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ORIGINAL ARTICLE

Improving preschoolers' mathematics achievement with tablets: a randomized controlled trial

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Abstract With a randomized field experiment of 433 preschoolers, we tested a tablet mathematics program designed to increase young children's mathematics learning. Intervention students played Math Shelf, a comprehensive iPad preschool and year 1 mathematics app, while comparison children received research-based hands-on mathematics instruction delivered by their classroom teachers. After 22 weeks, there was a large and statistically significant effect on mathematics achievement for Math Shelf students (Cohen's $d = .94$). Moderator analyses demonstrated an even larger effect for low achieving children (Cohen's $d = 1.27$). These results suggest that early education teachers can improve their students' mathematics outcomes by integrating experimentally proven tablet software into their daily routines.

Keywords Early childhood education · Preschool · Mathematics · Curriculum · iPads · Tablets · Computer-assisted instruction · Child development · Number sense · Kindergarten

Introduction

Evidence shows that mathematics knowledge at school entry is a strong predictor of future academic and economic success (Geary et al. 2013; Watts et al. 2014). Yet, mathematics instruction in preschool classrooms is infrequent (Brenneman et al. 2009; Perry 2000). Early education teachers in the USA and Australasia report that they feel less prepared to teach mathematics than other subjects (MacDonald et al. 2012; National Research Council 2009).

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Moreover, qualitative studies show preschool teachers use little mathematics language in their classrooms and introduce few structured mathematics activities (Rudd et al. 2008; Schoenfeld and Stipek 2011; Young-Loveridge et al. 1998). Tablet computers may be an effective tool to help early educators deliver consistent and high-quality mathematics instruction (Blackwell 2014; Zomer and Kay 2016).

In this study, we employ a randomized controlled trial to examine the learning benefits of playing Math Shelf, a comprehensive iPad mathematics app for preschool and year 1 students. We investigate if children who play Math Shelf on tablets perform better on numeracy assessments than students that engage in teacher-led hands-on mathematics instruction. We also examine if student background characteristics affect mathematics growth rates differently in the Math Shelf versus the hands-on mathematics condition.

Tablets to improve early mathematics learning

With thousands of learning apps designed for 3- to 5-year-olds, young children have become frequent tablet users (Neumann and Neumann 2014). Yet, the popularity of touchscreen devices has raised concerns about the potential negative impact on young children's cognitive, social, physical, and emotional development (American Academy of Pediatrics 2015; Carson et al. 2014; Hernandez 2014). These concerns, along with scant evidence that tablet apps improve preschoolers' learning (Berkowitz et al. 2015), support calls for limiting screen time (National Association for the Education of Young Children 2012; Department of Health 2014). In his qualitative study of tablets in a New Zealand year 1 classroom, Falloon (2013) concluded that "there is a need for a closer and more critical look at app design . . . to improve the educational quality (p. 506)."

Expanding on Falloon's (2013) research, an international team of early childhood experts illustrated how screen time can be beneficial when app developers attend to and incorporate strategies from the learning sciences (Hirsh-Pasek et al. 2015). An investigation of tablet use by preschoolers in Australia found that children could transfer what they learned about solving a problem (Tower of Hanoi) on a touchscreen device to physical objects (Huber et al. 2016). Other studies conducted in New Zealand (Falloon 2014), Canada (Sinclair and Heyd-Metzuyanim 2014), England (Clark and Luckin 2013), and the USA (Schacter and Jo 2016) show that preschool apps that integrate best educational practice advance young children's learning, creativity, and problem-solving skills. Moreover, four recent experimental studies demonstrated that tablets mathematics apps significantly improved young children's mathematics achievement (Berkowitz et al. 2015; Outhwaite et al. 2017; Pitchford 2015; Schacter et al. 2015). The nascent research on tablets in preschool and year 1 settings suggests that apps designed based on the learning sciences can enhance problem-solving, mathematics achievement, and children's language and talk (Blackwell 2014; Khoo et al. 2015).

