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COMPUTER MATHEMATICS GAMES AND CONDITIONS FOR ENHANCING YOUNG CHILDREN'S LEARNING OF NUMBER SENSE

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ABSTRACT

Purpose - The present study was designed to examine whether mathematics computer games improved young children's learning of number sense under three different conditions: when used individually, with a peer, and with teacher facilitation.

Methodology - This study utilized a mixed methodology, collecting both quantitative and qualitative data. A random sample of 62 children distributed across four classrooms in a public pre-kindergarten center participated in the study. The four classrooms served as teacher-facilitated, peer-facilitated, individual play, and control classrooms. Several sources of data were used, including informal observations and the "Test of Early Mathematics Ability-3 (TEMA-3)" developed by Ginsburg and Baroody in 2003.

Findings - The results showed that mathematics computer games improved children's understanding of number sense, especially when supported by a teacher's skillful facilitation and scaffolding.

Significance - The results of the study are significant as they inform teachers who integrate computer mathematics games in their curriculum and highlight the importance of scaffolding in supporting children during play. The findings further emphasize that offering children computer-based games to play without proper support and scaffolding does not necessarily lead to better and improved learning of number sense.

Keywords: Mathematics computer games; number sense; teacher scaffolding; teacher facilitation; mathematical learning.

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INTRODUCTION

Research studies of young children show that early experiences children have with numbers, either at home or in early learning settings, form the foundation for mathematical learning in school (Desoete & Gregoire, 2007; Jordan, Kaplan, Locuniak, & Ramieni, 2007; LeFevre et al., 2009; Sarama & Clements, 2015). Furthermore, research evidence suggests that children who have a well-developed number sense are able to succeed in early mathematics and beyond in primary grades (Aunio & Niemivirta, 2010; Chesloff, 2013; Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Geary, Hoard, Nugent, & Bailey, 2013; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Malofeeva, Day, Saco, Young, & Ciancio, 2004; Nguyen et al., 2016; Sarnecka & Lee, 2009; Siegler et al. 2012). In mathematics, number sense is defined in a variety of ways. In this study, The Early Math Collaborative-Erikson Institute's (TEMCEI) definition of number sense was used. According to TEMCEI, number sense is "the ability to understand the quantity of a set and the name associated with that quantity" (2014, p. 30). As a key building block of learning arithmetic for the early grades, number sense "connects counting to quantities, solidifies and refines the understanding of more and less, and helps children estimate quantities and measurement" (The EMCEI, 2014, p. 30). In its 2009 report, Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity (National Research Council, 2009), the Committee on Early Childhood Mathematics underscored the importance and requirement of number sense for success to school mathematics. However, researchers who observed learning environments for young children (pre-kindergarten or center-based settings) claim that children are not provided with stimulating or challenging play experiences to expand their mathematical understanding (Clements & Sarama, 2016; Levin, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010, Tudge & Doucet, 2004). For example, Tudge and Doucet (2004) observed 39 preschoolers (White and African-American children from middle and working class) over the course of one week (a total of 180 observations) in a variety of settings including homes, childcare centers and public spaces. Across the 180 observations, they found that 60% of the three-year-olds observed had no mathematical experience of any kind. Brenneman, Stevenson-Boyd, and Frede (2009) also confirm that despite the existence of learning standards and increased curricular attention to mathematics, there is still not enough emphasis on learning mathematical concepts in early childhood programs or classrooms. Likewise, Clements and Sarama (2016) explain that even well-regarded programs for young children tend to give more focus to language and social development than to mathematics concepts. Furthermore, Clements and Sarama (2016) argue that this lack of attention to mathematics learning occurs even though many children, especially from minority and low-income groups, later experience difficulty in school mathematics.

When and How Children Learn Mathematics: Role of Computer Games

Young children begin acquiring number sense early in life through interaction with materials such as words, pictures, symbols, and objects (like blocks) in their environments while being prompted and guided by parents, older siblings, or peers (Broody & Wilkins, 1999; Griffin, 2004). Through play and stimulated interaction with their environments, young children begin to understand the meaning and relationship among numbers, recognize the size of the numbers, use symbols to measure objects and events and treat numbers as a sensible system (Hunting et al., 2012; Wang & Hung, 2010). Because of these daily routines and activities, children develop early mathematics skills that they later bring to pre-K or kindergarten. Research shows that this early development is a strong predictor of children's later mathematics achievement (Clements & Sarama, 2016; Cross, Woods, & Schweingruber, 2009; Duncan et al., 2007; Fuches et al., 2010; Pruden, Levine, & Huttenlocher, 2011). What is most surprising is that this early development of mathematics skills also predicts later reading achievement even better than early reading skills (Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2005). Building on the early mathematical foundation, early childhood teachers should help young children develop early mathematical skills by continuing to use play with concrete learning materials and objects (manipulatives) to introduce children to more mathematical concepts and ideas related to number and spatial sense, patterns, measurement, and estimation (Diezmann & Yelland, 2000; Jung & Conderman, 2013; Sarama & Clements, 2009; Tournaki, Bae, & Kerekes, 2008). Research suggests that young children who are not provided opportunities to participate in guided learning and purposeful activities to expand their understanding of mathematical concepts will be at an increased risk for having persistent mathematics difficulties in kindergarten and elementary schools (Mazzocco & Thompson, 2005; Perry & Dockett, 2008).

Today, computer technology has become one of the learning tools that is accessible to many young children at home or at least in preschools and kindergarten classrooms. Early education research (e.g., National Association for the Education of Young Children (NAEYC) and Fred Rogers Center, 2012) reminds us that computers only supplement and do not replace childhood activities such as playing with physical objects (art, blocks, sand, water, books, etc.,). However, when computers are used in developmentally appropriate ways by children and supported with adults' guidance and modeling, these computers can function as tools for learning, and engage children in fun and challenging activities (Falloon & Khoo 2014; Reeves, Gunter, & Lacey, 2017; Office of Educational Technology, 2016). Moreover, the combination of visual displays, animated graphics, and speech, combined with the option to replay and to receive immediate feedback provide a good learning environment for children. Hence, the attractive features of computer technology and developmentally appropriate software applications have resulted in touchscreen tablets emerging as a common feature in young children's learning environments.

