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Measuring with Murray: Touchscreen technology and preschoolers' STEM learning[☆]

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ABSTRACT

American students rank well below international peers in the disciplines of science, technology, engineering, and mathematics (STEM). Early exposure to STEM-related concepts is critical to later academic achievement. Given the rise of tablet-computer use in early childhood education settings, interactive technology might be one particularly fruitful way of supplementing early STEM education. Using a between-subjects experimental design, we sought to determine whether preschoolers could learn a fundamental math concept (i.e., measurement with non-standard units) from educational technology, and whether interactivity is a crucial component of learning from that technology. Participants who either played an interactive tablet-based game or viewed a non-interactive video demonstrated greater transfer of knowledge than those assigned to a control condition. Interestingly, interactivity contributed to better performance on near transfer tasks, while participants in the non-interactive condition performed better on far transfer tasks. Our findings suggest that, while preschool-aged children can learn early STEM skills from educational technology, interactivity may only further support learning in certain contexts.

1. Introduction

The domains of science, technology, engineering, and mathematics, known collectively as STEM, have been deemed essential to preparing American children for the U.S. workforce. For example, the U.S. Department of Education has predicted significant increases in the need for STEM-related jobs through 2020 (National Center on Education and the Economy, 2008; US Department of Education, 2010). Comprehensive and innovative educational initiatives within the STEM disciplines are essential in order for America to remain competitive in an increasingly global market.

Yet, in recent years, children in the United States have continued to fall behind their international peers in both math and science. In 2009, the Programme for International Student Assessment (PISA) found that the U.S. ranked 20th of 67 countries in science, well below the international average. In 2012, the U.S. ranking dropped an additional four spots. In addition to poorer performance on math and science assessments, American students have shown less interest in STEM learning compared to their international peers (President's Council of Advisors on Science and Technology, 2009). In light of these findings, educators and policymakers have turned their focus to increasing STEM engagement and learning across grade levels, especially in early childhood education, where these domains have been historically underrepresented (Ginsburg & Golbeck, 2004).

Although much of the focus on STEM learning has occurred in the K-12 sector (Parette, Quesenberry, & Blum, 2010), some studies have shown that preschool-aged children are not only naturally inclined to explore STEM concepts that are embedded in everyday life (e.g., finding patterns, building structures, and asking how and why questions), but also have the cognitive capacity to link these real world experiences to the underlying scientific concepts, provided that they have appropriate scaffolding from adults (Bonawitz, van Schijndel, Friel, & Schulz, 2012; Brenneman, 2011; Callanan & Oakes, 1992; Carey, 1985).

In recent years, many new technologies have been developed to encourage early engagement with STEM-related concepts and ideas. A search for “science” or “math” in Apple's Kids App Store garners dozens of results. Further, the recent boom in access to

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mobile technology across socioeconomic lines (Rideout, 2013) has led many people to believe that these apps may be a particularly promising way to deliver educational content to young children, that is, if they are well designed and age appropriate (see, for example Hirsh-Pasek et al., 2015). Despite the educational potential of these technologies, very little empirical work has focused on determining the degree to which these types of apps are effective in supporting learning. The present experimental study looks at whether educational technology is, in fact, a potent way to facilitate early STEM learning among preschool-aged children and whether interactivity is a critical component of these technologies.

2. Literature review

2.1. Using technology to support learning

Within the last several decades, a wide array of media technologies has become accessible to young children (Rideout, 2013). Media that have been deemed educational are among the most popular choices for families with children age zero to eight (Rideout, 2014). Fisch (2004) explains that educational media are intended to supplement formal education by exposing children to topics that they might not otherwise encounter and provide compelling experiences that encourage children to spend additional time exploring concepts that they are learning about in school. In fact, research has shown that children benefit when developmentally appropriate content is coupled with entertaining narratives (Anderson, Huston, Schmitt, Linebarger, & Wright, 2001; Dingwall & Aldridge, 2006; Fisch & McCann, 1993; Linebarger, Kosanic, Greenwood, & Doku, 2004; Mares & Woodard, 2005).

