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Improving low-income preschoolers mathematics achievement with Math Shelf, a preschool tablet computer curriculum

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ABSTRACT

Low-income preschoolers begin Kindergarten behind their middle and high-income peers in mathematics, and these achievement differences grow as they progress through school. Technology can provide cost effective and scalable solutions to improve young children's mathematics outcomes (Levin, Glass, & Meister, 1987; Slavin & Lake, 2008). The aim of this study was to test Math Shelf, a tablet computer curriculum designed to improve at risk preschoolers' mathematics performance. Two hundred and seventy-three children participated with intervention students playing Math Shelf on tablets for 15 weeks, while comparison students participated in their regular classroom mathematics curriculum. At the end of the intervention, there was a significant and sizable effect on the mathematics posttest for *Math Shelf* students (Cohen's $d = 1.09$, $p < .001$). *Math Shelf* students learned approximately one year more mathematics than control students. Our results suggest that teachers can significantly increase low-income preschoolers' mathematics knowledge in a relatively short amount of time by implementing evidenced-based tablet software.

1. Introduction

A substantial number of children—typically those living in low-income communities—start kindergarten with inadequate mathematics knowledge (Griffin, 2002; Jordan, 2007; Siegler, 2009; Starkey & Klein, 2008). Effective and scalable mathematics interventions for economically disadvantaged preschoolers are needed because math knowledge measured at school entry predicts both secondary school academic success and future economic opportunity (Duncan et al., 2007; Geary, Hoard, Nugent, & Bailey, 2013; Watts, Duncan, Siegler, & Davis-Kean, 2014). This study tested Math Shelf, a tablet computer curriculum designed to improve at risk preschoolers' mathematics performance.

1.1. *Tablets in preschools*

With the introduction of the iPad, tablet computers have rapidly found their way into American preschools (Neumann & Neumann, 2014). Fifty-five percent of preschool teachers report having at least one tablet in their classroom (Wartella, 2015). Preschoolers find tablets highly motivating, and learn how to use them almost immediately (Boddum, 2013; Flewitt, Messer, & Kucirkova, 2014). Tablets touch screens allow children with limited fine motor skills to operate these devices with their fingers, thereby eliminating the more complex hand–eye coordination required to use a keyboard and mouse (Cooper, 2005). Moreover, tablets are lightweight and mobile, permitting children to play with them indoors and outdoors (Neumann & Neumann, 2014). With thousands of learning games designed specifically for three to five year olds, young children have become frequent tablet users (Neumann & Neumann, 2014; Schneider et al., 2012; Tahnk, 2011).

Qualitative research, media accounts, and wide use demonstrate that preschoolers find tablets highly engaging (Clark & Luckin, 2013; Common Sense Media, 2013; Peckham, 2013). Less studied, however, are the educational benefits of tablets in preschool classrooms. Thus, early education researchers are calling for studies that examine the potential of tablets to improve young children's academic outcomes (Falloon, 2014; Kucirkova, 2014; Neumann & Neumann, 2014; Orrin & Olcese, 2011).

In this study we evaluate Math Shelf, a preschool tablet mathematics curriculum. The software integrated the mathematics instructional materials and sequence created by Maria Montessori, developmental mathematics theory, and mathematics content

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from evidenced-based early interventions.

1.2. Montessori mathematics instruction

Math Shelf's content and instruction are influenced by Maria Montessori's mathematics materials and instructional sequence. Dr. Montessorri created dozens of mathematics “jobs” that confer learning through action to develop low-income children's understanding of number (Lillard, 2005; Piaget, 1970). Each Montessori “job” communicates clear goals, provides for self-assessment and corrective feedback, and uses manipulatives to learn by doing (Montessori, 1967). Theoretically, the Montessori approach embodies many features known to enhance young children's learning and development (Glenberg, Jaworski, Rischal, & Levin, 2007; Lillard, 2005, 2011) including the matching of learning materials to each child's individual skill level, allowing for choice and autonomy, and engendering feelings of independence and control (Bransford, Brown, & Cocking, 2000).