Computer games are one of the highly used applications for children. Previous studies have shown that computer games can be useful in enhancing children's memory capacity, attention span, literacy, and problem solving strategies, which can, in turn, affect their academic achievements (Beschorner & Hutchison, 2013; Chou, Block, & Jesness, 2012; de Aguilera & Mendiz, 2003; Green & Bavelier, 2003; Linebarger, Piotrowski, & Lapierre, 2009; Kermani & Aldemir, 2015; Kucirkova, Messer, Sheehy, & Fernández Panadero, 2014; Reeves, Gunter, & Lacey, 2017; Ross, Morrison, & Lowther, 2010). However, while the literature supports the use of computer programs for children and provides evidence that they enhance children's cognitive abilities (e.g., attention, memory, literacy), it is not clear under what conditions (e,g., individually, with adults, with older or same-age peers) computers games improve children's learning. In this study, the researcher addresses this gap by 1) examining whether children's learning of number sense could be supported and improved through the integration of computer mathematics (CM) games in the pre-kindergarten (pre-K) curriculum, and 2) exploring the conditions under which the CM games will be most beneficial in supporting children's learning of number sense.

THEORETICAL FRAMEWORK

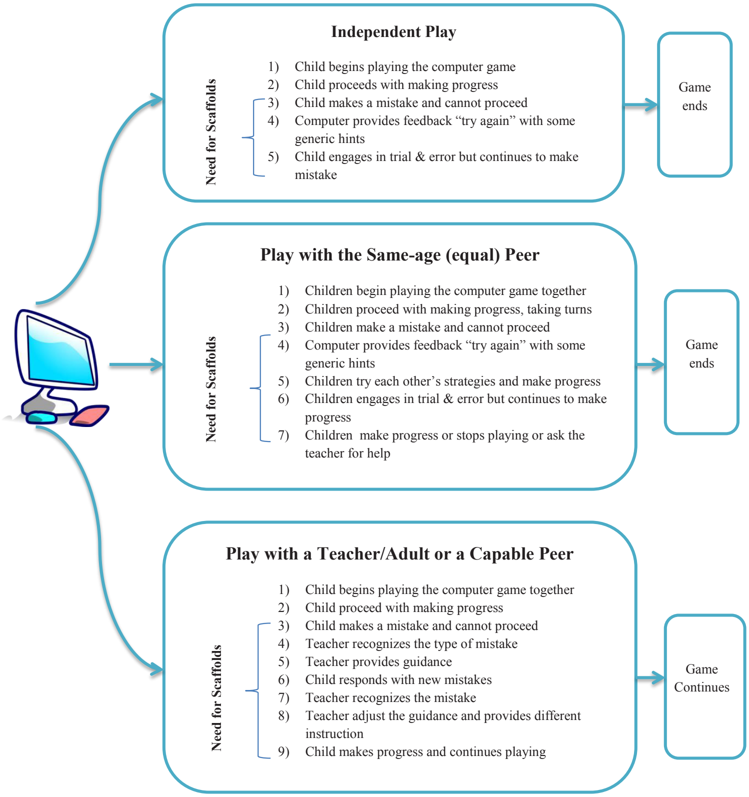
The researcher used principles of instructional design as a framework to select well-designed computer software games for the pre-K curriculum (Gagne, Wager, Golas & Keller, 2005; Smith & Regan, 2005). A well-designed instructional game was defined as a program that (1) used careful analysis of children's cognitive and linguistics needs (age-appropriate content and language); (2) incorporated the concept of play (multi-sensory activity with emphasis on language and social interaction) while engaging the child in learning mathematical concepts; (3) offered well-sequenced activities within the game's structure and properly monitored the child's progress by providing feedback; and (4) allowed the child to control the process of learning by re-playing any parts of the game.

The researcher also used the Vygotskian zone of proximal development (ZPD) and the concept of scaffolding for designing the study and making sense of the data. According to Vygotsky (1978), the ZPD is the difference between what a child can learn independently and what she or he can learn with the help of a more knowledgeable and skilled partner (or peer) or adult. The term "scaffolding" was later introduced by Wood, Bruner, and Ross (1976), in an attempt to explain the concept of teaching in the ZPD. It describes the type of instructional and interactional support offered by a teacher to facilitate learning. Scaffolding includes a variety of strategies such as modeling, questioning, hint, and direction (van de Pol, Volman, & Beishuizen, 2010; Wood, Bruner, & Ross, 1976). In the process of scaffolding, the teacher or an adult helps the child master a task or a concept that the child is initially unable to perform independently. As the child gains competence, the teacher lessens the support, allowing the child to work independently and complete the task (Lipscomb, Swanson, & West, 2004).

The concepts of ZPD and scaffolding were further used to define and predict the teacher's or the peer's role and the application of scaffolding during the interactive processes of learning from a computer game (see Figure 1). As shown in Figure 1, it can be predicted that when children play with a computer game, three conditions could occur. A child may play with the computer game independently with or without the teacher's presence. It is also likely that children play together as a team or as equal peers, again with or without the presence of the teacher. And finally, children may play with the computer game while being observed and guided by an adult/teacher or a more knowledgeable peer. Figure 1 further shows that when children play independently with a computer game that does not use artificial intelligence and cannot adjust its guidance (questions, hints, feedback) with the children's progress and mistakes, and only uses general questions, hints, and feedback, it is likely that the children either interact with the game through trial and error or get frustrated when they are unable to figure out their mistakes. The process, therefore, may eventually result in stopping the play or asking for the teacher or adults' help if they are present. Thus, the scaffolding that occurs in a computer game may not be enough to assist some children in learning mathematical concepts. On the other hand, when children play together as a team or as equal peers, it is likely that they use each other's strategies when encountering difficulties and move forward by completing each stage of the game and, if successful, eventually win the game (completing the task embedded in the game). As conceptualized by Wood, Bruner, and Ross (1976), even though peers with equal abilities can assist and support each other when playing a game, they may not be able to recognize each other's mistakes in order to identify a proper strategy to continue progressing. Thus, while the possibility of completing the challenging stages of the game is much higher in comparison with playing independently, there is still a chance of ending the play without completing it.

According to Vygotsky (1978), children learn more while interacting and having a social dialogue with a knowledgeable adult or peer (Vygotsky, 1978). Based on Vygotsky's theory, the adult's (or a knowledgeable peer's) role is to recognize the child's abilities and stretch those abilities by working within the child's ZPD. In other words, a knowledgeable adult/teacher (or peer) takes the child's responses to diagnose the areas of needs and then adjust her/his guidance to the child ZPD. Therefore, when a child is playing a computer game in the presence of an adult/teacher or knowledgeable peer, it is more likely that he or she uses the guidance to make continuous progress in the game and successfully complete it. Figure

1 visualizes the process of interacting with a computer game, given different learning conditions.