Prior work on the role of educational media in early learning has focused on a wide variety of topics, like early literacy (Jennings, Hooker, & Linebarger, 2009; Linebarger et al., 2004), prosocial skill acquisition (Mares & Woodard, 2005), and adoption of healthy behaviors (Borzekowski & Macha, 2010). Few studies have examined the role that mediated experiences play in early STEM learning, however. One exception is the body of research on *Cyberchase*, an animated television show for children ages 8–11, funded by the US Department of Education's Ready to Learn initiative. *Cyberchase* was designed to foster positive attitudes towards math and to teach mathematical reasoning and problem solving. Results from one summative study demonstrated that, compared to non-viewers, children who watched the show once a day over a four-week period showed a significant increase in the quantity *and* quality of problem solving heuristics in the areas of nonstandard measurement and irregular shapes (Fisch, 2003). However, the work on *Cyberchase* looked mostly at television as the primary learning platform, and the population of interest was older children. There remains a dearth of empirical research on STEM learning from media in the preschool years, especially from newer technology platforms.

2.2. New learning opportunities from interactive technology

As noted, decades worth of research on children's learning from media has focused primarily on the impact of exposure to educational television. More recently, though, there has been a growing sentiment that newly popular interactive technologies,[1] such as tablets and other touchscreen devices, may offer learning opportunities above and beyond what more traditional platforms, like television, can provide. Indeed, virtually all American households with children now have some sort of touchscreen device, and parents report being more likely to turn to interactive media as an educational tool for their young children than to traditional television (Wartella, Rideout, Lauricella, & Connell, 2014). In light of the prevalence of today's interactive technologies, the American Academy of Pediatrics has relaxed their guidelines advising against screen time for young children (Brown, Shifrin, & Hill, 2015). Previous guidelines suggested prohibiting screen time for children under 2 and limiting it to 2 h or less for children over 2 (American Academy of Pediatrics, 2013). Under the current AAP policy, it is acknowledged that children are growing up “in a world where ‘screen time’ is becoming simply ‘time’,” and parents are encouraged to use media jointly with their children, model responsible media use, and set limits based on the child's individual needs (Brown et al., 2015).

Despite the growing consensus that new interactive technologies offer inherently different opportunities for children than more traditional platforms, we do not have a thorough understanding of just how these experiences differ. While children and media scholars have begun to investigate the differential effects of interactive platforms such as computers and touchscreens versus traditional video platforms on child learning, the body of research is small and findings are mixed (Lauricella, Pempek, Barr, & Calvert, 2010; Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009; Zack, Gerhardstein, Meltzoff, & Barr, 2013).

Much of the research targeted toward learning from interactive media has focused on literacy outcomes, like story comprehension, by comparing e-books to traditional print books (Jones & Brown, 2011; Krcmar & Cingel, 2014; Lauricella, Barr, & Calvert, 2014). When considered together, the findings are inconclusive. For example, Krcmar and Cingel (2014) found that, in a joint parent-child reading situation, preschool-aged children showed significantly greater story comprehension from a traditional storybook compared to an e-book. However, in a similar study, Lauricella et al. (2014) found no difference in story comprehension between a traditional storybook and an interactive computer storybook. Across these and similar studies, there has not been any clear pattern of evidence demonstrating enhanced literacy learning from digital technology compared to traditional platforms.

Beyond the small body of research on literacy learning from digital media, even less has been done in other areas of education. In contrast to literacy, there is reason to believe that STEM concepts might lend themselves more easily to newer media technology platforms. Science and math skills are typically taught in more interactive ways than literacy by utilizing, for example, experiential methods (Carver, 1996). Thus, the affordances of interactive technologies might be particularly helpful for learning science and math concepts via media. Encouragingly, Huber and colleagues (2016) recently demonstrated that preschool-aged children were able to learn how to complete a problem solving task on a touchscreen device and transfer that learning to a 3D physical context. Problem solving is considered a building block of STEM, so this points to the promise of STEM learning from interactive technologies. While this study compared touchscreen learning to tactile, three-dimensional learning, it did not compare touchscreen learning to learning from more traditional, non-interactive media platforms. The present study seeks to address this gap in our understanding.

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[1] We define an interactive technology as one that invites the child to physically manipulate the platform in order to advance the action and is contingent to the child's manipulations. Because tablets and touchscreens are by far the most ubiquitous platforms in American households that meet these criteria, we will focus our discussion on these platforms.

3. Theoretical framework

3.1. How children learn from interactive technology

There are several educational and developmental theories that suggest that physical experience is an integral part of learning. For example, experiential learning theory (Kolb, 2014; Kolb & Fry, 1974) is a learner-centered model of education, where learning is defined as a cyclical process of action and reflection. Distinct from more traditional rote or didactic learning, in which the learner plays a passive role, experiential learning is the process of learning through experience, or learning by doing. Likewise, educational practices that are based on experiential learning theory encourage hands-on activities that allow learners to directly manipulate and engage with the materials and reflect on that experience (Carver, 1996). Recently, scholars have drawn on experiential learning theory when investigating game-based learning and serious games (De Freitas & Oliver, 2006; Kiili, 2005; Ruben, 1999). Kiili (2005) argues that games provide a unique opportunity to utilize educational theory in a fun and engaging context. Therefore, as long as apps and interactive technologies are well designed from an educational standpoint, they should also allow for more experiential learning than less hands-on platforms.

