning to focus on bolstering students' skills that cross-cut all of the STEM domains (NGSS Lead States, 2013). Cognitive scientists refer to these skills as *higher order thinking,* which consists of the abilities to flexibly reason about new information, to integrate new and old knowledge, and to create new insights through inferencing, comparison, and analogical reasoning (e.g., Lewis & Smith, 1993; Richland & Simms, 2015). Higher order thinking is crucial for success within STEM fields (Goldwater & Schalk, 2016; Jee et al., 2013; Richland & Begolli, 2016; Richland & Simms, 2015) and, correspondingly, has been emphasized in many recent guidelines and standards aimed at improving STEM education. For example, the Common Core's *Standards for Mathematical Practice*, prioritize skills for sensemaking, abstract reasoning, searching for and using common structures across problems and domains, and understanding *why,* not just *how* (National Governors Association Center for Best Practices, 2010). Similarly, the National Research Council (2012) describes the cross-cutting concepts for K-12 science education as relying heavily on relational reasoning; for example, observing patterns across events to facilitate relational questions and understanding the scientific method through cause-and-effect relational systems.

The open-ended and exploratory nature of informal learning can provide children with valuable practice in higher order thinking (Haden, 2010; Sobel & Jipson, 2015) and practice applying that thinking to novel situations (Hirsh-Pasek et al., 2015; Jant, Haden, Uttal, & Babcock, 2014; Song et al., 2017). For example, when preschool-aged children are confronted with unclear causes for a given effect, they implement scientific reasoning, including experimenting with the materials to isolate and test different aspects of the toys (Chen & Klahr, 1999; Cook et al., 2011). This process is related to the scientific method, involves flexible reasoning (one aspect of higher order thinking), and can also be activated within formal STEM classrooms. Similarly, in makerspaces or tinkering labs, children are challenged to solve problems by using tools and materials (e.g. scissors, hammers, wood) to build and create problem solutions, thereby gaining knowledge about the core principles of science and engineering (Bevan, Petrich, & Wilkinson, 2014; Lachapelle & Cunningham, 2007). Thus, informal learning contexts are particularly relevant for STEM development in young children and can provide children with rich opportunities for STEM engagement (Bell et al., 2009; Fisher, Hirsh-Pasek, Newcombe, & Golinkoff, 2013; Marcus, Haden, & Uttal, 2017).

Maximizing the Potential of Informal STEM Learning

As the prior review suggests, informal STEM learning experiences can play an important role in advancing skills and interests that, ultimately, may lead to future STEM educational and career pursuits. Informal learning opportunities can expose children to STEM content, promote positive STEM attitudes and interest, and encourage higher order thinking skills. However, the benefits of informal learning are often not fully realized due to a variety of factors and conditions. Given this state of affairs, we leverage research in cognitive science to make three policy recommendations to advance the impact of informal STEM learning: 1) incorporate cognitive science–based learning practices into informal learning contexts, 2) increase accessibility and diversity of informal STEM experiences, and 3) create explicit connections and coherence between formal and informal STEM learning opportunities. Figure 1 displays how these three recommendations fit together to mutually support early STEM learning. For each of our three recommendations, we outline the **obstacle** that the recommendation aims to address, the **evidence** that supports the recommendation, and a brief summary of how the recommendation

Figure 1. **Illustrating the overlapping impact of the three recommendations for supporting informal STEM learning, particularly through bidirectional connections between Schools, Cultural Institutions, and Families.**



can be **implemented** through policy and funding decisions, including for future research.

Recommendation 1: Incorporate Cognitive Science–Based Learning Practices

Obstacle to Informal Learning

Although the benefits of informal learning are well documented, the difficulty of abstracting the underlying STEM principles can make it difficult for high-quality and generalizable STEM learning to occur in informal ways without some support. In order for children to benefit from this informal learning within the classroom as well as in informal and oftentimes novel contexts, they must be able to transfer and generalize learned concepts from one setting to another (Bransford & Schwartz, 1999; Day & Goldstone, 2012). Research findings show that transfer requires the abstraction of critical relational structures, which involves attending to information beyond superficial features (Gentner, Loewenstein, Thompson, & Forbus, 2009; Hummel & Holyoak, 1997). For example, to use what they learned about the functions of gears in a museum, a child at the exhibit must not only attend to the colors of the various gears but must also attend toward the less obvious exhibit lessons about force, shape, and movement that can then be applied in the science classroom. That is, transfer of underlying STEM concepts from this exhibit can only occur when the child attends toward the deeper scientific relations. Unfortunately, overcoming perceptual features, such as color, to consider and abstract underlying structure is quite difficult (Gentner et al., 2009; Goldstone & Sakamoto, 2003).

