Computers in Human Behavior 55 (2016) 223–229

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

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

John Schacter [a, *], Booil Jo [b]

[a] The Teaching Doctors, 22 Pearce Mitchell Pl., Stanford, CA 94305, United States
[b] Department of Psychiatry and Behavioral Sciences, Center for Interdisciplinary Brain Sciences Research, Stanford University, United States

ARTICLE INFO

Article history:
Received 4 September 2015
Received in revised form
15 September 2015
Accepted 16 September 2015
Available online 25 September 2015

Keywords:
Preschool
iPads
Mathematics
Tablet computers
Low-income children
Intervention

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

* Corresponding author.
E-mail address: schacter@teachingdoctors.com (J. Schacter).

http://dx.doi.org/10.1016/j.chb.2015.09.013
0747-5632/

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