Montessori's early mathematics curriculum teaches subitizing, one-to-one and cardinal counting, quantity and numeral sequencing, matching quantities to numerals, number magnitude, place value, number decomposition, and operations. Moreover, preschool children find Montessori “jobs” highly motivating (Lillard, 2005). Compared to traditional school, children in Montessori classrooms exhibit higher levels of feeling alert and energetic, enjoyment and interest, and flow (Rathunde & Csikszentmihalyi, 2005).

1.3. Developmental mathematics theory

Infants are born with the capacity to represent number in a nonverbal manner (Feigenson & Carey, 2003; Mix, Huttenlocher, & Levine, 2002). They can identify small quantities (i.e., less than three), approximate larger number sets (Berch, 2005; Mix et al., 2002), and recognize transformations of small sets (Wynn, 1992). These preverbal number knowledge skills appear to develop without instruction (Feigenson, Dehaene, & Spelke, 2004; Jordan & Levine, 2009).

As infants become toddlers they acquire language. Through interactions with parents and caregivers young children come to understand that numbers represent quantities and have magnitudes, that counting involves one-to-one correspondence and fixed order, and that sets can be transformed through addition and subtraction (Gelman & Gallistel, 1978; Griffin, 2004). Unlike preverbal number knowledge, this symbolic number knowledge is developed through interactions with adults (Feigenson et al., 2004; Jordan & Levine, 2009; Starkey & Klein, 2008).

For young children to perform the formal mathematics required in school, they must be able to link their understanding of numbers to symbolic representations (Carpenter, Hiebert, & Moser, 1983; Gersten, Jordan, & Flojo, 2005). While most children enter school with the symbolic number skills necessary for mathematics success (Ginsburg, Lee, & Boyd, 2008), a large number of children living in low-income communities begin kindergarten without these competencies (Griffin, 2002; Jordan, 2007; Siegler, 2009).

1.4. Evidenced-based early mathematics interventions

To develop low-income preschoolers' symbolic number understanding, researchers have created a variety of effective early mathematics interventions (Baroody, Eiland, & Thompson, 2009; Chard et al., 2008; Griffin, Case, & Siegler, 1994; Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012; Ramani & Siegler, 2008). The majority of these interventions teach a similar set of mathematics skills (e.g., subitizing, one-to-one counting, the cardinal principle, numeral identification, matching quantities to numerals, numeral sequencing, place value, and number magnitude), using manipulatives, board games, number lines, number tiles, and a variety of short high-interest activities.

Ramani and Siegler (2008) intervention had four year olds play board games with consecutively numbered, linearly arranged, equal-size spaces. These children performed statistically significantly better on number line estimation tasks, number identification, and number magnitude assessments than children that played an identical board game, but with colors instead of numbers. Baroody et al.'s (2009) intervention improved low-income preschoolers' number knowledge by using manipulatives to teach verbal counting, object counting, and numeral-quantity relationships. Nancy Jordan and colleagues implemented numerical board games, number line activities, and created high interest place value games to advance low-income children's number knowledge (Dyson, Jordan, & Glutting, 2013; Jordan et al., 2012). Finally, Sharon Griffin's effective early number interventions (1994, 2004) expose preschoolers to quantities, counting, and formal symbols, then provide multiple opportunities for constructing relationships among these three ways to understand number.

1.5. Math Shelf: a preschool tablet mathematics curriculum

Math Shelf is an iPad preschool mathematics curriculum based on Maria Montessori's mathematics materials and sequence, developmental theory, and evidenced-based early number interventions. Math Shelf activities foster engagement through scaffolded short-term mathematics goals that challenge each student. In order to match math activities to each child's skill level, Math Shelf students take a placement test. The results determine where in the curriculum sequence each child begins (see Method section for more detail).