Although abstraction is always challenging, it can be particularly difficult in perceptually rich environments, such as museum exhibits. Perceptually rich environments capture children's attention, promote engagement, and provide concrete and meaningful contexts to ground abstract information (Fyfe, McNeil, Son, & Goldstone, 2014; Petersen & McNeil, 2013). However, these rich environments can also make it difficult for children to attend to and abstract the underlying principles that are provided in a lesson or experience (Fisher, Godwin, & Seltman, 2014; Fyfe et al., 2014; Kaminski, Sloutsky, & Heckler, 2009; McNeil, Uttal, Jarvin, & Sternberg, 2009). Nevertheless, perceptual richness does not make abstraction impossible. Cognitive science research provides substantial evidence of general learning practices that can be used to promote abstraction and STEM learning across many diverse settings: rich language, structural alignment, and gesture.

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Evidence-Based Solution

The use of rich language, structural alignment between examples or ideas, and gesture by teachers, parents, and caregivers can support early STEM learning, promote abstraction and transfer, and enable children to connect the knowledge gained within informal settings and more formal contexts. Below, we highlight evidence gathered in the lab and in informal learning environments indicating that each of these tools is useful for STEM learning and can be successfully implemented in informal learning contexts.

Language. Substantial research suggests that having specific vocabulary can help people solve problems in math (Hornburg, Schmitt, & Purpura, 2018; Purpura, Napoli, Wehrspann, & Gold, 2017; Purpura & Reid, 2016), patterning (Fyfe, McNeil, & Rittle-Johnson, 2015), and spatial reasoning (Casasola, Bhagwat, & Burke, 2009; Loewenstein & Gentner, 2005). Knowledge of specific words can also help children understand more general relations, such as same and different (Christie & Gentner, 2014) and combine features of objects (Loewenstein & Gentner, 2005). For example, in one experiment, an experimenter hides an object and children are asked to find the object in another, analogous, location (Loewenstein & Gentner, 2005). Children who watched the objects be hidden while hearing the locations of objects described using spatial language (e.g., "I'm putting it on the shelf," "I'm putting it at the top") were better able to find the object in the new, but analogous, representation than children who heard generic language (e.g., "I'm putting it here"), despite both seeing the same hiding scenario and being asked to map between the same visual representations. The specific kinds of vocabulary may also matter; children performed better when the highly interrelated terms top, middle, and bottom were used relative to on, in, and under (Loewenstein & Gentner, 2005). Overall, these studies suggest that understanding and using the particular vocabulary for STEM-relevant problems can help children think about higher order relations (e.g., the relations of same and different or relations like "on") and abstract information across representations.

In addition to specific vocabulary, language and linguistic interactions during everyday activities relate positively to children's STEM-related talk and learning (e.g., Gunderson & Levine, 2011; Pruden et al., 2011), as well as to children's engagement in STEM (e.g., Benjamin, Haden, & Wilkerson, 2010; Braham, Libertus, & McCrink, 2018; Crowley et al., 2001; Hanner, Braham, Elliott, & Libertus, 2019; Levine et al., 2010; Marcus et al., 2017). In particular, the quantity and quality of parents' numerical and spatial talk predict children's numerical and spatial language use, as well as their mathematical and spatial thinking (e.g., Gunderson & Levine, 2011; Levine et al., 2010; Pruden et al., 2011). Furthermore, this relation is mediated by children's own language use (Pruden et al., 2011) and encouraging children to engage in inquiry through conversations with adults can increase children's ability to engage in high-quality explanations themselves (Peterson & French, 2008), further emphasizing the role of language and social learning.

Once children start explaining their thinking, gaps in their knowledge are revealed, creating an opportunity for adults to respond to these explanations, promoting continued conversation (Sabbagh & Callanan, 1998;Thompson, 2006). Children's explanations and subsequent questions can in turn be critical for initiating scientific discovery and revising their intuitive theories of how the world works (Callanan & Jipson, 2001; Haden, 2010). In engaging in these conversations, adults and children co-construct scientific knowledge (Hirsh-Pasek, Golinkoff, Berk, & Singer, 2009; Rogoff, 1990). Moreover, parents or other adult conversation-partners can scaffold children's STEM thinking by providing comparisons and analogies (Valle & Callanan, 2006), using open-ended prompts or questions (e.g., wh-questions; Benjamin et al., 2010; Crowley et al., 2001; Eason, Nelson, Dearing, & Levine, 2019), and connecting novel situations with children's prior experiences and interests (Crowley & Jacobs, 2002), all of which have been shown to help children encode information, generate scientific evidence, and learn target concepts.

Experimental work not only suggests causal linkages between parent–child conversations and outcomes for children's learning but also demonstrates that conversational strategies can be trained with positive results (Benjamin et al., 2010; Boland, Haden, & Ornstein, 2003; Gutwill, 2006; Haden et al., 2014; Jant et al., 2014). For example, simple prompts provided to parents to ask open-ended questions (e.g., Who, What, Where, and How) when engaging with their children in museum exhibits can support children's learning and retention, as well as transfer of learning across contexts and over time (Benjamin et al., 2010; Eberbach & Crowley, 2017; Jant et al., 2014). Likewise in another museum-based study, compared to parents who did not receive instruction, those who did receive conversation starters and tips reported higher learning for themselves and their children (Herts et al., 2018).