Independent Play

1) Child begins playing the computer game
2) Child proceeds with making progress
3) Child makes a mistake and cannot proceed
4) Computer provides feedback "try again" with some generic hints
5) Child engages in trial & error but continues to make mistake

Play with the Same-age (equal) Peer

1) Children begin playing the computer game together
2) Children proceed with making progress, taking turns
3) Children make a mistake and cannot proceed
4) Computer provides feedback "try again" with some generic hints
5) Children try each other's strategies and make progress
6) Children engages in trial & error but continues to make progress
7) Children make progress or stops playing or ask the teacher for help

Play with a Teacher/Adult or a Capable Peer

1) Child begins playing the computer game together
2) Child proceed with making progress
3) Child makes a mistake and cannot proceed
4) Teacher recognizes the type of mistake
5) Teacher provides guidance
6) Child responds with new mistakes
7) Teacher recognizes the mistake
8) Teacher adjust the guidance and provides different instruction
9) Child makes progress and continues playing

Figure 1. Visualization of how scaffolding steps occur during child play with computer games

RESEARCH QUESTIONS

The study attempted to answer the following questions:

1. Do computer mathematics games improve children's learning of number sense?
2. Under which of the following conditions (individually, with a peer, or with teacher facilitation/scaffolding) are the use of computer games most beneficial in supporting children's learning of number sense?

METHODOLOGY

Context of the Study

This study took place in a state-funded pre-K center in a mid-sized town in a southeastern state in the U.S. This state-funded program serves economically disadvantaged (children in families with annual incomes at or below 75% of the State Median Income) or developmentally at-risk children. The risk factors include limited English proficiency, identified disability, chronic health condition, and/or low-performance results on developmental screening tests. This pre-K center uses *Creative Curriculum® for Preschool*, which is a comprehensive, project-based early childhood curriculum designed to foster the development of the whole child through teacher-led small and large group activities. The curriculum provides teachers with guidance on how to (a) create learning environments that are responsive to children's varying needs and abilities, and (b) teach in the content area. It also incorporates 38 research-based objectives for development and learning that are most predictive of school success and offers strategies for promoting children's social-emotional development as well as content area skills (Dodge, Heroman, Colker, & Bickart 2014). In addition, within the context of *Creative Curriculum®*, pre-K teachers use an assessment system called *Learning Accomplishment Profile* -3rd Edition (LAP-3). This assessment procedure provides a systematic method for observing the skill development of children functioning in the 36-72 month age-range. LAP-3 is often used by professionals, especially teachers in early childhood programs because it gives a more complete assessment of a child's acquired skills and emerging skills than most standardized instruments (Sanford et al., 2003).

Participants

Classroom teachers from one state-funded pre-K center in the area were invited to participate in this study. Four classroom teachers volunteered to take part in this study. All four teachers were Caucasian women, and had an average of 17.5 years of teaching experience (range of experience was 7-29 years). All teachers were lead teachers in their pre-K classrooms and had the state teaching licensure in birth-kindergarten instruction. All four teachers used *Creative Curriculum®* and *The Learning Accomplishment Profile-*3rd Edition (LAP-3) in their classrooms.

Upon the classroom teachers' agreement to participate, parents or guardians of the children in all four classrooms (72 families in total) were contacted via a letter outlining the purpose of the study and requiring written parental consent for their child to take part. The letter was translated into Spanish for Latino families. Parents who did not return the letter were considered to have not granted permission for their child's participation in pre and posttests. Consequently, the study included 62 children in pre-K (average age 60.5 months (SD=3.7) who had returned parent or guardian permission slips and participated in pre and posttest assessments. Table 1 provides a summary of the participating children's demographic information. As Table 1 shows, the 62 children were distributed across the four classrooms, with each class showing a similar ethnic profile as well as academic performance for children.

Table 1

Demographic Information of Participating Children

Category	**Condition A Teacher-facilitated**	**Condition B Peer-facilitated**	**Condition C Individual play**	**Condition D Control group**	**Percentage**
Gender	N=16	N=16	N=15	N=15	N=62
Male	8	10	8	10	36 (58%)
Female	8	6	7	5	42%
Ethnicity					
Black	9	9	8	7	53%
White	3	2	1	3	15%
Hispanic	3	4	4	4	24%
Multi- Racial	1	1	2	1	8%
Free/reduced lunch	13	15	13	14	89%
Children receiving IEP	5	0	1	1	11%
Children w/ access to computer at home	10	8	11	9	62%

Design of the Study

The study employed a pretest-intervention-posttest design, examining whether computer mathematics (CM) games as a form of instructional intervention improved children's understanding of number sense. The effectiveness of the instructional intervention was further examined under three different experimental conditions. Table 2 summarizes the design of the study. In conditions B and C, the teacher interacted with the children only to promote initial engagement, answer questions, or to redirect any inappropriate behavior. No facilitation or scaffolding regarding the mathematics concepts or the game was provided during computer play. The fourth classroom served as a control (CO) group which was not provided with any of the CM games. Children in the control group still had access to computers during their regularly scheduled center time; however, the software games that they played with did not match any of the ones used for the experimental intervention conditions.

Table 2

Design of the Study

	Conditions	**Intervention**	**Characteristics**
Experimental	Condition A	Teacher-facilitated computer play (TF)	Using Vygotsky's ZPD as a framework, under this condition the lead teacher provided explicit instruction and scaffolded children's learning during play with CM games.
	Condition B	Peer-facilitated computer play (PF)	In this condition, children in pairs or small groups of 3 engaged in the free exploration of the CM games and peers provided support and help to each other during the play. Children served as equal partners with regard to ability level and content knowledge about math and computer game.
	Condition C	Computer only individual play (IP)	In this condition, children independently engaged in free exploration of CM games.
Control	Condition D	Control group (CO)	This group was not provided with any of the CM games.

Materials

A total of 10 computer games focusing on number concepts were selected using the principle of instructional design explained earlier.

The CM games served as an instructional intervention. Prior to the implementation, the CM games were reviewed by the researcher and two of the participating classroom teachers to determine whether they 1) were appropriate for young children, 2) permitted children to practice discrete skills in math as well as problem-solving techniques, 3) were inexpensive and readily available for purchase, and 4) were easy to use to supplement classroom instruction, given teachers' and parents' computer skills. The content in the selected games offered and supported concepts or skills such as counting, numeral recognition and naming, identification of various properties of numbers (e.g., 8 comes after 7), quantity discrimination, measuring, and estimation and prediction.