Beginning games in Math Shelf teach the quantities 1 to 3 focusing on subitizing, one-to-one counting, matching different quantity representations, and counting to apply the cardinal principle (see Fig. 1). Two games teach these skills (16 activities per game) using three different virtual manipulatives (i.e., digital fingers, Montessori colored beads, and Montessori counters/dot cards), for a total of 32 unique activities.

Next, three games teach subitizing, counting to apply the cardinal principle, numeral identification, matching numerals to quantities, comparing quantities, and sequencing numerals and quantities from 1 to 6. Each game includes 15 unique activities, and employs a different virtual manipulative (i.e., Montessori number rods, colored beads, and counters/dot cards), along with digital Montessori numeral tiles (see Fig. 2).

Children who demonstrate mastery of numerals and collections 1 to 6 (i.e., completing 75 unique activities at an 80% correct level), practice the same mathematics skills, but with numerals and quantities from 1 to 9 (see Fig. 3).

After playing 109 different Math Shelf games, young children recognize that the numerals 1 to 9 represent quantities and have magnitudes; they understand successive numbers and can order numerals and quantities from least to greatest; they count and apply the cardinal principle; and they subitize different collection representations to 9. Instruction proceeds by using children's subitizing skills to teach counting on and addition facts within 6 (Fig. 4).

Finally, Math Shelf teaches place value. Place value games employ the colored and golden bead manipulatives and the Montessori hundreds' board. First, the quantities and numerals from 10 to 20 are taught (Fig. 5). Then, children learn the quantities and numerals from 20 to 100. In place value activities children compose and decompose numbers into tens and units. They also use the

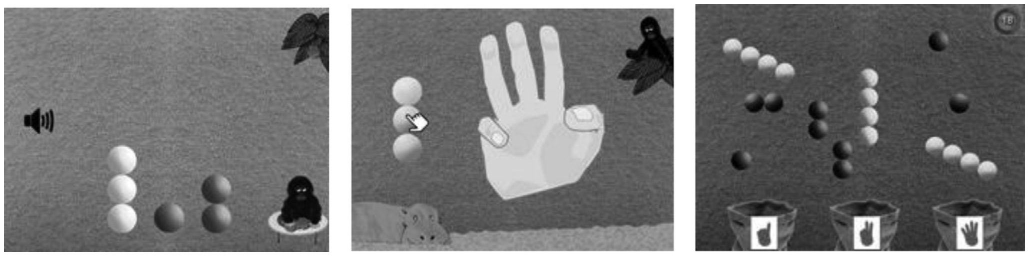

Fig. 1. Colored Beads 1 to 3. Panel 1 poses a series of questions that ask the child to touch the quantity that corresponds to the named number without counting (subitizing). In Panel 2 children practice one-to-one counting bead and finger representations 1 to 3. Panel 3 requires the child to match the bead quantity to the finger representation by sorting.

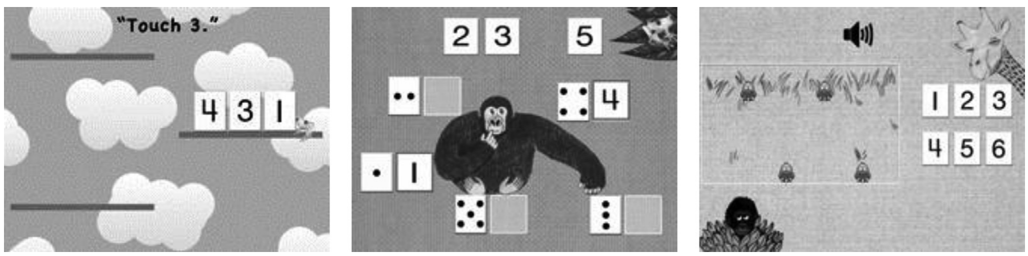

Fig. 2. Dot Cards 1 to 6. Panel 1 teaches numeral identification using a jumping game. Panel 2 requires students to sequence the number cards one to five, then match numbers to dot card quantities. Panel 3 teaches the cardinal principle where children count the animals (in this example ducks), and touch the last number counted.