Structural alignment. Typically, structural alignment involves mentally or physically aligning two or more representations, including situations, events, objects, concepts, or procedures, to afford the discovery of similarities and differences between the representations. When representations are aligned, learners are able to extract similarities that enable them to go beyond surface features and focus on underlying structures that are essential to STEM learning (Gentner, 2010; Gentner et al., 2016). In discovering these similarities and differences, the common structure underlying these representations becomes more salient (Catrambone & Holyoak, 1989; Christie & Gentner, 2010; Gentner & Gunn, 2001; Gentner, Loewenstein, & Thompson, 2003; Gentner & Markman, 1994; Markman & Gentner, 1993; Sagi, Gentner, & Lovett, 2012). This salience facilitates learning and transfer by allowing for easier abstraction of the underlying structure (Doumas & Hummel, 2013; Gentner & Hoyos, 2017; Gentner et al., 2016; Goldwater & Schalk, 2016; Kotovsky & Gentner, 1996).

Structural alignment and comparison through verbal analogies, diagrams, and mental imagery are often used in formal STEM classrooms (Richland, Holyoak, & Stigler, 2004; Richland, Zur, & Holyoak, 2007) and can support learning of formal STEM concepts ranging from decimal values to causal systems (e.g., Goldwater & Gentner, 2015; Mason, 2004; Thompson & Opfer, 2010). Recent evidence also indicates that structural alignment and comparison can support children's reasoning and learning in informal educational contexts. Inviting children to compare example structures and explore models can support learning of engineering information (Benjamin et al., 2010; Gentner et al., 2016; Haden et al., 2014), and support transferable learning (Marcus et al., 2017).

Museum designers often work to include opportunities for structural alignment at their exhibits, which is referred to as indexing and involves connecting and relating parts of exhibits and prior knowledge to aspects of the environment (Hornecker, 2010). For example, at an exhibit in a natural history museum, there may be ways to interact with the videos of dinosaurs we often see on television right next to a bone replica of a dinosaur (Hornecker, 2010). Having a video representation and the dinosaur fossils side by side can help parents engage in conversations with their children that facilitate connections between these representations. Similarly, as a means for connecting historical or complex concepts to visitors' current knowledge, designers often use more familiar symbols within their exhibits. For instance, designers may choose to use a Coca-Cola can to represent global trade within an exhibit on historical trade routes (Muntean et al., 2017). The familiarity of symbols facilitates visitors' comparisons and associations with prior knowledge, providing parents and children with a jumping off point for abstraction.

Gesture. Gesture also plays a powerful role in communicating ideas, gaining insight, and revealing knowledge (Goldin-Meadow, 2015; Kita, Alibali, & Chu, 2017; Newcombe, 2017; Novack & Goldin-Meadow, 2017). Even children as young as 2 or 3 years of age understand that gesture provides crucial information and they can learn novel information from watching gestures (Novack, Goldin-Meadow, & Woodward, 2015), making it a particularly promising way to encourage and support early learning.

Gesturing while providing verbal instructional information does lead to better learning than just providing information in speech across a variety of domains, including math equation solving (e.g., Cook, Duffy, & Fenn, 2013), symmetry (Valenzeno, Alibali, & Klatzky, 2003), and conservation of liquid (Ping & Goldin-Meadow, 2008). Similarly, linking gestures in particular (e.g., pointing back and forth between two objects) can encourage children to better connect two referents to each other, facilitating their understanding of how things like maps represent other spaces (Yuan, Uttal, & Gentner, 2017). Additionally, encouraging children themselves to gesture can reveal earlier understanding not available in speech (e.g., Roth, 2000), help children both construct and communicate scientific insights (Crowder, 1996; Crowder & Denis Newman, 1993), make sense of the challenges with which they are confronted (e.g., Kirsh, 2010; Roth, 2002), and make them more likely to benefit from later instruction (e.g., Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Pine, Lufkin, & Messer, 2004). In one study on children's spatial sensemaking and problem solving within the informal engineering context of a makerspace, children's gestures were found to facilitate communication between children, adults, and peers, and helped children identify mistakes in their thinking and opportunities for iterations in their engineering designs (Ramey & Uttal, 2017).

Combining these learning practices. These three evidence-based learning practices may be combined to yield maximum benefits. Gesture and speech are highly linked (e.g., Church, Kelly, & Holcombe, 2014; Kelly, Healey, Özyürek, & Holler, 2015) and instruction that involves both speech and gesture is often more successful than when either is used alone (Congdon et al., 2017; Young, Cartmill, Levine, & Goldin-Meadow, 2014). Moreover, both language and gesture can facilitate structural mapping (Gentner, Anggoro, & Klibanoff, 2011). Thus, these tools are not independent and when combined in meaningful ways may have even more dramatic benefits for learning.