Instrumentation and Data Sources

Two instruments were used to measure the improvement of the children's understanding of number sense, and to establish the children's ability level at pretest, i.e., the *Test of Early Mathematics Ability, 3rd Edition (TEMA-3)* and *The Learning Accomplishment Profile – 3rd Edition (LAP-3).* TEMA-3, developed by Ginsburg and Baroody (2003), was used to measure children's understanding of number sense. TEMA-3 is a standardized norm-referenced test with reliability of .82 - .93, and validity of .54 -.91 (moderate to strong relationships). The TEMA-3 test is known to be appropriate for children of ages three years and zero months through eight years and 11 months. The test consists of 72 items measuring informal early mathematics (concepts of relative magnitude, counting, calculation with objects present) and formal mathematics understanding (reading and writing numbers, number facts, calculation in symbolic form). According to the National Council of Teachers of Mathematics (2008), these skills comprise the number sense and operations curricular strand. The standard scores are used as the primary criterion measure to control for both age effects and population variance (Allen & Yen, 1979).

The Learning Accomplishment Profile - Third Edition (LAP-3) was used to establish children's ability level at pretest stage. Children's existing LAP-3 scores were used to verify similarity across four groups regarding children's cognitive performance. The LAP-3 measure is collected as part of children's enrollment in a state-funded program. When children attend the pre-K in this district, they are assessed during the academic year at three different points (beginning of the year (September), mid-year (February), and end of the year (May)) using LAP-3. As mentioned previously, LAP-3 is a criterion-referenced assessment instrument measuring development in the domains of gross motor, prewriting, cognitive, language, and social/emotional. Participating teachers shared their students' LAP-3 cognitive scores with the researcher.

In addition to the above-mentioned instruments, the following data sources were used to examine the conditions in which either teachers or peers interacted with the children during CM games. Informal observation was used to examine teacher's mathematical scaffolding strategies (e.g., providing explanation, modeling, hints, and feedback) in condition A, and to document peer interaction behaviors (e.g., modeling/giving directions, encouragement to stay on task, collaboration (turn taking)), including individual children's behaviors in conditions B and C during the CM games. The researcher observed each of the experimental condition A, B, and C for about 30 minutes on two different occasions: at the beginning and towards the end of the intervention period. Moreover, during the intervention period, each experimental condition (A, B, and C) was also videotaped for 30 minutes. The researcher viewed the videotapes in addition to the observation notes. Participating teachers from the three intervention conditions were also asked to keep a journal to reflect on their experience as well as children's interaction behaviors around CM games. These reflective journal notes were used to supplement and support the findings of the study.

Procedures

The entire experimental task took place at the pre-K center for a duration of seven weeks from late-March to mid-May (one week of the pretest, five weeks of intervention and one week of the posttest). After parental consent forms had been received, children were pre-assessed on their knowledge of number sense using *Test of Early Mathematics Ability*, 3rd Edition (TEMA-3). Project personnel with prior training and experience with the instrument administered the TEMA-3 individually to all participating children. The pretest was administered at tables outside the participating classrooms. Each test took approximately 25-35 minutes per child. Some children took longer to complete testing as they had attempted more test items.

The entire pretest took one week to be completed. Once the pretest was completed, all children in the experimental conditions were offered the CM games to play within their respective classroom during their center time which lasted about 90 minutes for all four conditions (experimental and control) and occurred in mid-morning. Each classroom (experimental and control) was equipped with three desktop computers, which were available to children for play during the center time as an interest area. In addition to the classrooms' desktop computers, the experimental condition groups were each provided with two additional laptop computers to facilitate the children's use of various CM games. According to the classroom teachers, all the children had already developed comfort and confidence with the use of computers (e.g., ability to turn on the computer, use the mouse with ease, click, double-click, and identify letters and numbers on the keyboard). During the center time for both experimental and control groups, classroom teachers and their assistants were present, but only experimental condition A received teacher facilitation for computer play. In all classrooms, teachers and teacher assistants were available to facilitate children's play in other interest areas (e.g., art, sensory, literacy, housekeeping, etc.). For the three experimental conditions, the teachers and teacher assistants also made sure that every child had the chance to play with all the 10 CM games at least twice (with an average of 20 minutes each) during the intervention period. Thus, every child in the experimental conditions played with the 10 CM games for about 6-6.5 hours in five weeks. To ensure the uniformity of time spent with each CM game among children across conditions, teachers kept a roster to record the amount of time each child spent on each CM game. Upon completion of the data collection in each classroom, the CM games were donated to the classrooms for the children to enjoy for the rest of the year.

At the end of the intervention, all 62 children were post-assessed using *Test of Early Mathematics Ability*, 3rd Edition (TEMA-3). The posttest followed the same procedure as the pretest and was completed in one week.

Analysis

This study utilized both quantitative and qualitative analyses to make sense of the data. The SPSS software was used to analyze the test data. A one-way analysis of variance (ANOVA) was run to determine the significance of the improvement from pre to posttest. The qualitative data were coded using a coding scheme extracted from the literature (Miles & Huberman, 1994) for both teacher scaffolding strategies and peer interactive behaviors. The coded passages were organized in tables and used to supplement and expand on the quantitative findings.

Video clips from the experimental conditions were viewed to verify a) in condition A, whether the teacher in condition A used scaffolding strategies (questioning, explanation, modeling, hints, and feedback) during the CM games, and b) in Condition B, what types of interaction behaviors (modeling/giving directions, encouragement to stay on task, collaboration (turn taking)) the children (peers) showed during their play with the CM games in condition B. Table 3 describes the researcher's coding scheme for identifying the type of scaffolding strategies used in condition A (teacher –facilitated) and peers' interaction behaviors in condition B (peer-facilitated).

Table 3

Definitions of Coding Categories for Teacher Scaffolding Strategies and Peer Behaviors

	Scaffolding Strategies	**Definition**
Teacher	Questioning	The teacher asks the child a question related to the content of the game.
	Explanation	The teacher explains to make something clear.
	Modeling/ Direct instruction	The teacher verbally or non-verbally demonstrates for the child how to complete a task.
	Hint	The teacher provides suggestions and clues to move the child along.
	Feedback	The teacher provides confirmation, corrections, positive or negative to the child.
Peer	**Interaction Behaviors**	**Definition**
	Modeling/ Giving direction	The peer verbally or non-verbally demonstrates to the child how to complete the task.
	Taking turns	The peer takes a turn to play with the CM games.
	Encouragement to stay and complete the game	The peer stays on the computer at least for 15 minutes

To validate the coded data for the video tapes, the coding and interpretation of the tapes were given to the participating teachers to review, confirm and suggest possible re-interpretation. Teachers' reflection data was also analyzed to explore their experiences during all three experimental conditions. Emerging themes and patterns were identified and used to summarize the overall data. Subsequently, relevant quotations and passages were extracted and used to help support the emerging interpretations and findings.