The current study integrates research from the learning sciences to create an early childhood mathematics app that advances young children's learning. To promote mathematical thinking and prioritize best teaching practice, we created Math Shelf, a preschool and year 1 iPad mathematics program. We then tested Math Shelf's efficacy through a large-scale randomized controlled trial. In the next section of this article, we describe how Math Shelf incorporates (a) developmental mathematics theory, (b) evidenced-based early mathematics interventions, and (c) Maria Montessori's mathematics activities to increase young children's mathematics achievement.

Developmental mathematics theory

Developmental theory suggests that infants are born with the capacity to represent number in a nonverbal manner (Feigenson and Carey 2003; Mix et al. 2002). They can identify small numbers (i.e., less than 3), approximate larger number sets (Berch 2005; Mix et al. 2002), and recognize transformations of small sets (Wynn 1992). As infants become toddlers, they acquire language and the ability to count. Counting extends children's number understanding (Baroody et al. 2006).

Around age 4, children typically begin to merge their schemas for making global quantity comparisons with counting (Griffin 2002; Jordan and Levine 2009; Montessori 1914). With teacher and parental guidance, children start to connect numerals with quantities, distinguish between successive numbers, and understand that numerals have magnitudes (Griffin et al. 1994; Sarnecka and Carey 2008; Schaeffer et al. 1974). As these symbolic number knowledge skills develop, children begin to construct a mental number list (Frye et al. 2013).

Building on developmental mathematics research, Clements and Sarama (2009) documented children's mathematics progression into a chronology of learning trajectories. A learning trajectory specifies a mathematics goal and articulates children's developmental path to reach that goal. Clements and Sarama (2009) have defined learning trajectories for: Counting, Comparing, Ordering and Estimating Numbers, Recognition of Number and Subitizing, Addition and Subtraction, Spatial Thinking, Geometric Measurement, etc. Math Shelf has incorporated the Clements and Sarama (2009) learning trajectory research into its instructional sequence.

Evidence-based early mathematics interventions

Math Shelf also relies on a wealth of research from evidenced-based early mathematics interventions (Baroody et al. 2009; Chard et al. 2008; Gersten et al. 2005; Griffin et al. 1994; Jordan et al. 2012; Ramani and Siegler 2008). These programs teach counting, numeral identification, matching collections to numerals, numeral sequencing, subitizing, number composition and decomposition, place value, and basic arithmetic.

Jordan and colleagues implemented board games, number line activities, story problems, and other activities to advance young children's number knowledge (Dyson et al. 2013; Jordan et al. 2012). The Baroody et al. (2009) early number interventions improved preschoolers' mathematics achievement by using manipulatives to teach verbal counting, object counting, and numeral-quantity relationships. Sharon Griffin's evidenced-based early mathematics program (2004) exposes preschoolers to quantities, counting, and formal symbols, then provides multiple opportunities for constructing relationships among these three ways to understand number. Finally, Ramani and Siegler (2008) found that teaching preschoolers board games with consecutively numbered, linearly arranged, equal-size spaces improved their number line estimation skill, number identification knowledge, and number magnitude understanding.

Similar to these evidenced-based early mathematics interventions, Math Shelf teaches counting, numeral identification, matching collections to numerals, numeral sequencing, subitizing, number composition and decomposition, place value, and basic arithmetic. Yet, instead of employing teachers and physical manipulatives, Math Shelf uses tablet computers to teach all mathematics content.

Montessori mathematics instruction on tablets

Finally, Math Shelf is influenced by the work of Maria Montessori (Montessori 1967). Over 100 years ago, Dr. Montessori developed a mathematics program that consisted of dozens of mathematics “jobs” that confer learning through action (Lillard 2005; Piaget 1970; Rigg 2004). Each Montessori mathematics “job” communicates clear goals, provides for self-assessment and corrective feedback, uses hands-on materials, and progresses in difficulty (Lillard 2005). Theoretically, the Montessori approach embodies many features that enhance young children’s learning and development including the matching of learning materials to each child’s skill level, allowing for choice and autonomy, providing for active engagement with a variety of learning materials, and engendering feelings of independence and control (Bransford et al. 2000; Lillard 2011).