Implementing Recommendation 1

Overall, these observations and experiments in lab-based settings, informal learning environments, and formal classrooms provide evidence for the potentially powerful role of language, structural alignment, and gesture in children's STEM learning. Below, we make a few concrete suggestions for facilitating the implementation of the tools and practices that have emerged from cognitive science research.

1. **Incorporate language, structural alignment, and gesture directly into learning experiences.** Informal learning settings such as museums, libraries, and makerspaces can be designed to promote cognitive science–inspired practices. For example, structural alignment can be facilitated by the design of spaces where visitors can see and manipulate models made by staff or by other visitors. Additionally, interactive exhibits or play spaces can use technology to incorporate vocabulary, language, and questions that focus children's attention on underlying STEM features and prompt their higher order thinking. These features can be implemented through local policies within the informal learning organizations.
2. **Reach informal child educators by training institutional staff**. Many of children's early informal learning experiences are facilitated by librarians, museum educators, and other professional informal educators. Local policies can be implemented to provide opportunities for professional development for informal educators on how to incorporate high-quality language, structural alignment, and gesture into their interactions with young children in a way that facilitates learning.
3. **Support parents in the moment with prompts.** Parents' use of these practices and engagement in high-quality informal teaching can be supported directly by providing prompts and information in settings where this learning is likely to take place. This method has already been successful in a museum setting by prompting parents' question asking (Benjamin et al., 2010; Eberbach & Crowley, 2017; Jant et al., 2014), but can be implemented in other ways as well. For example, encouraging parents to connect multiple pieces of an exhibit or designing the exhibit in a way that makes these connections more natural. Additionally, some recent work suggests that these prompts can be effective even in surprising places, such as grocery stores and public parks. For example, signage with questions about fruits and vegetables directed at parents and children can increase conversations in grocery stores (Ridge, Weisberg, Ilgaz, Hirsh-Pasek, & Golinkoff, 2015) and placing life-sized math and science games in parks and playgrounds can increase children's STEM talk during play (Hassinger-Das et al., 2018). Local governments can provide funding to incorporate these design elements into public spaces that families typically visit and companies, such as grocery stores, should be encouraged to implement these prompts and tips into their businesses.

Moving Forward Through Research

Although it is clear that these practices are effective for supporting learning, much more work is needed to better understand the most effective ways to encourage families and people who design informal learning environments to make use of these practices when engaging in informal STEM learning. For instance, although there is much more work highlighting the use of and benefit of language during informal interactions, there is less work investigating the role of teacher's language in formal settings. For gesture, however, the reverse is true: there is much more work on the role of gesture in formal learning contexts, such as the classroom, than there is in informal learning contexts, such as nondidactic play. Partnerships between researchers and cultural institutions that incorporate diverse linguistic and cultural perspectives will facilitate progress in our understanding of how best to support children's STEM learning.

Recommendation 2: Increase Accessibility and Diversity

Obstacles to Informal Learning

In principle, anyone, of any age, race, or gender, can engage in informal learning. Informal learning can occur anywhere and likely occurs throughout children's early lives in ways that families are not explicitly aware of. However, the kinds of informal learning children engage in or have access to may heavily depend on various factors, including economic access, geographical proximity to cultural institutions and other learning environments, feelings of exclusivity or inclusion, and decisions based on the types of leisure and learning valued in different cultures (Hill, McQuillan, Hebets, Spiegel, & Diamond, 2018; Hill, McQuillan, Spiegel, & Diamond, 2018; Medin & Bang, 2014; Stein, Garibay, & Wilson, 2008). For example, within urban areas, museums may not be accessible by public transportation or may simply be too far from families in different areas of the city, resulting in limited access to these *designed* informal learning opportunities (Mardis, 2013). Even for those who have physical access to museums, parents and children from cultures that value more didactic learning experiences or view elders as knowledge holders, may feel uncomfortable with the inquiry-based learning approaches often used by museums (Stein et al., 2008).

Additionally, stereotypes can play a role in children's access to STEM-related activities in particular. For example, playing with STEM toys, such as Legos or videogames, is related to STEM abilities (Serbin, Zelkowitz, Doyle, Gold, & Wheaton, 1990), but many STEM-oriented toys appeal more to boys than to girls and are purchased more for boys than girls, perhaps due to gender stereotypes (Jirout & Newcombe, 2015; Levine, Foley, Lourenco, Ehrlich, & Ratliff, 2016). Consequently, boys often spend more time than girls playing with these toys (Serbin et al., 1990). Therefore, with these differences in early experiences, it may not be surprising that boys tend to report more interest in technology and computer-based activities then their female peers (Cooper, 2006; McKenney & Voogt, 2010).