FINDINGS

Quantitative Results

The results of the ANOVA indicated a significant difference between pre and posttest TEMA-3 scores [F (3, 61) = 4.13, p=.01] at p<.05 level, suggesting that all participating children (both experimental and control groups) improved in their understanding of number sense from pre to posttest. Table 4 presents the ANOVA test results.

Table 4

Results of the ANOVA Test

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
TEMA-3 Pretest	Between Groups	116.811	3	38.937	.164	.920
	Within Groups	13800.867	58	237.946		
	Total	13917.677	61			
TEMA-3 Posttest	Between Groups	2286.160	3	762.053	4.130	.010**
	Within Groups	10701.533	58	184.509		
	Total	12987.694	61			

p value= *<.05 and ** <.01

Further comparisons (post hoc) using the Tukey test were conducted to find any differences between the three experimental and the control group. The results indicated that the mean score for teacher-facilitated condition A (M=111.00, SD = 13.87) was significantly different from the peer-facilitated condition B (M=98.25, SD=14.35), individual play condition C (M= 98.06, SD=14.89), and control group condition D (M=95.60, SD=10.74). However, there was no indication that the peer-facilitated group performed better than the individual play condition or the control group. The results suggest that children who played with CM games while receiving facilitation and scaffolding from their teacher (condition A) performed significantly better in their posttest in comparison with children in peer-facilitated, individual play, or control group. In other words, it seems that when computer games are accompanied with teacher facilitation and scaffolding, they improve children's understanding of number sense.

Table 5 presents the means and standard deviations of the TEMA-3 pre and posttest scores for each condition and the results of all children on the LAP-3 cognitive test taken at the beginning, mid- and end of the year. As is shown in Table 5, the pretest mean scores for TEMA-3 and mean scores for the mid-year LAP-3 cognitive test were at about the same level for all conditions, confirming that the children were equal in their cognitive abilities at the start of the experiment/intervention. However, a comparison of the mean scores of the LAP-3 cognitive test at the end of the year showed that the children's improvement in condition A was the highest by a considerable margin, demonstrating the importance of teacher-facilitated scaffolding.

Table 5

Mean Scores for TEMA-3 (Pre and Posttest) and LAP-3 Cognitive at the Beginning, Mid- and End of the Year

Condition	TEMA-3 (Pretest) (sd)	TEMA-3 (Posttest) (sd)	LAP-3 Cognitive Score (sd)		
			Beginning of the Year	Mid-Year	End of the Year
Condition A Teacher-facilitated (N=16)	94.25 (13.37)	111.00 (13.87)	29.25 (17.35)	61.68 (12.49)	74.75 (11.21)
Condition B Peer-facilitated (N=16)	92.50 (15.30)	98.25 (14.35)	43.86 (16.53)	56.56 (16.60)	68.00 (17.22)

(continued)

Condition	TEMA-3 (Pretest) (sd)	TEMA-3 (Posttest) (sd)	LAP-3 Cognitive Score (sd)		
			Beginning of the Year	Mid-Year	End of the Year
Condition C Individually Play (N=15)	94.73 (18.05)	98.86 (14.89)	37.26 (17.72)	53.33 (15.21)	68.66 (16.44)
Condition D Control Group (no CM games) (N=15)	91.26 (14.73)	95.60 (10.74)	33.66 (14.24)	58.93 (12.96)	71.93 (9.30)
Total N=62	93.19 (15.10)	100.85 (14.59)	35.90 (17.00)	57.67 (14.40)	70.85 (13.90)

Table 6

Examples of Scaffolding Strategies and Frequency of Occurrences during CM Games

	Scaffolding Strategies	**Examples**	**Frequency (Percentage)**
Teacher	Questioning	“What number is this?”; “Which basket has more basketballs?”).	12 (13%)
	Explanation	“You have to count all the objects in the basket one by one to get the total. You can use your fingers. It will help you to keep track of which ones you have counted already.” “Sometimes it helps to cover the numbers that you have to take away—then you count the ones that are left.”	8 (10%)
	Modeling/ Direct Instruction	“Use this number line so that you can see which numbers are smaller than 5 and which numbers are larger than 5.” ”See 6 has the ball at the bottom, and 9 has the ball at the top, like this” [models writing a 6 and 9]; “Click on number 5 here!”; “Let’s count the number of buttons first…”	31 (34%)
	Hint	“Look at the numbers on the whiteboard.”; “Count again starting with one”; “Use the escape key.”	15 (16%)
	Feedback	“That is not a 9, it’s a 6”; “You can do it.”, “Nice Job counting all the way to 10!”	25 (27%)

(continued)

	Interaction Behaviors	**Examples**	**Frequency (Percentage)**
Peer	Modeling/ Giving Directions/Instruction	“This is how you click.”; “Drag it there.”; “Click on 5.”; “Push this.”; “You have to count the balls first.”; “6 goes after 5.”; No, not that one, this one.”; “Click on 10, 1 and 0.”	23 (41%)
	Taking Turns	“You click one number, and I click one,”; “You just did it, it is my turn now.”; “I didn’t have a turn, it’s my turn.” “You’re clicking all the numbers; I wanna do it too.”	20 (35%)
	Encouragement to Stay and Complete the Game	“Yeah, you did it”; “let’s do the roller coaster game.”; “How many tickets [prize] you have?”; “ I wanna do the dinosaur game.” ; “Mrs. O, we won!”	13 (23%)

Observational data including the video clips were analyzed to examine teacher scaffolding strategies in condition A (teacher-facilitated condition) as well as peers’ behaviors in condition B (peer-facilitated) during CM games. Ninety-one statements matching the list of teacher scaffolding categories were extracted from the observational notes and the video clips in condition A. The same procedure was used for the peers’ behaviors in condition B, and 56 statements were extracted that matched the list of categories for peer-facilitated behaviors. Table 6 provides frequency and examples of the scaffolding strategies used by the teacher in condition A, as well as peers’ interaction behaviors in condition B. As Table 6 shows, the teacher used more scaffolding strategies in the form of modeling or direct instruction (34%) followed by feedback (27%), hint (16%), questioning (13%), and explanation (10%). With regard to peers’ interaction behaviors in the peer-facilitated condition, peers used more modeling or direct instruction (41%) followed by turn-taking (35%) and encouragement to stay and complete the game (23%).