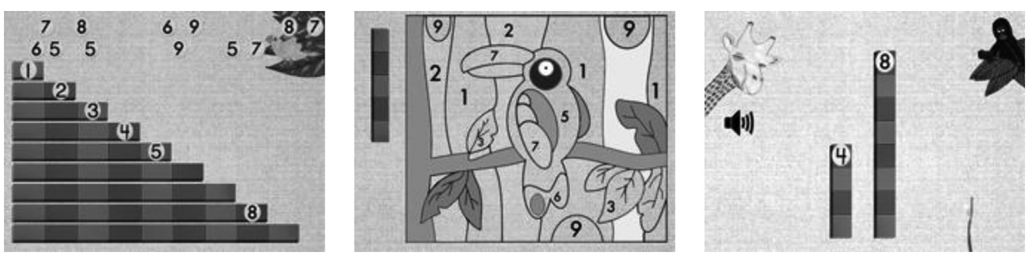

Fig. 3. Number Rods 1 to 9. Panel 1 asks children to sort the number rods least to greatest, then drag the flying numbers to the correct rods. In Panel 2, children match the rod quantity to the number in order to color the picture. Panel 3 has children touch either the smallest or largest number rod. As this activity progresses, children must determine magnitude with only numerals.

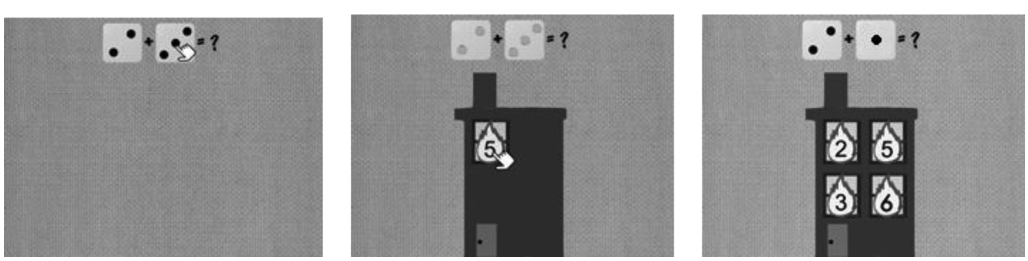

Fig. 4. Addition within 6. Panel 1 builds on children's subitizing knowledge, by teaching them to count on to solve addition problems. In Panel 2, after the child counts on, she is instructed to touch the sum. Panel 3 illustrates the goal of the game (i.e., to solve several problems correctly to put out the different fires).

Montessori ten numeral cards and the unit numeral cards to represent different bead quantities shown.

Math Shelf teaches a wide variety of early number skills in a sequence that provides ample practice and opportunities for children to build flexibility and fluidity with numbers.

2. Material and method

2.1. Participants

Thirteen preschool classrooms were selected from a network of over 300 publically funded preschools serving predominately low-income four year olds in Los Angeles. Ten classrooms were assigned to the intervention with three classrooms assigned to the comparison group. Assignment to intervention and control conditions was conducted based on administrative convenience, and therefore was not randomized. At the pretest date, the sample consisted of 227 students (173 treatment students, and 54 comparison group students). During the posttest date there were 162 students (123 treatment, and 39 comparison participants). The attrition rates were similar to those reported by the preschools the previous year, between 19% and 34%. Students' characteristics are listed in Table 1.