Additionally, theories of embodiment (Clark, 2008; Varela, Thompson, & Rosch, 1992) suggest that our physical bodies both aid and constrain how we interact with and reason about phenomena in the world. That is, our ideas, thoughts, and understandings are shaped by our prior and ongoing physical experiences. Embodiment has been a useful framework for understanding mathematics learning and reasoning (Kontra, Lyons, Fischer, & Beilock, 2015; Trninic & Abrahamson, 2012). For example, Kontra et al. (2015) found that college students who had a brief physical experience with science content performed better on a written quiz about that content than their peers who did not have the physical experience. The authors explain that the activation of sensorimotor brain systems supports more efficient learning, and they argue that science concepts are particularly well suited for learning via physical experience. Extending this idea of learning via physical experience, scholars have begun to examine the ways in which interactions with touchscreens may impact learning. Specifically, researchers are interested in how learners organize themselves and use their bodies when interacting with touchscreens (Fleck et al., 2009; Marshall, 2007; Marshall et al., 2009; Piper, Friedman, & Hollan, 2012; Rick, Rogers, Haig, & Yuill, 2009).

In a similar vein, research on child development emphasizes that children are better able to learn science and math concepts when they are presented in multiple modalities (Bosse, Jacobs, & Anderson, 2009; Gelman, Brenneman, Macdonald, & Román, 2009; National Science Teachers Association, 2014). Technology is one way to add the haptic modality to a learning experience. Indeed, prior research suggests that haptic feedback is particularly useful for learning STEM concepts because it provides more of a “real-life” experience and a more immersive learning environment (Hamza-Lup & Stanescu, 2010; Han & Black, 2011; Minogue & Jones, 2006).

In summary, major learning theories suggest that interactive media can serve as a useful platform for children to learn and practice new skills. Building on previous work (e.g., Fisch, 2003, 2009; Kirkorian & Pempek, 2013), we hypothesize that children who engage with an educational game that teaches measuring, through either an interactive or non-interactive experience, will show evidence of learning above and beyond that of children in a baseline context (*H1*). Moreover, we contend that children who engage with the game in an interactive way will exhibit greater evidence of learning than peers who engage with a non-interactive version of the game (*H2*). To address these hypotheses, we have utilized a between-subjects experimental design to investigate the role of interactivity in children's learning of a foundational STEM skill.

4. Method

4.1. Participants

Efforts were made to include participants from a variety of geographic areas in the United States in order to increase generalizability. Thus, participants were recruited in one of three ways. Forty-three percent of participants ($N = 27$) were recruited through a database of families in the Chicago area that had opted to receive research participation notices. Thirty-eight percent were recruited from a similar database in the New York City area. The remaining 18% were recruited from a preschool classroom in a small city outside of Los Angeles. All recruitment and consent documents were approved by the host university's institutional review board.

A total of 63 preschool-aged children participated in the study. Of the 63 children whose parents granted consent, two were unable to complete the testing session, and one was removed due to experimenter error. The final sample of 60 children (42% male) ranged in age from 45 to 68 months ($M = 58.06$, $SD = 7.00$). Participants represented a fairly diverse sample in terms of both race/ethnicity and socioeconomic status. Table 1 presents demographic information of the sample.

4.2. Procedure

Participants were randomly assigned to one of three conditions. In all three conditions, the stimulus material was displayed on a touchscreen tablet (Microsoft Surface 2). Participants in the interactive condition ($N = 20$) played an interactive game that teaches

Table 1
Sample demographics.

Variable	Min.	Max.	Mean (*SD*)	Percent
Child's age in months	45	68	58.06 (7.00)	
Child's sex				
Males				41.7
Females				58.3
Child race/ethnicity				
White				51.7
Black				11.7
Hispanic				15.0
Asian/Pacific islander				8.3
Multi-racial/other				13.3
Parent's relationship to child				
Mother				73.3
Father				13.3
Other				13.3
Parent's age in years	21	48	36.25 (6.89)	
Parent's education				
High school/GED				1.7
Some college				10.0
Bachelor's degree				26.7
Master's degree				43.3
Advanced degree				6.7
Household income				
Less than 10,000				5
10,000–14,999				1.7
15,000–24,999				10.0
25,000–49,999				6.7
50,000–99,999				20.0
100,000–149,999				18.3
150,000–199,999				3.3
200,000 or more				20.0