Math Shelf: a preschool and year 1 tablet mathematics program

To reiterate, Math Shelf[1] is a tablet mathematics program designed based on developmental theory, evidenced-based early number interventions, and Maria Montessori’s early mathematics approach. When children begin playing Math Shelf, they take a placement test that assigns them to games and activities that match their knowledge and skill level. This placement test sets each student on an appropriate mathematics learning trajectory. Children with minimal mathematics knowledge begin with sorting, matching, and seriation activities. They progress to one-to-one counting, matching different quantity representations, and numeral identification exercises from 1 to 3 (Fig. 1).

Next, students are introduced to counting to apply the cardinal principle, subitizing, sequencing numerals and collections, and matching numerals to quantities from 1 to 6, then 1 to 9 (Fig. 2).

After playing approximately 180 unique activities, children come to 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 fluently subitize different collection representations.

Instruction proceeds by using children’s subitizing skills to teach addition within six (Fig. 3). First, students add using dice and bead representations. Next, they engage in activities with an adapted Rekenrek, a visual model designed to support basic

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

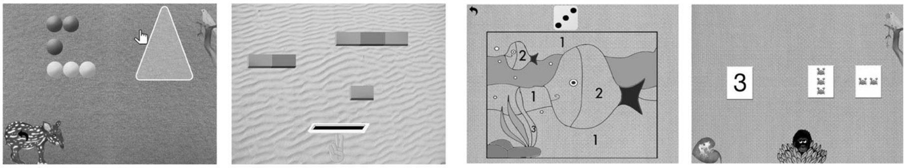


Fig. 1 Learning 1 to 3. *Panel 1* is a seriation task using the Montessori colored beads. In *panel 2*, children practice one-to-one counting, then matching Montessori Number Rods to finger representations. *Panel 3* shows a coloring activity where children connect die representations to numerals. Lastly, *panel 4* requires children to drag the numeral on the left over its correct representation on the right

arithmetic calculations (Treffers 1993). Then, children add with countable numerals (i.e., numerals with dots on them representing their value). Last, children add numerals.

Finally, Math Shelf teaches place value. Children begin with the quantities and numerals from 11 to 19 (Fig. 4). They progress to quantities and numerals to 99 using virtual Montessori golden bead manipulatives. Finally, students build numerals and quantities to 999 by arranging both virtual golden bead manipulatives and Montessori numeral cards.

Research questions

1. Will children who play Math Shelf perform better on numeracy assessments than similar students that engage in research-based hands-on mathematics activities delivered by their classroom teachers?
2. Does initial numeracy knowledge, gender, or race affect mathematics learning growth rates differently in the Math Shelf versus the hands-on mathematics condition?

Method

Participants

Letters were sent to school principals that are part of a large Catholic diocese in the USA. Thirty principals volunteered their preschool classrooms to participate in this study. Of those 30 preschool classrooms, 20 were randomly selected to participate. Twelve were randomly assigned to the Math Shelf condition, and eight were randomly assigned to the research-based hands-on lessons group. Consent letters describing the study's procedures and duration were sent home for parent/guardian signatures. The

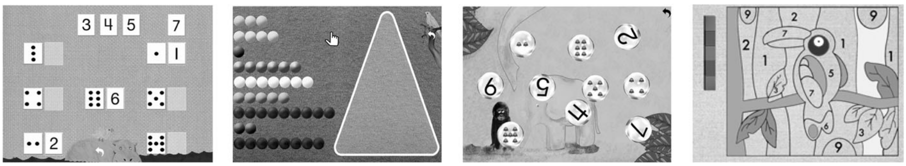


Fig. 2 Learning 1 to 9. *Panel 1* asks children to order numerals, then drag numerals to each quantity. In *panel 2*, students sequence the Montessori colored beads. *Panel 3* asks children to match collections to numerals. Lastly, *panel 4* requires students to count the different Montessori Number Rods and select the correct numeral to color the picture

