Storybooks and STEM: Using Books as a Tool to Support Early Childhood Family STEM Learning

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There is growing interest in increasing opportunities for science, technology, engineering, and mathematics (STEM) learning for families before children enter kindergarten, recognizing the important role that these experiences play in preparing children for school and building lifelong STEM learning and interest development pathways (Alexander et al., 2015; McClure et al., 2017; Morgan et al., 2016; Shwe Hadani & Rood, 2018). At this age, children's storybooks are a ubiquitous and critical learning resource, and one with huge potential to support STEM learning. They are also a primary way that children learn about the world and engage in conversations with family members and other significant adults, even as the use of other media and technology increases (Common Sense Media, 2013; Geerdts et al., 2016). On average, children in preschool and early elementary school across the U.S. spend 30 minutes every day reading or being read to (Common Sense Media, 2013). Especially before children learn to read, storybooks create the context for in-depth learning conversations with parents and other adults, which are the central drivers of STEM learning and development more broadly at this age (NASEM, 2016; NRC, 2000). The inherent social nature of shared booked reading, either in the classroom or at home, is often cited as an important reason underlying the benefits of storybooks for promoting STEM learning (Hojnoski et al., 2014; Kelemen et al., 2014; Waxman et al., 2014).

There is a large body of literature highlighting the benefits of storybooks for children's learning, especially from classroom studies (e.g., Hassinger-Das et al., 2015; Monhardt & Monhardt, 2006; Neuman & Kaefer, 2018) and research in clinal laboratory settings (e.g., Elia et al., 2010; Ganea et al., 2014; Waxman et al., 2014). Recently, a variety of projects have been launched to explore how storybooks can also serve as a tool for STEM engagement and learning in informal and out-of-school education settings, such as afterschool programs, museums and science centers, and home-based family programs.

This paper summarizes four recent projects focused on family learning for preschool-age children (three to five years) using early children's fiction books as a tool for engaging families in STEM topics and skills. The first section (*Storybook STEM*) presents results from a national survey of researchers and educators using children's books to support STEM engagement and learning in early childhood. The next three sections provide examples and research findings from specific projects, including an effort to develop books that engage families with mathematical conversations (*Storytelling Math*), a research study looking at how books can engage preschool-age children in science practices and evidence-based explanations (*My Sky Tonight*), and a national effort to train informal STEM education professionals to effectively integrate books into

their STEM programs (*Leap into Science*). The final section synthesizes emergent ideas across the four projects and suggests promising areas for future education and research efforts.

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National Survey Results on the Use of Children's Books to Support STEM Learning

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Subject/problem. Although the idea of combining storybooks and STEM education is not new (e.g., Claud, 2000), there has been a renewed and expanded interest in this area, especially as an approach to broadening STEM access and learning in early childhood (Popov et al., 2017). A variety of active projects across the country are using fiction books and reading activities as avenues for STEM engagement with young children and families. However, there is almost no coordination among these groups, including building on prior work, aligning research questions, or sharing and synthesizing results.

Design/procedure. To address this problem and advance ongoing research and education efforts, the National Science Foundation-funded Storybook STEM project conducted a national survey in 2019 with researchers and educators to describe how professionals from a variety of fields and sectors are using children's books to support STEM learning for preschool-age children and their families, especially in out-of-school settings. The data collection was part of a broader effort that culminated in a convening of experts in December 2019. The electronic survey was distributed broadly through email, listservs, newsletters, professional organizations, and social media to individuals working in the following sectors: libraries, afterschool programs, museums and science centers, informal STEM education, early childhood education, and developmental and cognitive psychology. Survey questions addressed the focus areas of participants using children's books for STEM learning (role, audience type and age, content domain, and educational or research setting), their goals for incorporating children's books in programs or research, the ways they have incorporated children's books in these contexts, and resources that have been helpful for using children's books as an educational or research tool. Close-ended responses were summarized using descriptive statistics. Open-ended responses were analyzed using qualitative, inductive analysis (Patton, 2015) to identity themes across responses.

Findings and analysis. In total, 231 individuals responded to the survey, including educators and teachers from both formal and informal learning contexts (59%), researchers (34%), designers and developers (15%), managers and administrators (14%), and other roles (11%),

such as policymakers, parents, children's book authors, librarians, and funders. These respondents reported using storybooks to support and enhance STEM learning across a range of ages (infancy to high school), audience groups (children, youth, families, professional development), STEM domains, and educational settings (libraries, classrooms, afterschool programs, informal learning institutions, homes, research labs, and more).