Evidence-Based Solutions

Today, many cultural institutions are working to create environments that are not just affordable but are also welcoming to diverse visitors. On a basic level, this includes adding signage in a variety of languages, which creates an inviting and welcoming environment for diverse visitors (Stein et al., 2008). On a deeper level, design decisions can help a diverse visitorship see their culture and identity represented within the museum space (Dawson, 2019; Falk, 2006; Stein et al., 2008). A central aspect of this identity-based approach to museum design and learning is an increase in the diversity of their staff members (Stein et al., 2008). Just as students of color reap academic benefits when their teachers share the same race/ethnicity, because they can better serve as role models and cultural translators (Egalite, Kisida, & Winters, 2015), children within museums are likely to feel more engaged and excited about STEM learning when the museum educators are relatable. Similarly, other design decisions, such as painting the walls colors other than white, playing music in typically quiet spaces, holding community nights that involve food and fun, and creating programming, such as story circles, that can include elders and children in both the presentation and acquisition of knowledge, may increase the approachability of spaces that have historically been curated for less ethnically and economically diverse populations (Levitt, 2015; Stein et al., 2008).

> Creating exhibits that appeal to a greater diversity of visitors requires museum curators and educators to design exhibits with input through conversations and dialogues with diverse communities.

Additionally, creating exhibits that appeal to a greater diversity of visitors requires museum curators and educators to design exhibits with input through conversations and dialogues with diverse communities (Wilson, 2000). Community-based design involves the creation of informal learning spaces in partnership with the people that the space will serve (Bang & Medin, 2010; Bang, Medin, Washinawatok, & Chapman, 2010). Taking this collaborative approach ensures that STEM learning opportunities reflect the community's interests, and that these projects respect the learning cultures and epistemologies of the people they will ultimately serve (Bang & Medin, 2010; Bang et al., 2010; Penuel, 2017). By taking into account the learning culture of the parents, children, and caregivers who will use the informal learning space, we can best promote more effective and sustainable learning. Furthermore, including community members in the process of designing the informal learning space gives them ownership of the STEM content presented there and the ways in which this content is conveyed (Bang & Medin, 2010). Consequently, community-based design may be a critical way to increase access to and learning in spaces that promote sustained STEM learning.

Community-based design has already been shown to be an effective way to promote STEM learning in informal contexts (Bang et al., 2010; Hassinger-Das et al., 2018). An Indigenous STEAM (Science, Technology, Engineering, Arts, and Math) camp, in which youth engage in primarily outdoor activities that promote STEM learning through Indigenous ways of knowing, is just one successful example of community-based design (Bang et al., 2010; Barajas-López & Bang, 2018). Indigenous people, including teachers, children, parents, and elders, have not only played roles in designing the camp, but they also hold leadership positions on the research team (Bang et al., 2010). The expertise of the researchers and designers who identify as Indigenous facilitated the inclusion of cultural practices and ways of knowing within the camp design, and ultimately helped promote youth learning, as they could view themselves as scientists (Bang et al., 2010).

Despite these examples of community-based design decisions, structured informal learning contexts, like museums, often remain inaccessible for many. Incorporating pop-up or traveling exhibits can help increase accessibility by widening the geographical availability of these informal learning opportunities (Feinstein & Meshoulam, 2014; Hartman & Hines-Bergmeier, 2015). Additionally, public libraries are often available in both urban and rural communities and may be able to facilitate informal STEM learning to a broader audience. For example, the Washington State Library is actively trying to encourage broader participation in STEM by implementing a circulation system where STEM kits, including robotics and advanced Legos, can be rotated to rural library branches that cannot typically afford to buy them (Lopez, Jacobson, Caspe, & Hanebutt, 2019).

…it is important for informal STEM learning opportunities to extend beyond the walls of brick and mortar institutions so that families can engage in informal learning wherever they live.

One of the benefits of informal learning is that it is not defined by its location, but rather its characteristics. … it has always been a way through which knowledge is passed between parents and children.

Lastly, it is important for informal STEM learning opportunities to extend beyond the walls of brick and mortar institutions so that families can engage in informal learning wherever they live. For example, there are many informal learning opportunities that occur during everyday and household activities, such as the care of animals and pets, outdoor activities (e.g., gardening), craftsmanship (e.g., weaving), the use of the Internet, and interacting with peers, all of which can provide opportunities for STEM engagement (Collier, 1988; Falk & Dierking, 2010; González, Andrade, Civil, & Moll, 2001; Luce, Goldman, & Vea, 2017; Mardis, 2013; Rogoff, 1990). One of the benefits of informal learning is that it is not defined by its location, but rather its characteristics. For this reason, informal learning has always been a way through which knowledge is passed between parents and children, and thus provides a lever for increasing the quality and quantity of STEM learning opportunities for young children.

Implementing Recommendation 2

We recommend multiple ways to increase the accessibility, diversity, and inclusivity of informal learning spaces, which can be implemented by local governments and internal policymakers at informal learning institutions.