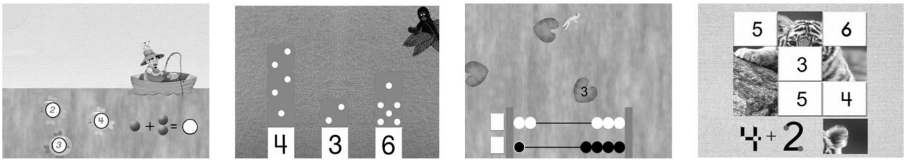


Fig. 3 Addition within six. *Panels 1 and 2* teach addition within six using bead and dice manipulatives. In *panel 3*, students use a modified Rekenrek to add within six. *Panel 4* illustrates how children add numerals to uncover a hidden image

pretest sample consisted of 433 children (259 Math Shelf students and 174 hands-on lesson students). The post-test sample included 378 students (231 Math Shelf and 147 hands-on lesson children). Student characteristics are listed in Table 1.

Procedures

Math Shelf Students assigned to Math Shelf played the app 2 days a week for 10 min each session over the course of 22 weeks. The iPads were available in classrooms for 1 h a day from Monday to Thursday. Teachers created a schedule that assigned half of the students to play Math Shelf on Monday and Wednesday and the other half to play on Tuesday and Thursday. On their designated day, children played for 10 min. The study began on September 14, 2015 and ended February 29, 2016. During the first 2 weeks of the intervention, teacher assistants supervised children while they played. Then, students were sent to the Math Shelf iPad center to play independently.

Research-based hands-on mathematics instruction Students assigned to the research-based hands-on mathematics instruction condition participated in two hands-on mathematics activities per week taught by their classroom teachers. The mathematics activities were drawn from Dr. John Van de Walle and colleagues' (2014) book, *Teaching Student Centered Mathematics (PreK – 2nd Grade).* Dr. Van de Walle and colleagues' (2014) book presents a practical guide based on a large body of research that describes how to teach early number knowledge to young children. Teachers in this condition were provided with a list of activities along with dice, counters, 10 frames, numeral cards, dot cards, and pattern cubes.

Teacher training Teachers in both conditions participated in separate 2.5-h face-to-face training conducted by the lead author of the study. Each training session showed teachers how to teach the following early mathematics skills: one-to-one counting,

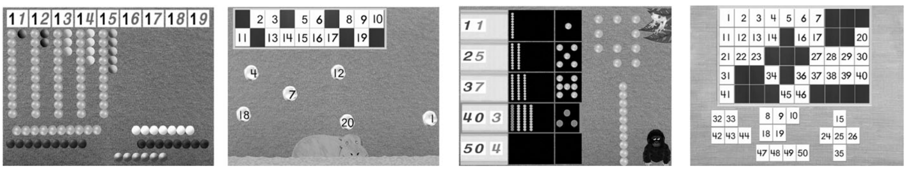


Fig. 4 Place value. *Panel 1* shows children representing the numerals 11 to 19. In *panel 2*, children drag missing numerals into the correct position on a 20 chart. *Panel 3* is a digital version of Montessori's Tens' Board. Lastly, *panel 4* has children complete a puzzle exercise from a 50 chart

Table 1 Baseline characteristics

Baseline characteristics	Intervention (Math Shelf) (n = 260)	Comparison (hands-on math) (n = 173)
Pretest: M (SD)	19.08 (8.71)	20.90 (9.84)
Age in years: M (SD)	4.59 (.36)	4.49 (.45)
Male: n (%)	134 (51.5%)	85 (49.1%)
Female n (%)	126 (48.5%)	88 (50.9%)
Race: n (%)		
Caucasian	127 (51.2%)	117 (67.6%)
Hispanic	71 (28.6%)	40 (23.1%)
African American	45 (18.1%)	15 (8.7%)
Asian	4 (1.6%)	1 (0.6%)
Multi-racial	1 (0.4%)	0 (0.0%)

cardinal counting, numeral identification, number composition and decomposition, subitizing, matching numerals to collections, number magnitude, place value, and addition within 6.

In the Math Shelf training, educators viewed screen shots of different Math Shelf games and activities that taught these skills. Teachers also created a schedule where students were assigned to play Math Shelf Monday-Wednesday or Tuesday-Thursday for 10 min each session.