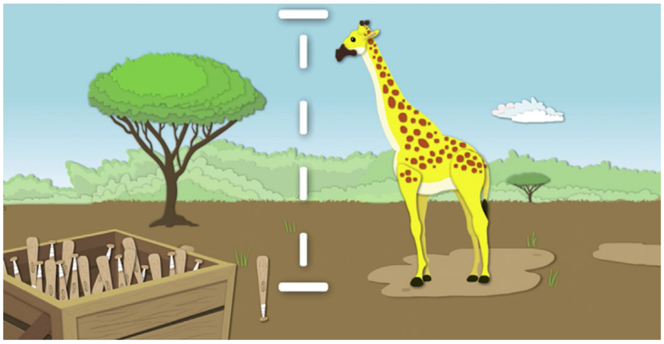

Fig. 1. Screen shot from stimulus game Measure That Animal.

approximate measuring, a STEM-related concept that is considered fundamental to math and science learning (Solomon, Vasilyeva, Huttenlocher, & Levine, 2015; Sophian, 2007). Participants in the non-interactive video condition ($N = 20$) viewed a video recorded version of the game that was otherwise identical in content to the interactive game. Participants in the control condition ($N = 20$) played a non-STEM related game that was otherwise very similar to the target stimulus in that it used the same character and similar interactive features.

A trained researcher conducted the experiment with each individual child participant in a quiet location. The researcher obtained informed consent from all parents and verbal assent from each child participant before beginning the study. As a warm up, the researcher engaged the child in a few activities to assess the child's verbal ability, counting, and familiarity with certain media characters. Immediately following this warm-up, the child played or viewed their randomly assigned stimulus on a tablet computer. Following exposure, children completed assessments of enjoyment and character appeal before, finally, completing a knowledge transfer task. Parents of participating children completed an online survey about the child's media habits, general behavior, and family demographics. Parents did not intervene during the child's participation. All testing sessions were video and audio recorded so that trained coders could score each of the assessments.

4.3. *Stimuli*

The target stimulus was an online game created by Sesame Workshop entitled "Measure That Animal," which is designed to teach young children about measuring. This was deemed an appropriate STEM-related concept to be used as the target skill in this study because understanding both standard and non-standard measurement units is critical to mathematics and science learning (Sophian, 2007; Wilson & Rowland, 1993). Moreover, measuring is a concept that young American children often find challenging (Lehrer, 2003; National Center for Education Statistics, 2013).

In "Measure That Animal," Murray Monster is introduced as a zookeeper who needs to measure zoo animals, but Murray forgot his measuring tape at home. A basket of household objects (e.g., baseball caps, stinky socks, etc.) appears on the screen beside a novel animal (e.g. gorilla, giraffe, penguin, etc.).[2] Murray asks the player to use the objects to help him measure "how tall" and then "how long" the animal is. For each measuring opportunity, a scaffold line appears to guide the child in understanding the dimensions of height and length (see Fig. 1). Players must drag the correct number of objects to the scaffold line. Each child in the interactive treatment condition played three trials of the game, measuring the length and width of three different animals.

In order to create a video version of this game for the non-interactive treatment condition, researchers used Camtasia Studio to record a screen capture while playing the game. Murray's interactive audio prompts were subsequently decoupled from the screen capture. The result was a video stimulus, where viewers would see and hear content that was identical to the interactive condition, except for the presence of Murray's interactive audio prompts. Participants in the non-interactive condition watched this video version of the game on the touchscreen tablet to maintain fidelity with the interactive condition in terms of the size of the viewing screen and the overall experience. However, the video was not responsive to touch, effectively disabling the interactive component of the touchscreen. Three different versions of the video were created to account for the random order of animals that is presented in the game. They were then rotated to control for potential order effects among the participants.

Participants in the control condition played a similar game, called "Murray Cleans Up," which does not feature any kind of measuring lesson, but is otherwise identical in production quality and style to the target stimulus. In this online game, which is also created by Sesame Workshop, the same character, Murray Monster, is introduced as a zookeeper who needs help washing the zoo animals. He instructs the child to click on different body parts of the animals in order to clean them up. As with the interactive treatment condition, participants in the control group played three trials of the game, washing three different animals.