Qualitative Results

The dynamic nature of scaffolding. The interaction between the teacher and children was further analyzed to explain the dynamic nature of scaffolding strategies. For example, in the following interaction, the teacher is observing Destiny playing with the mathematics games on the computer. Destiny is a 4.5 year-old African-American girl and the only child living with her mother in a public housing complex close to the school. She is a tenacious puzzle solver and has recently shown some interest in playing with the CM games at school. There is no computer at Destiny's home though occasionally she gets to play games on her mother's smartphone. While observing Destiny, the teacher noticed that she was having a problem with her counting while at the computer. The teacher, Ms. Brown, sat beside Destiny looking at the screen and initiated the following facilitation for Destiny:

Ms. Brown: Use your fingers to count. How many are those [counting with the child, 1, 2, 3, ….8], 8 minus 2, take away 2?
Destiny: 6
Ms. Brown: Here you have to add, do you remember this symbol [the plus], it means you have to add
Destiny: 1, 2
Ms. Brown: 2 +1, you have two, add one more. How many would that be?
Destiny: 3
Ms. Brown: That is right! Go to the next one.
Ms. Brown: You have 4 and how many more? It says add 5 more, do you need to use my fingers?
Destiny: Yes
Ms. Brown: Okay how many fingers is that?
Destiny: 5
Ms. Brown: 5, okay so use that 4 and add my 5 fingers to it, count them, one at a time, and how many that is all together? Count those [pointing to Destiny's fingers] and then add my fingers to it.
Destiny: 1, 2, 3, 4, 5, 6, 7, 8, 9,
Ms. Brown: Ooh, it worked out didn't it? Okay, what does that sign mean to add or take away [pointing to the sign]?
Destiny: Add
Ms. Brown: Add! Okay, so that means we have to add again
Destiny: 1
Ms. Brown: and then 5 more, do you have 5 fingers? Use them
Destiny: 1, 2, 3, 4, 5, 6
Ms. Brown: Good thinking. See if you're right. Oh, you were right! Good job.
Ms. Brown: Okay is that add or take away? [Pointing to screen]
Destiny: Add, no, take away!
Ms. Brown: Take away. What do you have to do to take away? How many are you taking away? Look
Destiny: 3

Ms. Brown: Oh so you gotta cover 3 up [helping Destiny to cover the 3 objects on the screen] How many are left?

Destiny: 1

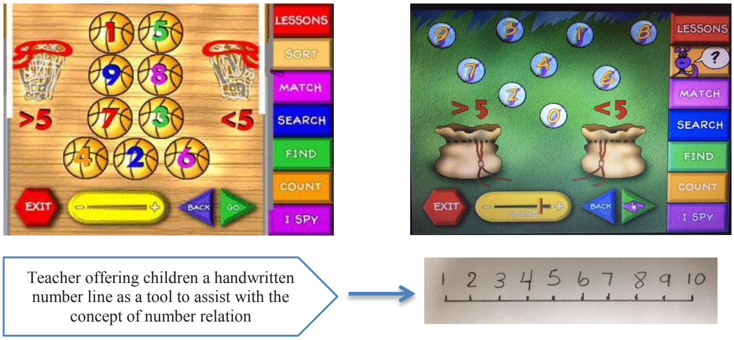
Ms. Brown: You’re right, remember the other day we did the goldfish and added them and took them away?

Destiny: Yeah we did that, and then we got to eat them.

Ms. Brown: We got to eat ‘em, we can’t eat this one. We’ll have to do the goldfish again maybe.

The interaction above shows how Ms. Brown scaffolded Destiny’s learning by carefully assessing what she was able to perform and then provided the right level of support to help her succeed in this mathematical task of addition and subtraction. To help Destiny complete the game, Ms. Brown utilized questioning: “How many are those?”; hint: “You have 4 and how many more”; feedback: “Good thinking… Oh, you were right! Good job!”; and “making connections: “You’re right, remember the other day we did the goldfish and added them and took them away?” When the numbers (quantities) were too large for Destiny to add or subtract on her own, Ms. Brown offered visual aids such as finger-counting (e.g., “use your fingers to count”) or covering the number on the screen (e.g., “use your hand to cover the number 3”) to help Destiny with the task completion. In situations where Destiny was able to add/subtract on her own, Ms. Brown was less explicit and offered more hints and encouragement strategies to keep her engaged with the task. This interaction highlights how Ms. Brown was able to support Destiny’s learning attempts and regulate the complexity and difficulty of the CM game for her. As a result of her scaffolding, Destiny not only was able to complete the task but also learned how to use her resources (figure counting) to add/subtract and to assess her own learning.

Interestingly, when facilitating and scaffolding children’s play with CM games, the teacher appeared to focus more on children who were perceived to need more help. For example, in one of the computer math games (Numbers: Dally Doo2), the children were asked to sort the numbered things into the areas marked more than (>) a given number, and less than (<) a given number (see figure 2). Some children seemed to be puzzled and were not able to answer the question. In this particular situation, the teacher offered a number line, which was simply a sentence strip with handwritten numbers, in order to assist the children in visualizing the concept of number relation (e.g., relative magnitude and position of numbers).



Teacher offering children a handwritten number line as a tool to assist with the concept of number relation

Figure 2. Sample screenshots of the mathematics game Sorting (greater/less than 5) from *Numbers: Dally Doo2*

Another example was when the teacher tried to explain the meaning of the questions that were ambiguous in the game. For instance, one of the questions in the *Log Ride* from the *Reading Rabbit* game required children to combine sets of 1 and 2 digit numbers for the desired sum

(_ + _ + _ = 10) (see figure 3).

Reader Rabbit Math 4-6 Full Walkthrough

Press esc to exit full screen

2 + 7 + 1 = 10

44:39 / 1:11:37

Figure 3. Sample screenshot of the mathematics game *Log Ride from Reading Rabbit*

For this particular game, the child was asked to find rungs of the ladder in varying lengths to equal the desired number. In this situation, the teacher brought in unifix cubes (concrete objects) to demonstrate strands with 10. She taught the children how to break the strand (unifix cubes) into smaller parts and how to add parts to make 10 (modeling the abstract concept of addition). These scaffolding examples underscore the pivotal role of a responsive teacher in learning contexts where the concepts are difficult for children to tackle on their own. In such contexts, the teacher can break down the tasks into parts supported with concrete examples (finger-counting, number line, and unifix cubes) to guide children in their ZPD as necessary.