1. **Facilitate access to and inclusivity of existing spaces.** Local policies within museums, libraries, and other cultural institutions should facilitate access to and engagement with their spaces. Importantly, this requires a multifaceted approach that includes the following: free and/or reduced visitor options, signage in multiple languages, hiring diverse staff, and establishing community partnerships that facilitate ongoing conversations about improving access and engagement with a diverse visitorship.
2. **Create spaces.** STEM engagement can be further promoted by creating opportunities for informal learning in spaces that are habitually used by families. Local governments and organizations can implement this by providing opportunities in public spaces, such as parks and bus stops, and within local businesses or organizations, such as grocery stores or laundromats, via prompts and design elements meant to engage both parents and children (Hassinger-Das et al., 2018; Ridge et al., 2015). Additionally, museums and libraries can make use of pop-up and traveling exhibits that can travel to rural or other areas that do not have easy access to cultural institutions because of geographical constraints.
3. **Implement community-based design.** Importantly, modifying and creating informal learning spaces in partnership with community members can best encourage access, diversity, and inclusion by incorporating a diverse set of voices and partner-

ships via community-based design. This approach requires local governments and policymakers, as well as directors and leaders of cultural institutions and organizations to partner with the communities they are hoping to serve. Thus, any policy that is to be implemented to increase access, diversity, and inclusion should be implemented through these community partnerships (see **Recommendation 3**).

Moving Forward Through Research

Although there are some recommendations that can be directly implemented, more research is also needed. In particular, priority should be given to research studies that specifically aim to broaden our understanding of children's informal STEM learning by investigating how informal learning occurs and the best ways to support it across diverse groups of children and community settings. Currently, much of the research on informal learning, particularly in designed settings such as museums, are with urban and middle-class children. Yet, cultural, racial, ethnic, gender, and linguistic differences (among others) in learning are not static or independent (Bell et al., 2009), making it critical to consider these factors when addressing children's informal learning and how best to support it (e.g., Bonilla, 2014). Additionally, while there has been growth in community-based design, as exemplified by the Indigenous STEAM summer camps (Barajas-López & Bang, 2018), these spaces have primarily been aimed at children in middle childhood and adolescence. Given the value of *early* informal STEM learning, more research is needed on how to best facilitate and use community-based design to promote learning in young children. Thus, funding agencies should prioritize research agendas that aim to investigate these issues in a way that incorporates community partnerships that can provide diverse perspectives.

Recommendation 3: Bridging the Pathway between Formal and Informal STEM Learning

Obstacle to Informal Learning

Throughout this report, we have emphasized that informal STEM can provide children with opportunities to increase their interest in STEM and develop higher order thinking skills that can be applied across STEM domains, setting children up for success in the STEM classroom. However, for the full benefit of informal STEM learning to be realized, it's critical that formal and informal learning contexts be *coherent;* that is, that they be connected to each other in ways that promote learning. These connections can be made in a variety of ways, including incorporating parents and other adults into children's learning through family-school partnerships (e.g., Christenson, 2004) and providing children with informal learning opportunities that connect in purposeful ways with their formal STEM education (e.g., Bouillion & Gomez, 2001; Eshach, 2007; Halverson & Sheridan, 2014; Ramey-Gassert, 1997; Rennie, 1994). By the same token, formal STEM learning curricula can better connect with the informal experiences that children are likely to have had that are relevant to the particular concepts being taught.

Evidence-Based Solution

Family–school partnerships have been a major source of interest for decades and continue to be an important component of research and practice (Epstein, 1995; Epstein, 1992; Epstein et al., 2018; Henderson, 2007). To build family–school partnerships in early education, preschool and kindergarten classrooms can provide parents and caregivers with information about what STEM learning is happening in the classroom and how various informal learning opportunities, either at home, museums, or other community programs or cultural institutions, can engage children in complementary learning experiences. Engaging school–community–family partnerships is associated with improvements in children's math achievement (Sheldon & Epstein, 2005) and interactive parent–child homework assignments can be beneficial for science learning (Van Voorhis, 2001). Additionally, through technology, design, and social media, we can provide platforms on which children can share their learning in a variety of settings. For example, Science Everywhere (Ahn et al., 2018) is a sociotechnical system that allows children to use a social media app to post about the science they are noticing in their everyday lives across a variety of settings. This platform is particularly remarkable because it takes advantage of public interactive displays that feature children's posts and provides opportunities for community members, including other children and adults, to engage with their learning and continue to foster connections (Ahn et al., 2018). Continuing to create spaces in which adults and children can connect learning across both informal and formal settings should be a key priority in fostering young children's STEM learning.