Overall, the responses highlighted the diverse ways that researchers and educators are using storybooks to engage children and their families. Storybooks are being used to support a range of goals, such as STEM content learning (25%), reading and literacy development (33%), and other more general outcomes (17%). Some respondents focused more on STEM-specific goals, some on other aspects of literacy and child development, and others on a combination of the two. Respondents emphasized the important role that children's books can serve to help launch activities and lessons (23%); connect learners to the content through a comfortable, familiar, and engaging format (20%); and provide a reference frame (e.g., characters, narrative) for subsequent STEM investigations (12%). A smaller number of responses (9%) focused on using children's books to broaden access to STEM or provide more diverse and equitable depictions of STEM topics and professionals. Researchers are also studying a range of questions about how children and their families engage with and learn from storybooks, including potential STEM learning and early literacy outcomes, family reading practices and conversations sparked by books, content and accuracy of STEM-based books, design and content factors that influence engagement and learning, and the potential of digital books.

Contribution to the teaching and learning of science. The survey results provide a unique summary of how children's books are being used by researchers and educators to support STEM learning in early childhood, the ways that educators believe these books can be effectively used and integrated into STEM programs, and the questions that researchers are currently pursuing to inform theory and practice. The results suggest a variety of areas for future research and development. For example, only a few researchers discussed studying how children's books can be integrated with STEM learning programs or contexts (or how parents and educators can be supported in this process), despite the emphasis by other respondents on using books to launch and frame STEM learning experiences. As a few respondents noted, there is also a need to expand efforts exploring how children's books can serve as a tool for supporting diversity and equity goals in STEM, including diversifying how STEM professionals and fields are portrayed in books.

What Good Can One Book Do? Board Books Sparking Change in Families' Math at Home

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Subject/problem. Growing numbers of literacy organizations distribute books to low-income families in settings from medical offices to playgrounds to Laundromats. Research on the impacts of book distribution has focused on changes in family literacy practices (e.g., Canfield et al., 2020; Mendelsohn et al., 2001). However, there has been little research on the impacts of such distribution on family STEM practices. Thus, to begin to contribute to this area, the team investigated the following: What is the impact on family math practices when low-income parents are given a math-themed fiction board book (for ages 0-3)? Mathematical development in the early years is a vital cornerstone: early math skills are a strong predictor of children's future academic success in many domains, including science (Claessens & Engel, 2013; Duncan et al., 2007).

Design/procedure. Head Start and Early Head Start teachers at 18 programs in a large East Coast city distributed a bilingual English/Spanish copy of *Banana for Two* (Mayer, 2017) to 429 parents, most of whom were African-American or Latinx. Parents were not given an orientation to the book; these programs occasionally offer parents resources to take home, which parents can decide to use or not. In Banana for Two, a brown-skinned parent and toddler shop for groceries while encountering and discussing issues germane to one-to-one correspondence (e.g., two bananas—one for each hand). The book includes a short and simply written note about the math and about the importance of math-focused communication with babies and toddlers. One to two months after distributing the book, teachers asked parents to complete an anonymous, multiple-choice survey about their experiences with the book. The response rate was 23%.

Findings and analysis. Nearly all respondents (99%) reported looking at the book with their children, and of those, over half (56%) cited doing so three or more times. The great majority reported that the book sparked gains in children's learning, in their own learning, and in the amount of math talk at home. For instance, 86% of parents reported that they believe children learned math as they looked at the book together, with most citing that children learned about one-to-one correspondence or counting. Furthermore, 88% of parents reported that they themselves gained new ideas for ways to engage their young children in conversations involving these topics and 73% reported including much more "math talk" (discussion of quantities and one-to-one correspondence) in their conversations with children after looking at the book together. Gains were independent of the number of times parents reported looking at the book with children, and in most instances, gains were independent of child age. The exception is in amount of math talk: 82% of parents with at least one child 2 or older reported that looking at the

book sparked greater gains in amount of math talk they initiated with their children, but only 59% of parents with children under 2 did so.

Contribution to the teaching and learning of science. Results suggest that distributing a math-themed board book to low-income parents of young children, without any book-specific modeling or orientation, can lead to substantial self-reported increases in family math practices at home. Since gains in reported amount of math talk were greater among those who had at least one child 2 years or older, it may be that parents with babies and young toddlers may benefit from additional reminders of the importance of communicating about math with young children.