The teacher's awareness of children's needs. The analysis of observational data and teachers' reflection notes revealed that during the first two weeks of the intervention, the teacher in condition A (teacher-facilitated) felt the need to motivate children whom she thought might otherwise give up and not complete the CM games. For example, the teacher spent some time at the beginning of the center time on demonstrating and modeling the use of the games to either individual children or in small groups. According to her reflection notes, she did this purposefully to build the children's enthusiasm and get them excited about the game. She thought familiarity and competence with the CM games could give the children the confidence to play longer. This finding demonstrates how the teacher in condition A used her information about children's skill levels in her classroom and tailored the experience of computer game play to their needs. The following two excerpts from the teacher's reflection journal well support the interpretation made above.

> "…I have noticed that often the logistics of the games (e.g., hand-eye coordination, maneuvering the mouse, busyness of the screen, etc…) may come across as too complex for young children to tackle on their own, and consequently, they may abandon the game too quickly or even before trying. Therefore, to build their confidence with the computer, I would take a few minutes early on to familiarize the children (individually or in small groups) to the logistics of the computer and computer games (e.g., moving the mouse, drag and drop, clicking on directional arrows, etc.) so they would feel confident and willing to try out and continue with the computer games..."

> "...For some of the children in my class who the computer was only for adults at home, they needed teacher permission to play with the computer. Thus modeling for them gave them permission to use the computer in a safe and appropriate manner…"

Another example of the teacher's awareness of children's needs (as illustrated in the excerpt below) was when the teacher monitored the Dual Language Learner (DLL) children more often during computer games, giving more explicit directions, and drawing the children's attention to the new or familiar concepts. In some instances, the teacher asked the children who seemed to have a good understanding of the games to assist other children in the class.

> ". . . For my Spanish speaking children where they may have difficulty understanding the verbal directions in English, I tried to give them more explicit instruction so that they can carry on with the games on their own. I also would pair them with those children who understood the concept of the game to work together to ensure success..."

The role of a peer during computer mathematics games. The analysis of observational notes including the video clip in condition B pointed to a pattern of facilitation that was very different from the one in teacher facilitation. The interaction below between Jamal and Jayden demonstrates how children assisted each other's learning during CM games. Jamal (5 years old) and Jaden (4.7 years old) are both African-American and very similar in their academic skills. Jamal has two younger siblings, and Jaden has one older brother. Jamal and Jaden are from the same neighborhood and ride on the same bus to school. Both Jayden and Jamal have access to a computer at home. It is important to note that the children in the peer-facilitated condition were grouped based on same-or-similar ability.

Jayden: It says "9"
Jamal: I know
Jayden: You gotta click on them all - all of them
Jamal: I KNOW!
Jayden: This one [Pointing to the number 9]
Jamal: I know how to do it myself

Jayden: There is lots of them. This one [Pointing to another]
Jamal: I can do it [Clicks on 6]
Computer: Try again
Jamal: [Clicks on a number]
Computer: Keep trying
Jayden: I told you. That's a 9! [While pointing to a 9]
Jamal: It is a 6
Jayden: No, it's a 9. You're taking toooo long [Jayden seized the mouse from Jamal and clicks on 9
Computer: Great!
Jayden: 9
Computer: Nice job!
Jamal, I wanna do it. It's my turn [Jayden gives the mouse back to Jamal]
Jayden: Was just helping
Jayden: Click on that one [Pointing to another 9]
Jamal: [Clicks on the 9]
Computer: Super!
Jayden: Super! You did it! Now, it is my turn!
Jamal: [Leaves the game]
Jayden: [Clicks on the next game and continues]
Teacher: Jayden, ask Jose if he wants to play with you on the computer

The interaction above demonstrates that, in contrast to the teacher in condition A who provided modeling and direction during the game, the peer was just playing with the game as an equal partner (e.g., "I wanna do it" "It's my turn") and appeared to be interested in completing the game as well. For example, as is shown in the interaction above, although Jayden seemed to be supporting Jamal in his quest to identify and click on the right numerals, no guidance/facilitation was provided to help Jamal distinguish 6 from 9, the cause of his errors with the game. Even the modeling and directions provided by Jayden were more like commands to speed up the process for Jamal so that she could take over the computer game. This is a typical behavior among children of same ability, where they play together as playmates. Moreover, it seemed that in the absence of teacher supportive scaffolding, children often relied on trial-and-error (randomly clicking on the keys and/or objects within the game) to finish the game.

In comparing Jayden and Jamal's interaction with Ms. Brown's facilitation of Destiny's game, it is apparent that Ms. Brown is more explicit in her teaching by offering a range of scaffolding strategies that are responsive to Destiny's ability level. In other words, while Jayden and Jamal were playing together, Ms. Brown was trying to assist and involve the child(ren) in learning from the games playfully. As is demonstrated in the sample interactions above, Ms. Brown elicited much greater participation from Destiny during the CM game than did Jayden in the peer-facilitated CM game. This finding supports Vygotsky's sociocultural theory which focuses on expert-novice interaction as an integral part of optimal scaffolding.

Playing individually with the computer mathematics games. The analysis of observational notes and video clip for children's play with the CM games in condition C revealed that the children showed enthusiasm to explore the CM games and enjoyed them as long as they were able to respond to the demands of the games on their own. However, when the demand (difficulty) was high, and the content of the CM games (e.g., task complexity, complicated instructions) was outside the child's ZPD, children often became frustrated with the games and eventually left them unfinished. Although the computer games offered some scaffolding to engage the child in the game, this was very generic in nature, focusing primarily on either confirming or disconfirming the child's responses (e.g., "Yeah, you got it right!"; "Way to go"; "Oops, not this one!"; Try again"). For example, when the difficulty level for the CM game (addition and subtraction) went beyond children's independent reach, they had to eventually abandon the game since the computer could not provide the targeted scaffolding they needed to tackle the challenges posed by the game.