Additionally, formal education programs can explicitly incorporate informal learning into their educational programs and facilitate school–community partnerships. For example, makerspaces, which facilitate creatively engaging in higher order thinking and early STEM skills, can be incorporated into preschool and kindergarten classrooms (Halverson & Sheridan, 2014). School libraries may also be an important hybrid space for bridging formal and informal STEM learning (e.g., Subramaniam, Ahn, Fleischmann, & Druin, 2012). Even in the formal classroom, socially motivated and inquiry-guided STEM activities that exemplify the benefits of discovery and exploration in informal STEM learning can improve the attitudes and performance of elementary school students (e.g., Paris, Yambor, & Packard, 1998). Furthermore, teachers and educational programs can incorporate well thought out field trips to museums and other informal STEM settings that connect with what is being taught in the classroom (e.g., Eshach, 2007; Griffin, 2004; Ramey-Gassert, 1997; Rennie, 1994; Wishart & Triggs, 2010). When informal experiences (e.g., museum field trips) are explicitly connected to children's STEM learning in the classroom (e.g., Rennie, 1994) and are focused on the transfer and communication of ideas (e.g., Wishart & Triggs, 2010), they may be particularly useful to children's STEM learning and engagement.

School–community partnerships can and should be bidirectional. For example, community schools and libraries can communicate about current STEM classroom learning so that the library programming can reflect the school learning in important ways and develop connections across content and grades. This allows children to receive formal STEM information in school and to supplement this learning with the opportunity to explore these same ideas in an informal and playful way, leading to deeper learning and the potential for positive attitudes and interest. Schools can also communicate with parents and encourage them to incorporate activities that build on STEM content that is being taught in the classroom.

Implementing Recommendation 3

Overall, these practices hold promise for connecting informal and formal STEM experiences and for supporting STEM learning for all children. Notably, when forging these partnerships, it is important to consider the strengths of both informal and formal educational settings to ensure they are brought together in thoughtful and mutually beneficial ways, in order to maximally benefit students' STEM learning and STEM interests (e.g., Adams, Gupta, & DeFelice, 2012).

1. **Connecting parents with informal and formal learning institutions.** Schools and informal learning institutions should provide information and support to families about ways parents and caregivers can promote children's STEM learning both within and outside the designed learning environments. This requires local policy to fund and support these programs within schools and other publicly funded programs, including libraries. Additionally, policymakers at museums, such as administrators and staff, can implement local programs; for example, providing visitors with information in pamphlet or email formats on ways to continue STEM learning at home throughout the day.
2. **Connecting across institutions.** Informal and formal learning environments must communicate with each other. Policymakers at schools can connect with their local informal learning institutions to provide information about their STEM education at school and encourage connection with programming at informal institutions, through fieldtrips or connected activities. Conversely, informal learning environments can connect with formal learning environments to provide access and information about their programming or bringing temporary makerspaces or other exhibits into classrooms. One way to create this connection is to have an informal educator from a local community institution occasionally present at school pick up or drop off to provide parents with information on free local events that will continue to foster children's learning outside of school. Additionally, schools need to learn about the cultural practices of the families they serve in order to meaningfully link their STEM classroom content to informal learning experiences that are happening at home.

Moving Forward Through Research

Although the need for bidirectional partnerships between family, school, and cultural institutions is clear, these partnerships are difficult to build and maintain (Epstein, 2013; Johnson, 2012; Penuel, 2017; Watters & Diezmann, 2013). Much more work is needed to develop best practice guides for developing successful and productive partnerships across a variety of cultural contexts. For example, given the recent emphasis on STEM integration across domains and the focus on inquiry and higher ordering thinking, it remains unclear how best to integrate the informal, domain-general approach to STEM learning with more formal, domain-specific approaches (English, 2016). In addition,

> Beginning [partnerships] when children are young and before they enter formal school … may help establish a habit of STEM engagement that will continue to support them throughout K-12 education and beyond.

school–community partnerships may vary between urban versus rural communities (Bauch, 2001), making it essential to investigate these questions within the context in which they will be situated and in partnership with local cultural institutions. Lastly, much of the current work focuses on these partnerships in later grades and with older children. However, beginning these partnerships when children are young and before they enter formal school (e.g., by engaging parents and caregivers in preschool or library programing) may help establish a habit of STEM engagement that will continue to support them throughout K-12 education and beyond.

Summary and Conclusions

Informal learning plays a critical role in supporting children's early STEM education. In particular, early informal STEM experiences allow children to engage in meaningful STEM learning across a range of contexts and at younger ages, supports the development of important skills, and does not require formal content knowledge or specific kinds of materials, but instead can be supported by activities parents and children are already doing. By expanding children's STEM experiences beyond those they have in the classroom, children will be better prepared for school-based learning, in STEM domains and more generally. In turn, this will improve STEM academic outcomes and interests, potentially enlarging and diversifying the STEM workforce.