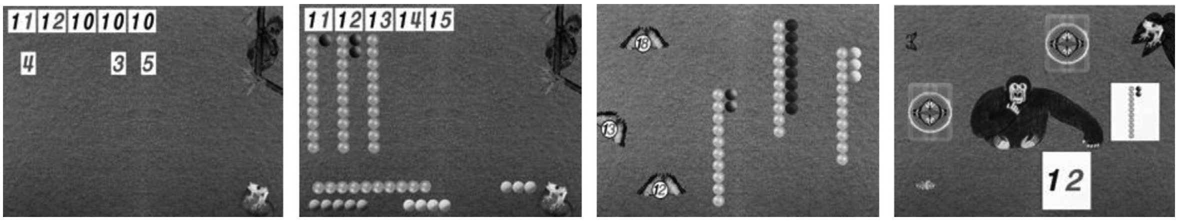

Fig. 5. Place Value 11 to 19. Panel 1 asks children make the numerals 11 to 15 learning that 10 and the unit cards form the teen numerals. In Panel 2, children drag the 10 bars and unit beads under each correct numeral from 11 to 15. Panel 3 is a butterfly game where students match numerals to quantities. Finally, in Panel 4 students first build quantities for teen numerals (not shown), then engage in a memory game matching quantity to numeral.

Table 1
Baseline characteristics.

Baseline characteristics	Intervention ($n = 173$)	Comparison ($n = 54$)	Group difference
Pretest: *M* (*SD*)	17.75 (10.62)	18.07 (10.10)	t(225) = −.20, p = .844
Age in months: *M* (*SD*)	56.1 (7.4)	55.7 (7.2)	
Male: *n* (%)	80 (46%)	25 (46%)	$X^2(1) = .00$, $p = .99$
Race: *n* (%)			$X^2(2) = 3.94$, $p = .14$
Hispanic	146 (84%)	40 (74%)	
Black	24 (14%)	11 (20%)	
White	3 (2%)	3 (6%)	

2.2. Procedures

Children assigned to the intervention played the Math Shelf games on iPads inside their classrooms. Students assigned to the comparison group participated in their regular classroom mathematics curriculum. Intervention teachers created a center with three iPads loaded with the Math Shelf software. The iPads were available for one hour a day from Monday to Thursday. Teachers developed a schedule assigning half of the students in their classroom to play Math Shelf on Monday and Wednesday, and the other half to play on Tuesday and Thursday. On their designated day, children played Math Shelf for 10 min. The study duration was 15 weeks beginning on February 9, 2015 and ending May 22, 2015. During the first two weeks of the intervention a teacher supervised three children playing at a time. Then, students were sent to the Math Shelf iPad center on their scheduled time and day to play independently. Each iPad was connected to headphones to reduce noise disruptions.

As described in the Introduction, Math Shelf is a mobile tablet preschool mathematics curriculum designed based Dr. Maria Montessori's mathematics approach.[1] Along with the Montessori mathematics tasks and sequence, developmental research and evidenced-based early interventions informed the content and sequencing decisions (Baroody et al., 2009; Chard et al., 2008; Clements & Sarama, 2009; Griffin, 2004; Jordan et al., 2012; Jordan & Levine, 2009; Ramani & Siegler, 2008; Siegler, 2009).

Math Shelf transformed five of Maria Montessori's physical manipulatives (colored beads, dot cards/counters, number rods, golden beads, and the hundreds board) into virtual manipulatives. These virtual manipulatives are used in a variety of activities, games, and puzzles to teach subitizing, counting (one-to-one, cardinality, counting on), sequencing quantities, numeral identification, matching numerals and quantities, sequencing numerals, comparing quantities and numerals, addition within 6, and number composition and decomposition to 100.

Prior to conducting this research, Math Shelf was developed and tested for 18 months in a Head Start center in northern California. During development activities were revised repeatedly after observing children play and conducting informal interviews with students and teachers. Math Shelf's numerous design iterations helped to ensure that the content, sequence of skills, and difficulty level of activities were developmentally appropriate before the experiment began.