In the research-based hands-on mathematics training, teachers practiced teaching lessons from Dr. Van de Walle and colleagues' (2014) book, *Teaching Student Centered Mathematics (PreK – 2nd Grade).* Teachers scheduled the days and times they would teach two mathematics activities each week. Educators also planned where they would place the math activities in their room and how they would check and provide feedback on student work.

Test administration

School office employees from each preschool tested all children individually on an iPad number sense assessment that provided audio and visual instructions. All children were pretested between September 14, 2015 and September 18, 2015 and post-tested between February 23, 2016 and February 29, 2016. Test administration scripts were strictly followed.

Measures

A 48-item iPad early mathematics assessment was developed for the study. The dependent measure included constructs that assessed recommended goals by numerous early education mathematics researchers (Jordan et al. 2010; Lee et al. 2007; Malofeeva et al. 2004; Seethaler and Fuchs 2010). The untimed test took children approximately 5 min to complete. Test-retest reliability was 0.93. Concurrent validity collected from a sample of 155 students in Texas preschools that took both the iPad assessment and the Bracken School Readiness Assessment Third Edition (2007) was 0.73. The iPad assessment measured the following concepts.

Numeral identification (six items) Five numerals from 1 to 10 were displayed, and students were instructed to touch the named numeral. The five numerals were presented in random order with correct answers appearing in different positions each time. Lee et al. (2007) reported Cronbach alpha coefficients of 0.88 and concurrent criterion validity of 0.59 with the Test of Early Mathematics Achievement-3 (Ginsburg and Baroody 2003) for numeral identification tasks. Clarke and Shinn (2004) documented predictive validity of 0.68 with the Woodcock-Johnson spring first-grade Applied Problems subtest (Woodcock and Johnson 1989).

Cardinal principle (six 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 0.86.

Numeral sequencing (nine items) Children were instructed to sequence numerals from 1 to 9. Seethaler and Fuchs (2010) employed a similar numeral sequencing task as part of their number sense battery. Reliability was 0.70 with predictive validity of 0.67 for the total mathematics score in first grade on the Iowa Test of Basic Skills.

Matching numerals to quantities (nine items) The United States Kindergarten Mathematics Common Core State Standards (National Governors Association 2010) 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.

Quantity discrimination (six items) Students were presented with four random numerals (ranging from 1 to 20) and asked to touch the largest numeral. All children received the same four random numerals in the same order. Clarke and Shinn (2004) reported test-retest reliability for quantity discrimination measures of 0.85 and predictive validity of 0.79 with the Woodcock-Johnson spring first-grade Applied Problems subtest (Woodcock and Johnson 1989).

Place value (six items) Children were shown bead representations from 11 to 50 using 10 bars and single beads to represent units. The child was asked to identify the numeral representing how many total beads were in the set. There were four numeral choices for each different bead representation problem. These items were an extension of Malofeeva et al. (2004) Number-Object Correspondence Task 3.

Addition within six (six items) In this task, children were presented with six different numeral addition problems within six and asked to select the correct answer from five different choices. These items were similar to the Kindergarten Common Core Sample Assessment addition problems (National Governors Association 2010).

Results

Table 1 shows the baseline characteristics of students randomized to the Math Shelf (intervention) and the hands-on mathematics instruction (comparison) conditions. For the primary outcome analysis, we employed standard linear mixed effects modeling (e.g., Raudenbush and Bryk 2002; Singer and Willet 2003). Specifically, we used a random intercept and slope model assuming a linear trend over time. In line with the intention-to-treat principle, we included all randomized individuals in the analyses for whom data was available from at least one of the three equally spaced assessments (pre, mid, and post-test). Data points that were not available were treated as missing at random conditional on observed information using a maximum likelihood estimation (Little and Rubin 2002). For the ML-EM estimation of our models, we used Mplus version 7.3 (Muthén and Muthén 1998–2015). All 433 individuals randomized either to the intervention ($N = 260$) or to the comparison condition ($N = 173$) were included in the mixed effects model as they had completed one or more assessments. Among the 433 students that participated in the study, 320 completed all three assessments, 85 completed two, and 28 completed one assessment. To adjust for inflation of type I error due to data dependency within clusters (i.e., students nested in 20 schools), we used the sandwich estimator (e.g., Carroll et al. 1995; Zeger and Liang 1986). This method provides the same point estimates as usual but provides corrected standard errors. Given the small number of schools, we chose this method as a reasonable alternative to a formal multilevel approach. Finally, we incorporated the MacArthur framework (Kraemer et al. 2002) in our longitudinal modeling for our exploratory moderator analyses. The change (slope) from pre- to post-intervention was treated as the outcome in the moderator analyses. We hypothesized gender, race (Caucasian vs. non-Caucasian), and baseline numeracy knowledge as potential treatment effect moderators.