In this study, distributing "just" one board book to low-income families appeared to make a difference in family math practices. In this instance, the math content was embedded in a fiction story situated in the familiar context of grocery shopping and featuring characters of color. Educators might consider finding ways to make more books with STEM content available to families, and additional research might explore impacts among families with slightly older children or other STEM topics.

A Cross-Storybook Analysis of How Story-Driven Investigations Engage Preschool-Age Children in Science Practices

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Subject/problem. Stories can be used as tools to structure and problematize science for children (Murmann & Avraamidou, 2014). Stories can also help motivate children to learn science, by helping the child understand why they should engage with a problem or concept (Murmann & Avraamidou, 2014). Stories generate interest, help us remember, and improve understanding (e.g., Norris et al., 2005). Yet, more research is needed on the ways we can use stories as tools to support young learners in the practices of science. Murmann and Avraamidou (2014) advocate for the importance of educators implementing story-based activities as an opportunity to facilitate the story as a learning tool. They further argue that story-based activities require scaffolds to facilitate educators' and children's use of stories in ways that will engage them in science practices about science phenomena. In this study, the team compared three story-driven programs with preschool-age audiences, as guided by the following research question: What elements in children's science storybooks influence young children's opportunities to co-construct evidence-based explanations when used as the foundation of story-driven investigations?

Design/procedures. As part of a larger project designing museum-based programs for preschool-age audiences (3 to 5 years), the team iteratively designed and improved three programs around children's storybooks: *Moonbear's Shadow* by Frank Asch, *Breakfast Moon* by Meg Gower, and *Magnet Max* by Monica Lozano Hughes. The programs each began with the educator reading the storybook to the children. This was followed by hands-on investigations of the story's phenomenon guided, as by the story's central question or problem. For example, after listening to a story about how Max and his friend tried to find out what objects were attracted to magnets around their house, the children conducted a similar investigation of objects placed around their museum's classroom. Programs concluded with the educator guiding children in generating representations (drawings) of the phenomena as part of a reflection and discussion. The team iteratively implemented each workshop three to four times with groups of 6-16 children, video recording each implementation from multiple camera angles. Through discussion with the museum educator, the team made improved each program's implementation towards our design-based goals.

The study used conjecture mapping, a design-based research approach, to guide analysis (Sandoval, 2014). A conjecture map includes: 1) a high-level conjecture describing how the design supports learning, 2) embodiments of the high-level conjecture in the design, and 3) mediating processes produced by the embodiments that lead to 4) desired outcomes. Embodiments, mediating processes, and outcomes became categories in the coding scheme, with elements within each concept map feature serving as a code used to analyze video data from the workshops. The team then analyzed patterns in overlap between codes within these categories to determine how embodiments produced mediating processes that then yielded the desired outcome: co-constructed evidence-based explanations.

Findings and analysis. The storybook, through its concepts, narrative, and questions, were purposefully designed into the program as represented by the conjecture map embodiments. This included a story-driven investigation that was designed to engage children in an investigation of the science phenomenon and central problem or wonderings from the storybook's narrative. This common design strategy yielded similarities and differences between workshops, specifically in what we found in how mediating processes (which arise from the design's embodiments) led to the proposed outcomes (co-constructed evidence-based explanations. First, children in all three workshops produced the target outcome (co-constructing evidence-based explanations with the educator) through a) discourse linked to the story's concepts and b) representations generated by the children. In other words, the educator used the main phenomenon from the storybook as the basis for leading discourse with the children around the investigation and reflection, resulting in co-constructed evidence-based explanations.

Second, the other mediating processes, narrative-driven discourse and gesture use, supported the outcome in some workshops and not others. Narrative-driven discourse strongly led to outcomes

for *Moonbear's Shadow* during investigations, weakly led to outcomes for *Breakfast Moon* during investigations, and weakly led to outcomes for *Magnet Max* during investigations and reflections. This difference may have arisen because the Moonbear character was represented within the investigation the children carried out. They used a small model of a bear to investigate shadows. This encouraged the educator to prompt children with specific questions or story elements from the *Moonbear's Shadow* storybook, features mostly absent in the other two programs. Gesture use, by children and educators, strongly supported outcomes for *Moonbear's Shadow* and *Breakfast Moon* but were absent in *Magnet Max*, during investigations and reflections. Differences in gesture use to mediate constructing explanations can be explained by differences in the science phenomena, specifically in the extent to which they required spatial reasoning.