"Murray Cleans Up" was chosen as the control stimulus because it mirrors the target stimulus in three primary ways. First, the featured character in both games is Murray, a lesser-known Sesame Street character. In both games, Murray is introduced as a zookeeper who needs help with the zoo animals. Since character interaction can have great effects on children's experiences with a program (Calvert, Richards, & Kent, 2014; Gola, Richards, Lauricella, & Calvert, 2013; Hoffner, 1996; Wainwright & Linebarger, 2007), we felt it important to keep the main character consistent across conditions. Second, in both games, children are interacting with animals (either measuring or cleaning them), keeping the secondary characters in the game consistent as well. Third, in both games, the interactive technology works in nearly identical ways, such that children are instructed to help Murray by touching and moving objects in the game to achieve an outcome, either measuring an animal or cleaning an animal.

4.4. *Measures*

4.4.1. *Verbal ability*

The Picture Naming Individual Growth and Development Indicator (Missall & McConnell, 2004) was used as a measure of verbal ability. The Picture Naming task is an expressive vocabulary measure that has been shown to be sensitive to children's development and correlates with other standardized measures of language development and literacy (Missall & McConnell, 2004). To complete the Picture Naming task, each child was presented with flashcards of color pictures of objects (e.g., food, animals, household objects, clothing) and asked to name as many as they can. The number of pictures named correctly in 1 min served as the child's verbal ability score ($M = 19.07$, $SD = 5.86$, $Range = 7$ to 31) (Missall & McConnell, 2004).

4.4.2. *Knowledge transfer*

Because the ability to transfer learning from one context to another is an adaptive skill that develops during early childhood,

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[2] Both the household objects and the animals are randomly selected by the game's internal algorithm.

knowledge transfer tasks are commonly used to assess children's ability to take what they've learned in a mediated context and apply it to a similar real world context (Barr, 2010). Thus, for our dependent measure, we developed a knowledge transfer task modeled after those used by Barr and colleagues (Barr, 2010; Vandewater, Barr, Park, & Lee, 2010; Zack et al., 2009, 2013) to assess children's ability to measure with non-standard units (i.e., the lesson taught in the target stimulus). Children were assessed at three levels: near transfer, medium transfer, and far transfer.

At each level of transfer, the child was asked to use a household item (i.e., Legos, circles, erasers) as a non-standard unit to measure the height and length of the animal or object on the page in front of them. In the near transfer assessment, each child was presented with a color picture of a duck and ten Lego pieces, all of the same size. The picture had an accompanying scaffold line from top-to-bottom to demonstrate the correct direction of measurement. Replicating the language used by Murray in the stimulus, the researcher asked each child to “use the Legos to measure how tall the duck is.” The child was given unlimited time to place the Legos on the paper to measure the duck and to count the Legos in order to answer the researcher's question. Next, the child was shown a second picture of the same duck with the scaffold line drawn from left-to-right. During this trial, the child was asked to “use the Legos to measure how long the duck is.” This task was considered near transfer because it was very similar to the stimulus in that the child measured an animal and was guided by a scaffold line.

In the medium transfer assessment, the child saw a color picture of a dog without any scaffold lines and was asked to measure how tall and how long the dog was using ten plastic poker chips (called circles). The removal of the scaffolding line made this task somewhat more difficult than the near transfer task, but the use of an animal kept some consistency with the stimulus. Finally, in the far transfer assessment, the child saw a color picture of a robot and was asked to measure how tall and how long the robot was using ten large erasers. This was the most challenging task because neither of the context clues from the stimulus were present; there was no scaffold line, and the child measured a robot rather than an animal. See Fig. 2 for sample images of each transfer level.

4.4.2.1. Coding. The child's performance was scored on a four-point rubric designed to capture various levels of understanding and ability. Dichotomous scores (yes = 1 or no = 0) were given for each of the following: (1) *attempt to measure* (i.e., Did the child demonstrate understanding of what it means to measure by placing the measuring objects in a straight line?); (2) *correct measurement direction* (i.e., Did the child measure either height or length appropriately?); (3) *correct* placement (i.e., Did the child correctly place non-standard units on the page (e.g., either edge-to-edge or close together but not overlapping) when measuring?); (4) *counting* (i.e., Did the child accurately count the number of non-standard units placed on the page, regardless of the number of non-standard units needed to achieve a correct answer?). At each level of the transfer task (near, medium, and far), a child could receive a maximum score of 8 (i.e., 4 points for each dimension). Two trained coders, blind to condition, scored each of these tasks (Krippendorff's α°=°0.91). Scores at each level of difficulty were averaged to obtain an overall composite score for transfer of knowledge.