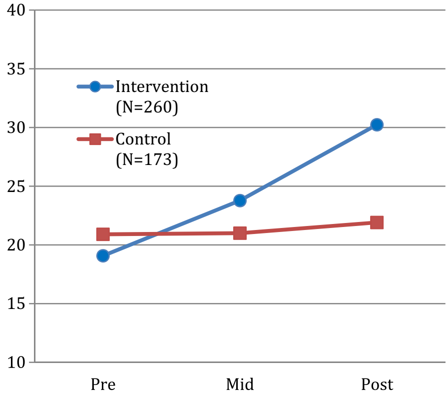
Intervention effect

Figure 5 shows observed longitudinal trajectories for numeracy knowledge. The mathematics assessment score demonstrates an increasing trend for the intervention group and little to no growth in the comparison group.

Table 2 summarizes the results of the longitudinal analyses using mixed effects modeling. We assumed linear trends for both groups allowing for individual variation initially (random intercept) and over time (random slope). At the midpoint assessment, the intervention showed a moderate effect with the standardized group difference of Cohen's $d = 0.49$. By end of intervention, the effect on mathematics performance is large with the standardized group difference of Cohen's $d = 0.94$.

Moderator variables

As exploratory analyses, we examined potential moderators of the intervention effect on numeracy learning. Three baseline variables were used as hypothesized moderators (pretest, race, and gender). The analytical criteria to detect moderators conformed to the MacArthur approach (Kraemer et al. 2002). All three variables showed no difference across the intervention and comparison groups at pretest, satisfying the eligibility criteria for moderators. In our mixed effects modeling framework, the key parameter



	Pre	Mid	Post
Intervention (N=260)	19.08	23.78	30.24
Control (N=173)	20.90	21.00	21.92

Fig. 5 Observed longitudinal trajectories for numeracy knowledge

of interest is the effect of the interaction between the intervention status and a potential moderator on the improvement in numeracy knowledge. If this parameter estimate is significant, a baseline variable satisfies the analytical criteria for moderators and therefore is identified as a moderator. Among the three baseline variables examined as potential moderators, pretest ($p < 0.001$) and race ($p = 0.033$) were found to be an intervention effect moderator. The effect of intervention was greater for students with lower pretest numeracy scores (pretest ≤ 18), and for non-Caucasian students. Table 3 displays the differential effects of the intervention for these subgroups.

Discussion

Math Shelf is a preschool and year 1 tablet mathematics program designed based on developmental theory, evidenced-based number sense interventions, and Maria Montessori's early mathematics approach. The results from this randomized trial demonstrate that Math Shelf students learned approximately 9 months more mathematics than comparison children (Cohen's $d = 0.94$, $p < 0.001$). This group difference effect size is large and statistically significant.

While all Math Shelf children learned more than teacher-led research-based hands-on mathematics students, exploratory analyses revealed that preschoolers with little

Table 2 Estimated mathematics assessment scores and intervention effects at mid- and post-intervention based on mixed effects longitudinal analysis

Assessment	Intervention	Control	Intervention–comparison difference	Effect size[a]	p value
Mid	25.177	20.494	4.683	0.486	<0.001
Post	30.783	21.416	9.367	0.940	<0.001

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

Table 3 Moderators of intervention effects at post-assessment based on mixed effects longitudinal analysis