Contribution to the teaching and learning of science. This study found that elements drawn from a children's science storybook, specifically the ways the storybook's phenomenon led to discourse and representations, informed how the educator guided children's co-construction of evidence-based explanations. Differences found in how storybooks can be used in program design to mediate children's evidence-based explanations may be due to differences in how the design takes up the role of the storybook's character(s) and nature of the science phenomena. Study findings suggest that some storybooks may lend themselves to investigations where the narrative plays a more central role than others. In the case of *Moonbear's Shadow*, the central character became an important feature of the model children used to investigate the phenomenon and thus created a natural point of entry for narrative-based discourse. The study also found differences between how program design mediated outcomes through the use of gesture because of differences in the spatial nature of phenomena. Gestures are, by their nature, inherently spatial (Goldin-Meadow, 2014); young children may have used more gestures around spatial phenomena to help them communicate more complex spatial ideas than they could convey with verbal responses (Sauter, Uttal, Schall Alman, Goldin-Meadow, & Levine, 2012). More research is needed that considers how these findings may inform future museum program designs as well as support for parents to scaffold their own use of storybook narrative to engage their children in investigating science phenomena.

Impacts of Connecting Children's Storybooks and Science to Increase Educator Knowledge, Confidence, and Skills Leading STEM Programs

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Subject/problem. Research suggests that the synergistic relationship between science and literacy provides multiple access points for children to develop scientific ideas while improving literacy skills (Douglas et al., 2006; Ford, 2006; Moje et al., 2001; Oliveira, 2015; Varelas & Pappas, 2006). Additionally, pairing hands-on science activities with children's books is a way to integrate science into community settings like libraries and early childhood centers where literacy is already a central focus, but science learning may be lacking. However, educators often lack the necessary resources and training to lead effective science and literacy programming, especially in low-income populations. (Ci, Freeman, & Lee, 2008, Harvard Family Research Project, 2007). Moreover, when educators receive training, it is often only in science or literacy, and therefore educators rarely gain an understanding of how to effectively integrate these subjects.

Design/procedure. The Leap into Science: Cultivating a National Network for Informal Science and Literacy project, first developed in 2007 through a partnership between The Franklin Institute and the Free Library of Philadelphia, is a nationwide program that intentionally pairs science and literacy in order to maximize learning for children and families. The Leap into Science model includes curriculum and training that focuses on the interconnected skills children are practicing when engaging in science and literacy learning. In 2017, the Leap into Science project was scaled through a national train-the-trainer network in order to enable informal educators from a wide range of informal learning institutions to confidently and effectively engage urban and rural communities in science and literacy learning. Educator outcomes were assessed through a mixed-method approach, including surveys, interviews, and observations.

Finding/analysis. Study results indicate that the Leap into Science project has significantly increased facilitator' interest in science, understanding of how children learn science and literacy, and confidence and beliefs of self-efficacy in science teaching (Ancelet, 2016; Ancelet & Luke, 2013; Luke et al., 2010). More recently, research shows that 52% more educators indicated they were highly confident leading science programs after Leap into Science training. At the same time, 26% more respondents said they were highly confident leading literacy programs. When asked to rate their level of knowledge about leading science and literacy

programs, 41% more respondents indicated they were highly knowledgeable about leading science programs and 20% more were highly knowledgeable about leading literacy programs after the training. Almost all respondents agreed that participating in the Leap into Science program helped them develop their skills leading science and literacy activities (97% and 91%, respectively). All respondents agreed they were comfortable facilitating literacy activities while the majority agreed they were comfortable facilitating science activities (100% and 96% respectively).

Contribution to the teaching and learning of science. There is a clear need to better understand how to develop curriculum and train educators to lead high-quality informal science and literacy programming for youth and families (Fleischman, et al., 2010; Gilbert & Yerrick, 2001; Settlage & Meadows, 2002). Results from the Leap into Science project suggest that by providing science and literacy curriculum and integrating these subjects in a high-quality training, educators will increase their confidence and skills, ultimately better supporting critical thinking in children.