5. Results

5.1. Analysis plan

Age, gender, verbal ability, parent's education, and household income were tested as potential covariates. Age was the only significant predictor of performance on the knowledge transfer task and was, therefore, included in all subsequent analyses as a covariate. Analyses of covariance (ANCOVA) were conducted to test the hypotheses that participants in both treatment groups would learn more from their experiences than participants in the control condition (*H1*) and that participants in the interactive condition would learn best from their unique experience (*H2*).

5.2. Transfer of knowledge

The first ANCOVA model tested the effect of condition on participants' overall composite score on the transfer task while controlling for the effect of age. There was a statistically significant difference in overall transfer score between the conditions, $F(2,56) = 4.58$, p°=°0.01, partial η^{2}°=°0.14 (see Table 2). Post-hoc comparisons revealed that participants in the interactive and non-interactive conditions scored higher on the overall composite score than their peers in the control group (p°=°0.03 and p°=°0.01, respectively). However, there was no statistically significant difference between participants in the interactive and non-interactive conditions (p°=°0.52).

Since overall performance decreased as the transfer task became more difficult, we used analyses of covariance to assess performance at each level of transfer.

5.2.1. Near transfer

Participants were asked to measure the height and length of a picture of a duck on a scaffold line using Lego pieces. There was a statistically significant difference between conditions, such that $F(2,56) = 3.39$, p°=°0.04, partial η^{2}°=°0.11. Pair-wise comparisons revealed that participants in the interactive condition scored higher on this task than children in the control condition (p°=°0.02). There was a marginally significant difference between participants in the non-interactive condition and their peers in the control condition, (p°=°0.06). Lastly, there was no difference in performance between participants in the interactive condition and their counterparts in the non-interactive condition (p°=°0.58) (see Table 2).

5.2.2. Medium transfer

Participants were asked to measure the height and length of a picture of a dog using plastic circles with no scaffold line present. There was a statistically significant difference between conditions,

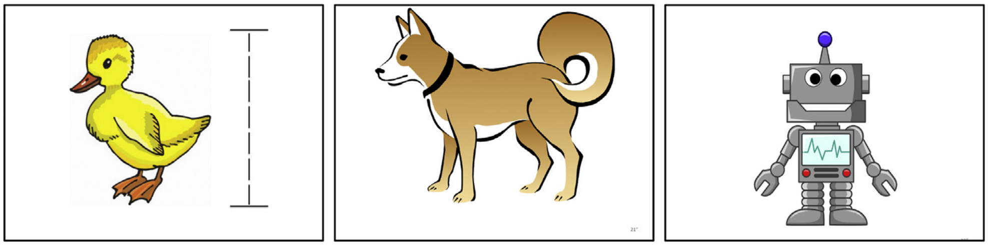

Fig. 2. Near, medium, and far transfer images.

Table 2
Covariate adjusted group means across levels of transfer.

	Interactive ($N = 20$)	Non-interactive ($N = 20$)	Control ($N = 20$)	All ($N = 60$)
	Adjusted mean (*SE*)	Adjusted mean (*SE*)	Adjusted mean (*SE*)	*M* (*SD*)
Overall transfer	18.46 (0.86)*	19.25 (0.86)**	15.75 (0.86)	17.82 (4.23)
Near transfer	6.92 (0.28)*	6.70 (0.28)$^+$	5.93 (0.28)	6.52 (1.38)
Medium transfer	6.07 (0.32)*	6.40 (0.32)**	5.13 (0.32)	5.87 (1.56)
Far transfer	5.47 (0.41)	6.15 (0.41)*	4.69 (0.41)	5.43 (1.91)

$^+ = p < 0.10$, $^*p < 0.05$, $^{**}p < 0.01$.
Note: Table presents estimates of group means controlling for age. Differences are compared to the control group.

such that $F(2,56) = 4.30$, p°=°0.02, partial η^{2}°=°0.13. Pair-wise comparisons revealed that participants in both the interactive and non-interactive conditions scored higher on this measuring task than those in the control condition (p°=°0.04 and p°=°0.01, respectively). Again, there was no difference in performance between participants in the interactive and non-interactive conditions (p°=°0.47) (see Table 2).

5.2.3. *Far transfer*

Participants were asked to measure the height and length of a picture of a robot using large erasers without a scaffold line. There was a statistically significant difference in scores between the conditions, such that $F(2,56) = 3.24$, p°=°0.04, partial η^{2}°=°0.10. Interestingly, we found a pattern of results opposite to those found in the near transfer situation. Pair-wise comparisons revealed that participants in the non-interactive, rather than interactive, condition scored higher on this measuring task than those in the control condition (p°=°0.01 and p°=°0.18, respectively). There was no difference in performance between participants in the interactive and non-interactive conditions (p°=°0.24) (see Table 2).