Lastly, Math Shelf administers a 30-item placement test to determine where in the curriculum sequence to place each child. The placement test is divided into six concepts with five items each: (1) subitizing 1–3, (2) matching numerals to quantities 1–3, (3) counting to apply the cardinal principal 1–6, (4) numeral sequencing 1–9; (5) number magnitude 1–9; (6) number composition and decomposition 11–20. Students that achieve 80 percent mastery on each part of the placement test advance to the next segment. At the point where a student does not achieve 80 percent mastery, the placement test ends, and the student is assigned to the game on his/her level. As expected the majority of children (62 percent) started the intervention playing the 1–3 games. Twenty-eight percent of treatment children (49 students) begin playing the 1–6 games. Five percent of treatment children (9 students) started playing the 1–9 games. The remaining eight children began with the addition within 6 games. Of the 8 children that began the intervention playing the addition within 6 games, all completed all games during week 8 of the study. These children were instructed to select the games and activities they enjoyed most and replay them during the remainder of the intervention.

2.3. Test administration

Employees from the Los Angeles Universal Preschools tested all children individually on an iPad number sense assessment that provided audio and visual instructions. All children were pretested between December 8, 2014 and December 19, 2014, and post-tested between May 25, 2015 and June 5, 2015. Test administration scripts were strictly followed.

2.4. Measures

A 44-item iPad early mathematics assessment was developed for the study. The dependent measure included constructs that

[1] © Math Shelf was designed and created by John Schacter, Ph.D.

assessed recommended goals by numerous early education mathematics researchers. The assessment included numeral identification and quantity discrimination measures studied by Lee, Lembke, Moore, Ginsburg, and Pappas (2007), and Jordan et al. (2012). The iPad assessment also incorporated number-object correspondence, and comparing quantity tasks created by Malofeeva, Day, Saco, Young, and Ciancio (2004) as part of their early mathematics assessment for Head Start preschoolers. Finally, the iPad early mathematics test employed numeral sequencing items similar to those in Seethaler and Fuchs (2010) early education mathematics number knowledge battery. The untimed assessment took children approximately five minutes to complete. Test-retest reliability was collected on a sample of 30 students (average age 4 years 5 months) who took the test seven days apart in a Head Start center in northern California. The test-retest reliability intra-class correlation was .93. The assessment tested the following concepts.

2.4.1. Quantity discrimination (6 items)

Students were presented with four random numerals (ranging from 1 to 10), and asked to touch the largest numeral. All children received the same four random numerals in the same order. The problems were as follows: (a) 1, 3, 7, 4; (b) 8, 2, 9, 5; (c) 2, 10, 3, 6; (d) 4, 2, 5, 1; (e) 8, 4, 3, 6; and (f) 7, 3, 6, 10. Clarke and Shinn (2004) reported test-retest reliability for quantity discrimination measures of .85, and predictive validity of .79 with the Woodcock-Johnson spring first grade Applied Problems subtest (Woodcock & Johnson, 1989).

2.4.2. Numeral identification (6 items)

Four numerals from 1 to 10 were displayed, and students were instructed to touch one of the numerals. The four numerals were presented in random order with correct answers appearing in different positions each time. Lee et al. (2007) reported Cronbach alpha coefficients of .88, and concurrent criterion validity of .59 with the Test of Early Mathematics Achievement-3 (Ginsburg & Baroody, 2003) for numeral identification tasks. Clarke and Shinn (2004) documented predictive validity of .68 with the Woodcock-Johnson spring first-grade Applied Problems subtest (Woodcock & Johnson, 1989).

2.4.3. Numeral sequencing (9 items)

Children were instructed to sequence the numerals from 1–9. Seethaler and Fuchs (2010) employed a similar numeral sequencing task as part of their number sense battery. Reliability was .70 with predictive validity of .67 for the total math score in first grade on the Iowa Test of Basic Skills.

2.4.4. Cardinal principle (5 items)

This series of items assessed the child's knowledge of counting and the cardinal principle. That is, after counting a group of animals on the iPad, the child was asked to identify the numeral representing how many total animals were in the set. These items were similar to nine items Malofeeva et al. (2004) developed called Number-Object Correspondence Task 3. Cronbach's alpha reliability was .86.

2.4.5. Comparing quantities (6 items)

In this task children compared four different quantity collections represented as dot cards from 1 to 9, then selected either the smallest or largest. Griffin et al. (1994) developed a similar task in their number sense assessment. Sasanguie, Van den Bussche, and Reynvoet (2012) reported that comparing quantities predicted a large and statistically significant amount of variance in children's future math achievement.