	Intervention	Control	Group difference	Effect size[a]	p value
Race					
Caucasian ($N = 244$)	31.94	23.94	7.99	0.80	<.001
Not Caucasian ($N = 189$)	29.22	17.36	11.85	1.19	< .001
Pretest					
Low ≤ 18 ($N = 214$)	25.18	12.58	12.61	1.27	<.001
High > 18 ($N = 217$)	36.15	30.16	5.99	0.60	< .001

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

number knowledge made tremendous progress (Cohen's $d = 1.27$, $p < 0.001$). Math Shelf has 90 unique games and activities that teach seriation, sorting, matching, subitizing, counting, matching numerals to quantities, sequencing numerals, and learning the cardinal principle from one-to-three. Extensive practice with small numbers has been shown by previous research to build a solid foundation for future meaningful number learning (Baroody et al. 2006; Benoit et al. 2004; Butterworth 2005; Hannula et al. 2010).

Exploratory analyses also revealed that non-Caucasian children made greater learning progress than Caucasian students (Cohen's $d = 1.2$, $p < 0.001$ and Cohen's $d = .80$, $p < 0.001$, respectively). Thus, this study provides initial evidence that using Math Shelf may be an early intervention that can help reduce the racial mathematics achievement gap in the American school system.

Implications for practice

There is promise in tablets' capacity to improve individualized learning, enhance young children's talk, and expand early educators' pedagogical practices (Blackwell 2014; Khoo et al. 2015). With this being said, preschool teachers struggle to find apps with quality content (Blackwell 2014; Falloon 2014). Early childhood teachers also face institutional barriers to implementing tablets in the classroom such as lack of training and support. And, many preschool educators' attitudes about teaching are at odds with the individualized learning opportunities that tablets can provide (Blackwell 2014).

To improve tablet integration into preschool classrooms, several early childhood researchers have proposed training teachers in how to (a) select effective learning apps, (b) observe and interact with children while they play, and (c) rework their teaching practices to embrace the learning potential that tablets can provide (Blackwell 2014; Falloon 2014; Khoo et al. 2015; Neumann and Neumann 2014).

These professional development offerings will likely improve preschool teachers' mathematics instruction. Yet these training approaches do not utilize the power of touchscreen technology. Tablet computers are efficient devices for collecting, analyzing, organizing, and disseminating information. Imagine an early learning mathematics app that collects individual children's performance data, groups children for differentiated instruction based on their performance, and then texts teachers' visual hands-on mathematics lesson ideas to teach different groups of students each week. Such an approach may be equally or more effective than offering preschool teachers mathematics professional development. Furthermore, children's learning growth is rarely linear (Hershberg and Robertson-Craft 2009). Children also learn at different rates. Some students acquire concepts quickly, while others need additional practice and instruction. Thus, an app that collects students' learning data weekly or bi-monthly, regroups students based on that data, and sends on-level lessons to teachers' mobile devices combines the benefits of tablet technology with the changing nature of students' learning.

We are currently piloting this new approach to improve mathematics teaching and learning in preschool and year 1 classrooms. Connecting students' performance data from the tablet to teacher classroom instruction may prove to be a fruitful frontier for developing early educators' mathematics instructional capacity.

Limitations

The first limitation of this study is that the research was conducted in private Catholic preschools, which are not subject to the same regulations as federally or state-funded preschools. The findings, therefore, may not be generalizable to public preschool classrooms. With this being said, two previous studies of Math Shelf were carried out in publically funded preschools and achieved similar results (Schacter et al. 2015; Schacter and Jo 2016). The second limitation of this research is the study did not implement a delayed post-test to measure whether numeracy knowledge gained from playing Math Shelf persisted. While other researchers have shown the lasting benefits of early number knowledge, a delayed post-test would provide direct evidence for lasting intervention results.

Conclusion

Our results suggest that Math Shelf is an easy to implement, engaging, and scalable early mathematics intervention that produces large and statistically significant mathematics learning. By delivering instructional activities that prioritize best teaching practices and promote the development of children's mathematical thinking, Math Shelf presents itself as an evidenced-based technology intervention that improves preschoolers' mathematics achievement.

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