Similarly to those in condition B (peer-facilitated), the children in condition C had to learn the CM games through trial-and-error with no scaffolding from the teacher; however, in contrast to the condition B (or condition A-teacher facilitated), the children in this condition did not have anyone (teacher or peer) to turn to for assistance and support in instances of difficulty. This lack of support in condition C often led to the children abandoning the CM games more quickly in pursuit of other play activities in the classroom. In the absence of support from the teacher (or computer), the children's choices were similar to those children in condition B and seemed to be random and less purposeful (Vygotsky, 1978).

DISCUSSION

The findings show that when provided with the opportunity to play mathematics computer games, children could learn from them. However, their learning is more extensive when supported by teacher facilitation and scaffolding. Comparisons between scaffolding strategies offered by the teacher, peer and CM game alone across the three conditions, revealed a distinct difference in the types and the quality of the support given to children. Computer mathematics games have the potential to motivate children and engage them in the learning process, but that process is easier to master when complemented by the teacher's support and guidance. Furthermore, as was evident in this study, computer games, at least as used in this study, are not designed to be responsive to the various levels and limits of children's understanding. In other words, when children are not able to communicate with the content of the game and understand the task, the computer games were not able to guide or adjust the embedded content to the child's level of understanding.

The findings also suggest that during independent play, when the children were not able to respond properly, they first tried to click various keys available to them (playing based on trial-and-error), but when unsuccessful they became frustrated, stopped playing and eventually abandoned the game. Similarly, when playing with an equal peer, though the children tended to encourage each other to stay with the task when encountering a problem. When the task required prior knowledge or the content of the task became difficult to understand, peers continued with the task for a longer period, but ultimately abandoned the task before completing it. These results confirm previous research findings on the importance of (expert) adult support and active mentoring of children's learning from computer play (Ezenweani & Atomatofa, 2013; Sarama and Clements, 2002). The type and quality of the teacher's scaffolding strategies in the teacher-facilitated condition appeared to have more impact on children's learning as evidenced by test results. Types of questions, just-in-time learning strategies, explanation and expansion of difficult concepts when needed, and activating prior knowledge and experience with number sense were among the effective strategies that the teacher used. It should be noted, however, that the teacher who facilitated the children's CM games in this study (condition A) was a veteran master teacher who was able to provide effective scaffolds. Thus, it is not clear whether a teacher with less experience or skill in using proper scaffolding strategies would have achieved similar results.

Finally, despite the children's only moderate gains in number sense when they worked with equal peers or individually, the results of teachers' reflections on condition B and C suggest that merely by reviewing and observing those computer games in play, teachers gained insight into new methods of teaching mathematical concepts to pre-K children. For example, the teacher in condition B wrote:

> "…After reviewing the software games and watching children's play with the CM games, I realized that I do provide children with a variety of manipulatives to explore on their own; however, I need to be more intentional in my planning of mathematics activities and make the conscious effort to draw children's attention to different mathematical concepts beyond what is obvious."

Similarly, the teacher in condition C wrote,

> " …I need to improve my mathematics vocabulary and language so that I can use the appropriate labels when working with children on math concepts."

Given that pre-K teachers often focus more on language and literacy skills (Clements & Sarama, 2016, National Research Council, 2009), mathematical computer games could have assisted them in introducing basic concepts in mathematics, thus served as professional development for teachers.

In summary, across the three experimental conditions, children who played with the CM games while receiving scaffolding from their teacher (condition A) showed a significant improvement in their learning of number sense from pre- to post-test. They stayed with the games consistently and seemed to enjoy playing with the CM games. In contrast, children who played the CM games with a peer of equal ability (condition B) or independently (condition C), with no scaffolding or support from their teacher did not show significant improvements in their learning of number sense. They often demonstrated frustration with the CM games and left the games without completing.

LIMITATION

The results of this study must be viewed within its context and limitation. The pre-K school targeted for this study served at-risk children from lower socio-economic background. This might have affected the findings of the study and limited its implications for other contexts. As it was shown in the demographic information of the participants, only 62% of the participating children had access to a computer at home. Over 1/3 of these children had no experience or exposure to a computer at home except those offered in school. Thus, is highly recommended for this study to be repeated in several other pre-K settings and across a variety of demographic and socioeconomic settings, to allow for further generalization of the findings (Mattoon, Bates, Shifflet, Latham, & Ennis, 2015). Also, the teachers who participated in the study volunteered to work with the researcher and were not randomly selected, although they were randomly assigned to one of the conditions.

IMPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The findings of this study support the view that current CM games can improve children's knowledge of number sense perhaps only, or at least primarily, if they are supported by a teacher or by adult scaffolding. These findings have important implications for teachers and researchers. On a practical level, computer games can be added to classrooms and homes to engage children in a variety of exploratory play. However, early childhood teachers as well as parents of young children need to be judicious and mindful of children's individual needs when investigating computer games available for purchase; the peer or individual play they invite may not necessarily help children learn. Moreover, teachers who have been routinely encouraged to provide children with the free choice of independent play on computers, on the assumption that access to educational computer games alone will always produce positive outcomes, should take caution. The complexity of the games' content and the mismatch between a game's content and a child's cognitive ability may very well produce different outcomes, with little to no learning, or frustration with the games. Teachers need to ensure that computer games are tailored to children's cognitive ability, their past experiences and preferences, and that children are closely observed and guided when playing computer games.

Computer mathematics games such as those used in this study are implemented in many of today's early childhood classrooms. This study showed that there are limitations in their ability to tailor the game content and stages of complexity to the child's ability level or developmental stage. Subsequently, used on their own or with peers, they may show similar limitations in scaffolding children's learning of mathematics concepts and skills. Certainly computer games or software applications of the future may already be incorporating a more advanced scaffolding design (e.g., artificial intelligence scaffolding strategy) where the software itself acts as the more capable partner (e.g., teacher, adult, capable peer) to support the learning process. However, additional research is still needed to gain further insights into the potential range and impact of computer games in children's learning, especially those designed for children who may have limited access to computers. In particular, attention should be paid to the quality, sequencing, and variety of scaffolding strategies offered in children's computer games. These scaffolds should be based as closely as possible on the kind of scaffolding shown in this study. Obviously, there is a need to examine other teachers' use of scaffolding strategies across a variety of CM games to discover whether a common pattern continues to emerge.

Lastly, the study could also be strengthened by a larger sample size. Despite its relatively small sample size, this study has shown uniform results across qualitative and quantitative data. The results point clearly to a need for more research in an increasingly important area, which is the design of mathematics computer games that are accessible to preschoolers and also reflect the most effective elements of teacher scaffolding.

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