2.4.6. Matching numerals to quantities (12 items)

Kindergarten Mathematics Common Core State Standards state that children should “understand the relationship between numerals and quantities.” To assess this skill, the iPad showed students various dot card quantity representations, and asked them to match each quantity to the correct numeral.

3. Results

To examine the baseline balance between the intervention and control groups, we compared the two groups in terms of baseline demographic variables and pretest score using two-sample t-tests (for continuous variables) and chi-square tests (for categorical variables). Table 1 shows that there were no statistically significant differences between the intervention and comparison groups in terms of number sense pretest, gender, and race.

Standard longitudinal linear mixed effects modeling (e.g., Singer & Willet, 2003) was employed to test the change from the pre-to post-intervention. Specifically, we used a random intercept model assuming a linear trend over time. We chose mixed effects modeling to better handle missing data and to stay in line with the intention-to-treat principle (Little & Rubin, 2002). Given that intervention assignment was not randomized, we conducted our longitudinal analyses with and without controlling for the baseline variables. However, the results with and without controlling for these variables were similar, and therefore we present the results from unconditional analyses. All individuals in the analyses for whom data were available from at least one of the two assessments (pre and/or post) were included. Data points that were not available were treated as missing at random conditional on observed information using a maximum likelihood estimation (Little & Rubin, 2002). For the ML-EM estimation of our models, we used Mplus version 7.3. Finally, we incorporated the MacArthur framework (Kraemer, Wilson, Fairburn, & Agras, 2002) for our exploratory moderator analysis. The change (slope) from pre-to post-intervention is treated as the outcome in the moderator analysis.

All 227 individuals assigned either to the intervention ($n = 173$) or to the comparison condition ($n = 54$) had a pretest score, and were included in the mixed effects modeling. At the time of the posttest, there were 51 dropouts who were assigned to the intervention and 15 dropouts assigned to the comparison group. Table 2 summarizes the results of our mixed effects modeling. There was a statistically significant and sizable effect for the intervention on number knowledge compared to the control group (Cohen's $d = 1.09$).

As exploratory analyses, we examined potential moderators of the intervention's effect on number knowledge. The analytical criteria used for detecting moderators conformed to the MacArthur approach (Kraemer et al., 2002), which was embedded in the mixed effects modeling framework. As described in Table 1, all three variables (pretest, gender, and race) showed no difference across the

Table 2
Estimated change from pre-to post-intervention based on longitudinal mixed effects modeling.

	Intervention	Control	Group difference
Pretest: *M* (*SD*)	17.75 (10.6)	18.07 (10.1)	
Posttest: *M* (*SD*)	30.3 (9.9)	19.2 (12.2)	
Pre-to-post change	12.5	1.1	11.4
p value	$p < .001$	$p = .396$	$p < .001$
95% CI	[11.11, 13.98]	[−1.45, 3.67]	[8.5, 14.4]
Effect size[a]			1.09

[a] Effect size (Cohen's *d*) was calculated based on observed standard deviation at post-intervention assessment pooled across the intervention and control conditions.

intervention and control groups satisfying the eligibility criteria for moderators.

In our mixed effects modeling framework, the key parameter of interest was the effect of the interaction between the intervention status and a potential moderator on the improvement in number knowledge. If this parameter estimate was statistically significant, a baseline variable satisfies the analytical criteria for moderators, and therefore was identified as a moderator. Among the three baseline variables examined as potential moderators, pretest was found to be an intervention effect moderator (see Table 3). The effect of the intervention on number sense was greater ($p = .006$) for those who started with lower pretest scores (lower 50%, pretest ≤ 15) compared to those with higher pretest scores (upper 50%, pretest ≥ 15). Table 3 illustrates the differential effects of the intervention for these two groups. Students with lower pretest number sense scores benefited almost twice (effect size = 1.53, $p < .001$) from the intervention compared to students with higher pretest scores (effect size = .79, $p < .001$). None of the baseline variables were found to be non-specific predictors of the outcome (i.e., predicting outcome regardless of the intervention status).