Policy recommendations and funding decisions should reflect the high-value role of informal learning for early STEM education, particularly when these efforts incorporate the voices of families with different cultural backgrounds and encourage partnerships between those involved in formal and informal learning opportunities in order to increase the coherence of learning in different contexts. Here, we outlined three specific recommendations that can help informal learning contexts and those invested in children's STEM learning support families in making the most of the informal learning opportunities they likely already engage in. First, informal learning contexts should incorporate cognitive science–based practices for enhancing children's ability to abstract and generalize the information and skills they are learning, in particular through language, structural alignment, and gesture. Second, informal learning contexts must seriously consider access and diversity in terms of the design, administration, and accessibility of their programs. This should start with community-centered input and design but must continue as a dynamic and ongoing process. Third, schools and cultural institutions should establish strong partnerships with each other and the families they serve in order to foster coherence across informal and formal STEM learning contexts. Each of these recommendations provides actionable steps that can be taken up by those invested in supporting children's early STEM learning, such as museums, libraries, schools, and other organizations. Additionally, however, there remains much to be learned about children's early STEM learning and how it can best be supported across a range of learning contexts, cultures, and linguistic backgrounds. Thus, each of these areas also requires additional research that can provide deeper insight into these questions and broaden our ability to support all children's early STEM learning.

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Author Bios

Michelle A. Hurst is a Postdoctoral Scholar at the University of Chicago and an affiliate of the Development and Research in Early Math Education (DREME) network. She received her Ph.D. in Developmental Psychology from Boston College in 2017 and her BSc in Mathematics and Statistics from McMaster University in 2012. Dr. Hurst studies cognitive development and has published in a range of developmental, cognitive, and educational journals. Her work focuses on mathematical cognition and how informal and formal learning experiences impact people's mathematical reasoning. Her work also investigates the role of different representations for math reasoning, such as written notation, graphical models, or real-world scenes or objects. Dr. Hurst approaches these research topics by studying a range of developmental ages, from preschool children to adults, using a variety of behavioral research methods, and considering both individual cognition and social context (e.g., the input of parents and teachers). Overall, the goal of her research program is to support advanced math learning by considering children's early intuitions about informal math, how these informal intuitions change as children learn new information and skills, and how formal math education can more effectively align with children's informal intuitions and knowledge.

Naomi Polinsky is a third year PhD student in the Cognitive Psychology graduate program at Northwestern University working under the mentorship of Dr. David Uttal. Prior to beginning graduate school, she received her BA from Barnard College in 2015. Polinsky's research focuses on young children's learning and problem solving within informal STEM-oriented learning settings, such as at the Chicago Children's Museum. Specifically, she is interested in how these informal spaces and activities can be designed and scaffolded to promote children's use of higher order cognitive processes and ultimately facilitate their learning. She received the 2019–2020 Northwestern University Institute for Developmental Sciences Graduate Student Fellowship to pursue this work.

Catherine A. Haden is Professor of Psychology at Loyola University Chicago. She received her Ph.D. in Psychology from Emory University, and completed a postdoctoral fellowship at the Center for Developmental Science at the University of North Carolina at Chapel Hill. Dr. Haden is a developmental psychologist who focuses on learning and remembering in early childhood. She has a long-standing interest in the sociocultural development of event and autobiographical memory. Her work on the ways that parents' structure reminiscing with their children demonstrates long-term impacts of early conversations about the past for developing memory skills. With funding from the National Science Foundation, and in partnership with Chicago Children's Museum, Dr. Haden's current work focuses on the ways that parent–child conversational interactions and storytelling during hands-on science and engineering activities can benefit children's STEM learning and subsequent remembering and transfer of knowledge. This developmental science research is contributing to exhibit design and facilitation strategies that advance real-world STEM learning opportunities for children and families. Dr. Haden is an Associate Editor of Journal of Experimental Child Psychology. She is a Fellow and president-elect of Division 7 (Developmental Psychology) of the American Psychological Association.

Susan Levine is the Rebecca Anne Boylan Professor in Education and Society at the University of Chicago. Her research examines early mathematical learning in the numerical and spatial domains and the instructional strategies that support this learning. She has shown that variations in the math language that children hear in the early home environment predicts their learning of foundational math concepts. She has also shown that math attitudes, notably math anxiety, is related to children's math learning by first grade. Moreover, Dr. Levine has found that there are intergenerational effects of math anxiety such that children who interact with math anxious parents and teachers are more likely to learn less math and to develop negative math attitudes. Importantly, her work shows that evidence supported interventions boost children's early math learning and change the attitudes of math anxious parents. The overarching goal of her research program is to increase the preparedness of all children for STEM achievement in elementary school and beyond. Dr. Levine has served as the co-PI of the Spatial Intelligence and Learning Center, an NSF Science of Learning Center and is currently the inaugural faculty director of the newly founded University of Chicago Science of Learning Center.

David Uttal is Professor of Education and of Psychology at Northwestern University. He is also Director of Northwestern's Spatial Intelligence and Learning Center. He is interested in the development of symbolic reasoning and spatial cognition. His 2013 meta-analysis of the influences of training and experience on spatial skills won the George Miller Award for the best paper in general psychology from the American Psychological Association. Currently, he is working with the Chicago Public Schools to develop and assess methods for enhancing spatially based problem solving in Career and Technical Education.

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