6. Discussion

Using a between subjects experimental design, we tested whether preschool children could learn a foundational STEM skill via an educational app (*H1*) and whether the interactive features of that technology would uniquely support learning (*H2*). Our findings suggest that child-targeted educational media can support preschoolers' learning of a novel measurement skill. Additionally, we found that children's performance on the transfer task varied as a function of the interactive media experience in different ways depending on the difficulty of the task. These two findings have implications for future studies of children's learning from media, as well as the production of high-quality educational media experiences for preschool children.

Our first hypothesis was supported; children in both treatment groups scored significantly higher that their peers in the control condition when the tasks were examined in aggregate. This is consistent with previous research demonstrating that preschoolers are capable of learning from mediated experiences that are both educational and of high quality (e.g., Anderson et al., 2000; Thakkar, Garrison, & Christakis, 2006). Furthermore, these findings provide evidence that preschoolers can learn from interactive gaming experiences on touchscreen devices. This is an important contribution to a small but growing body of literature on children's learning from new technologies. Because of the great appeal of touchscreens and mobile devices for children, there has been a strong push to use these interactive technologies to support informal learning of STEM concepts starting at very young ages. Yet, little conclusive evidence has been shown in support of this idea. Our findings provide strong empirical support for the assertion that young children can learn foundational STEM skills from new media technologies and apply them to non-mediated contexts.

While it is important to demonstrate that children can learn from mediated experiences, an additional goal of this study was to examine the unique effect of interactivity on children's learning, as few studies have directly compared interactive and non-interactive mediated experiences. While there was no difference in performance between participants in the interactive and non-interactive conditions for overall transfer, follow-up analyses, which divided the composite score based on level of difficulty of the transfer task, resulted in an interesting pattern of findings. For near transfer, where the task was most closely aligned with the content of the learning experience, participants in the interactive condition scored higher than children in the control group (see Table 2). At the medium level of transfer, where the scaffold lines were removed, participants in both the interactive and non-interactive conditions score higher than participants in the control group. At the farthest level of transfer, where the task was most different from the stimulus material in that the scaffold lines were removed and the child was asked to measure a novel object, participants in the non-interactive condition performed better than participants in the control condition, while those in the interactive condition did not. These findings suggest that interactivity may be most helpful in contexts that are highly similar to the original learning context, but may not have a lasting effect once the transfer task becomes too far removed from the original learning context.

When attempting to understand how young children learn from media, it is important to consider the cognitive effort required to comprehend the information being presented in 2D form (video or touchscreen) as well as the working memory capacity needed to successfully complete these tasks (see the discussion of children's cognitive capacity in Fisch, 2004). Previous work has supported cognitive load theory as an underlying mechanism in the struggles that infants face when processing 2D content (e.g., Lauricella et al., 2010; Zack et al., 2009, 2013). Cognitive load is often a consequence of increased emphasis on the peripheral elements of instruction (Paas, Renkl, & Sweller, 2003; Sweller, 1988). Correspondingly, Fisch (2004) argues that effective instructional material may facilitate learning by directing cognitive resources toward relevant learning activities rather than elements of the material that might be distracting.

This study is among the first to examine the unique impact of interactivity on children's learning. Our findings suggest that, unlike identical non-interactive experiences, interactivity may place undue burdens on young children's cognitive capabilities, particularly when the child must transfer learning to novel situations (i.e., far transfer). It could be that children in the interactive condition devoted a significant portion of their limited working memory resources to the physical requirements of manipulating the touchscreen during game play, negatively impacting their ability to attend to the general concept of measuring. Therefore, when the transfer task was very similar to the learning context, they excelled at the task because they were able to mimic the physical action that they focused on during gameplay. However, in far transfer, where they had to apply the very specific skill taught in the game to dissimilar task, these participants were unable to apply the more general measuring concept as easily. Presumably, children in the non-interactive condition, who did not have to focus on the physical manipulation of the game, were able to devote more working memory resources to absorbing the overall concept of measuring. Therefore, when the task became a bit more difficult and more removed from the exact experience they viewed, these participants were still able to apply what they learned from viewing the educational material.