4. Discussion

The results from this study demonstrate that children who played Math Shelf learned statistically significantly more mathematics than preschoolers who participated in their regular classroom mathematics curriculum. Applying Hill, Bloom, Black, and Lipsey's (2007) effect size interpretation for normative change, the group difference effect size of ($d = 1.09$) was large, and can be translated as Math Shelf students being 12 months ahead of the comparison group in terms of their numeracy development.

Math Shelf uses technology to deliver instruction, provide feedback, monitor use, and engage preschoolers in considerable amounts of numeracy practice. Our results provide evidence that tablet software can significantly improve public preschoolers' mathematics outcomes. Math Shelf provided consistent effective mathematics instruction and practice for low-income four year olds, which research shows does not occur in the majority of public preschools (Early et al., 2005; Rudd, Lambert, Satterwhite, & Zaier, 2008; Starkey & Klein, 2008). Moreover, teachers integrated Math Shelf into their classrooms, monitored students' play, and solved the few technology issues that arose with little difficulty. Finally, computer interventions cost less over time and can be more effective than purchasing a new curriculum and providing teacher training (Fletcher & Sigmund, 2011; Levin, Glass, & Meister, 1987; Slavin & Lake, 2008). Thus, evidenced-based tablet interventions, like Math Shelf, can be a cost effective and scalable approach to improving low-income preschoolers mathematics achievement.

While all Math Shelf children learned more than control students, exploratory analyses revealed that preschoolers with little number knowledge made tremendous progress (effect size = 1.53, $p < .001$). Children with minimal number knowledge need significant practice subitizing, counting, matching different representations, and learning the cardinal principle from 1 to 3 to form a strong foundational for meaningful number learning (Baroody, Lai, & Mix, 2006; Benoit, Lehalle, & Jouen, 2004; Butterworth, 2005; Hannula, Lepola, & Lehtinen, 2010). Math Shelf students with little number knowledge played over 30 activities that taught these skills. Only after mastering these number concepts did children advance.

Table 3
Estimated moderator effects.

	Pretest	Posttest
Some prior number knowledge		
Intervention	25.1	36.3
Control	26.1	26.9
Minimum prior number knowledge		
Intervention	9.1	24.1
Control	9.4	8.2

4.1. Limitations

The first limitation of this study is that control group participated in their current preschool mathematics curriculum. We are planning to implement a study that compares Math Shelf to an effective preschool mathematics curricula to assess Math Shelf's efficacy against an active comparison group. A second limitation of this research was the fact that we did not analytically account for possible classroom effects. Unfortunately, a thirteen-classroom sample size is too small for multi-level analyses. This omission may have resulted in an inflated Type I error rate. Third, because the study was conducted in publically funded preschools serving predominately low-income children, the findings may not be generalizable to classrooms that serve middle- or high-SES children. With that being said, Math Shelf may be more effective in these settings as both teachers and parents have better opportunities to support mathematics learning. Or, Math Shelf may be less effective, because of other learning opportunities children already experience with teachers and parents. Lastly, this study did not implement a delayed posttest to measure whether the number knowledge gained from playing Math Shelf persisted. While other researchers have shown the lasting benefits of early number knowledge, a delayed posttest would provide direct evidence for lasting intervention results.

4.2. Conclusion

The importance of early numeracy skills to future mathematics achievement is clear (Jordan, Glutting, & Ramineni, 2010; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Watts et al., 2014). This experiment provides evidence that Math Shelf, a tablet preschool mathematic curriculum, substantially increases low-income children's number knowledge. By placing greater emphasis on evidenced-based tablet mathematics applications, public preschools can improve low-income children's mathematics achievement and future economic opportunities (Geary et al., 2013).

Author note

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