Discussion for NARST Storybook and STEM Session

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In the four research projects summarized in this paper, there is evidence that storybooks can be purposely imbedded in programs to encourage their use as a way of supporting early childhood STEM education among families. Each research project furthers information on successful mechanisms to accomplish this goal. And each project raises new questions. In the survey that addresses the lack of data and coordination for research questions and shared results, the smallest percentage of respondents identified primarily as parents (and included other categories). This raises the question of how we reach more of those who may need the support of educators to encourage regular family reading practices and conversations that will spark children's interest in how things work and how we use information in our problem solving.

The second research project explored the impact on family math practices when bilingual (English and Spanish) books were distributed through Head Start and Early Head Start programs. The results were encouraging. What can be done to increase the response rate (23%)? What were the new ideas that they reported for more "math talk," and how was this incorporated in home life? The finding that gains were independent of how many times the parent reported looking at the book with children bears more investigation. Did parents read it themselves repeatedly? A longitudinal study following math talk in the home would be helpful.

In the third research project, in which books were the focus of a museum-based program for preschoolers, the researchers noted that more work is necessary to design support for parents to scaffold storybook narrative toward investigating phenomena. And in the fourth research project, the explicit pairing of science and literacy in workshops assisted informal science educators in gaining confidence to include science to support children's critical thinking. These projects all suggest that some form of support greater than what is now generally available would help parents gain confidence in introducing STEM along with reading in their homes. How can the science education community facilitate this support in a culturally sensitive way that honors existing family narratives?

The important connection between working with parents and STEM education is through identity development. How we are in the world depends largely on the narratives we develop for ourselves, a finding that Avraamidou explained well in studying first year science teachers (2018). In the science education community, our overarching goal is to teach how science benefits both our individual survival and our group collaboration for democracy (AAAS, 1989; NRC, 1996; NGSS Lead States, 2013). In our homes then, we can include stories of not only how the world works but how we are a part of the process—members of a community of knowledge users and seekers. The research in this paper on storybooks and STEM assumes that we can support a family narrative that transmits to children that their families are a part of the science learning community as they continue to gain literacy skills.

The environment that parents provide can support a child's interest in STEM (Sha et al, 2016). The relationship between learning science and stories begins in the home, where parents talk with their children about how the world works. How has our family used resources within our culture to live? Where have our homes been? How have we migrated? What foods do we prepare? Research done by Duke and colleagues (2003) has shown that children who absorb these stories are more resilient, knowing that they have a dependable social structure through family identity. The role of stories in our lives is so strong that Jonathan Gottschall titled his book on the subject, *The Storytelling Animal, How Stories Make Us Human* (2012). He provided evidence that our need to make sense of the world undergirds our need to tell stories. Favorite books are read over and over. They have the comfort of what is familiar (Katz & Avraamidou, 2018).

The presence of books in our homes speaks to family values of the written word. A wide selection of books available today presents a variety of family configurations and cultures, along with the rest of the flora and fauna inhabiting and adapting on earth. Reading researchers note the close bond of a parent and child, where the warmth of touch is appropriate and what feels "right" is established. Imitation is an early and continual teaching/learning mechanism (Meltzoff & Marshall, 2017). It follows that if reading is important to parents, by imitation, it can become

important to their children. The richness of STEM learning can be a component of the conversations that a parent is able to initiate with children if recognized and noted.

Further research is needed on how to stimulate and prepare parents to have these STEM-rich conversations as they read many classic books. Carol and John Butzow authored *Science Through Children's Literature* in 1989 for the classroom teacher. They connected familiar storybooks with traditional science content teaching. There is no general resource like this for out-of-school science educators working with parents. How do we assist large numbers of parents who may not have the education and resources that science educators have? How do science educators honor family cultures and stimulate families to have conversations with their children that will include habits of mind to help them solve the problems that we cannot foresee ourselves in a rapidly changing world.

Similarly, the question remains of how we reach a greater number of families with the STEM-related possibilities in storybooks. There are two models that come to mind. The Reading Is Fundamental program has been distributing free books for decades to improve literacy within families. They have many partners and resources, but the website does not currently list any science themes. In the Jewish community, a concern for cultural continuity engendered the PJ Library program in which families may register to receive free books each month with Jewish themes. A 2013 study concluded that families read the books and became more aware of their cultural heritage, with some engaging more frequently because of the book program. Let us learn from these successes, perhaps form partnerships, and increase the impact of what we have learned about storybooks and their potential for imbedding "my family as science participants" into family identity narratives. Much more research is needed on how parents come to learn and use what the current findings suggest.

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