Alternatively, it could be that interacting with a touchscreen increases the salience of the screen itself, thus binding the educational material to the on-screen context. This idea is supported by DeLoache's dual representation theory (DeLoache, 1991, 2000), which suggests that increasing the physical salience of a model makes it more difficult for young children to appreciate its symbolic representation. DeLoache (2000) found that decreasing the physical salience of a scale model by placing it behind a window made it easier for young children to understand the symbolic representation of the model and use that understanding to successfully complete a memory retrieval task. Yet, increasing the physical salience of the model by having children manipulate it in their hands made it more difficult for the children to utilize the model's symbolic representation in the memory retrieval task.

In the current study, we may have effectively increased the physical salience of the tablet by encouraging children to touch and manipulate it with their hands, making it more difficult for them to think of the tablet as a learning tool and apply the presented information to new contexts. It is important to note that the transfer tasks increased in difficulty in two ways. First, while scaffold lines were present in the near transfer task, they were removed for both the medium and far transfer tasks. Second, contextual change also occurred over the three transfer tasks. During the near and medium transfer tasks, the participants were asked to measure pictures of animals, maintaining consistency with the zoo theme present in the stimulus. For the far transfer task, however, the context changed in that participants were required to measure a non-animal. According to this theory of screen salience, it could be that for participants in the interactive condition, their learning was so bound to the on-screen context that they struggled to apply the information to a dissimilar, non-animal context.

6.1. *Limitations*

This study is not without limitations. First, because the transfer tasks increased in difficulty in two ways, context and scaffolding support, it is difficult to determine which factors may have caused the observed changes in performance across levels of difficulty. Second, these were highly controlled one-time exposures, in which participants played or watched the game for a relatively brief period of time. Previous research has demonstrated that young children learn through repetition and often play games and watch media content repeatedly (Crawley et al., 2002; Mares, 2006). Therefore, it is unclear how learning may differ when exposure occurs in a more naturalistic setting. Third, the stimulus games were originally developed for a desktop or laptop computer, rather than a touchscreen device. As a result, the manual manipulation was a bit less intuitive than in apps that are designed specifically for touchscreens. This may have contributed to an increase in cognitive load beyond what would have occurred in a more streamlined app. Future research aims to address these concerns.

6.2. *Practical implications*

Given the United States' current standings in math and science performance (PISA, 2012), and the fact that the quality of early learning experiences predicts later educational attainment, it has become increasingly important to find ways to encourage STEM learning in the early years. Opportunities for early STEM learning are often lacking in preschool classroom curricula, but there are opportunities for young children to engage in informal STEM learning outside of the traditional classroom setting. Mobile games and educational apps that feature STEM content are becoming more widely available. When well designed, this technology can offer meaningful opportunities for young children to engage with STEM content, learn through exploration, and practice newly acquired skills.

Despite this established potential, there is little empirical evidence to suggest that these technologies promote learning. Moreover, the context in which this learning occurs is largely unknown. This study contributes to our understanding of the relationship between interactivity and learning by demonstrating that educational technology, whether interactive or non-interactive, can be a successful tool for teaching preschool-aged children STEM-related concepts and skills.

Fueled by the potential of educational technology to support science and math achievement, there has been a strong push by federal and state governments to bring interactive technologies into all classrooms (US Department of Education, 2010). School districts around the country are spending millions of dollars to equip early childhood classrooms with touchscreen tablets (Jones, 2013). However, the results from this study suggest that the contribution of interactivity to learning should not be overstated given the absence of additional evidence. It may be that more traditional experiences, like those provided by video technology, can, in certain contexts, be just as useful in supporting STEM learning for preschoolers.

On the other hand, the patterns of results at each transfer level do suggest that interactivity may support learning under particular circumstances. Our findings suggest that interactivity is most helpful to young children when the learning context very closely mirrors the real-world setting. This is useful information for media producers, who may want to strategize by focusing their interactive efforts on skills and topics that have very similar transfer goals, while reserving broader conceptual lessons for more traditional media platforms. Likewise, parents and educators can use this information in choosing appropriate apps and technologies for their children, considering specific skills or goals for learning.

7. Conclusions and considerations for future research

There is still much to discover with respect to the specific attributes of new digital technologies that are most critical to supporting children's learning. Many scholars and industry experts argue that the interactivity of these technologies is key, but our findings suggest that interactivity may help under certain circumstances and hinder in others. Future research should seek to discover the mechanisms by which interactivity influences learning, so that we might achieve a better, more nuanced understanding of the boundaries of the relationship between interactivity and learning from digital media. With or without the interactive component, it does seem that well-designed educational media can support foundational STEM learning for young children. When used in tandem with other forms of education and instruction, digital technologies may in fact contribute to children's academic performance in the areas of science, technology, engineering, and mathematics.

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