Examining Computational Skills in Prekindergarteners: The Effects of Traditional and Digital Manipulatives in a Prekindergarten Classroom

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Abstract

The authors investigated benefits of digital technology compared with traditional manipulatives in relation to preschoolers' development and learning of computational skills. The sample consisted of twenty-four 4- and 5-year old children who attended a half-day prekindergarten program five times a week in a university laboratory school in the Midwestern United States. Children participated in small group instruction targeting computational skills. In one class, the teacher provided traditional manipulatives. In the other class, the same teacher provided digital manipulatives in the form of touch tablets with software apps. Both groups of children demonstrated significant increases in correct responses to computation questions on the Test of Early Mathematics Ability—Third Edition (TEMA-3). This practitioner study contributes to current research by using performance-based assessment to compare the impact of digital versus traditional manipulatives on young children's computational concepts and skills.

Introduction

In North America, digital technology has become common in personal lives and educational settings. Today's digital technology comes in many forms, including smart phones, video game systems, tablets, mp3 players, and electronic book readers, and is not confined to a given place; it has become mobile. Young children enter prekindergarten with varying levels of exposure to digital technology and a wide range of related skills (Parette, Quesenberry, & Blum, 2010).

Cultural-historical activity theory (CHAT), which was derived from neo-Vygotskian theory, views digital technology as both a tool to be taught how to use and as a tool for teaching (Rivera et al., 2002). CHAT has principles in common with 2012 guidelines for developmentally appropriate practices developed by the National Association for the Education of Young Children (NAEYC). Both share the view that children learn from social interactions with adults, need to be challenged appropriately to think at higher levels, and require a variety of opportunities to gain knowledge and understanding and practice related skills (National Association for the Education of Young Children, 2012; Rivera, Galarza, Entz, & Tharp, 2002).

Developmentally appropriate use of digital technology by young children and its incorporation into early childhood programs are frequently debated in the field (Rivera et al., 2002). Research indicates that computers are effective tools for increasing children's mathematical knowledge (Vernadakis, Avgerinos, Tsitskari, & Zachopoulou, 2005). Educators generally agree that using digital technology with older children is developmentally appropriate but have not always agreed on whether it is acceptable practice in early childhood classrooms (Zevenbergen, 2007). NAEYC and the Fred Rogers Center for Early Learning and Children's Media have developed a position statement on developmentally appropriate practices for the use of digital technology in early childhood settings. The statement approves its uses with young children but states that educators have a critical responsibility to make informed decisions about technology and should keep in mind what is age appropriate, individually appropriate, and culturally appropriate (National Association for the Education of Young Children, 2012). There is growing agreement that when digital technology is used appropriately, it may assist or enhance the learning experience (Clements, 2002; National Association for the Education of Young Children, 2012). At the same time, others assert that foundational principles rooted in human development must not be ignored (Rivera et al., 2002); some educators continue to prefer the more traditional approaches to teaching and learning.

Manipulatives and Mathematics in the Early Learning Environment

Historically, educators have provided learners in early childhood settings with handheld, three-dimensional objects known as manipulatives. In the 1830s, Friedrich Froebel designed and introduced a series of manipulatives to kindergarten children in Germany (Manning, 2005). Froebel’s manipulatives, or gifts, as he called them, were designed to assist children in establishing geometric and numerical relationships (Saracho & Spodek, 2009). In the early 1900s, Maria Montessori developed a set of manipulatives she termed sensorial materials, which were introduced to children in her schools (Edwards, 2006). Research supports the use of manipulatives in developing young children’s mathematical understanding (Sarama & Clements, 2004). Based on the premise that early learners’ thinking is fundamentally concrete, the use of manipulatives provides a necessary support for such learners (McNeil & Uttal, 2009).

Manipulatives often make math concepts more concrete and understandable for young children’s whether used at play with a peer or in formal one-on-one activities with a teacher. Three-dimensional objects used for building and counting, such as Unifix cubes and counters, are still present in early learning environments today. Educators typically introduce these materials both informally and formally, allowing learners to explore them during both play and direct instruction.

In its 2010 position statement on mathematics, NAEYC maintains that high-quality early learning programs establish a strong mathematical curriculum. NAEYC asserts the following mathematical concepts should be present: numbers and operation, problem solving, reasoning, measurement, and geometry. Additionally, NAEYC discusses the importance of well-planned and thoughtfully implemented lessons. These lessons may include the use of either traditional, three-dimensional manipulatives, or they may incorporate the use of digital technology (National Association for the Education of Young Children, 2010). Linder, Powers-Costello, and Stegelin (2011) recently concluded:

> As the academic demands in mathematics become greater at the kindergarten and primary levels, the need to develop more systematic and developmentally appropriate strategies to introduce young children to mathematics concepts within natural environments, relationships, and settings becomes even more important. Children who love to explore numbers and number relationships are better prepared for their future academic experiences. (p. 36)

The classroom learning environment facilitates the acquisition of mathematical concepts when children are able to make patterns, problem-solve, and explore spatial relationships during play (Linder et al., 2011). Meaningful classroom interactions using tangible objects connect learner’s prior knowledge and encourage future exploration.

The Inclusion of Digital Technology in the Early Learning Environment

The inclusion of digital technology and its related tools and software in the early learning environment is not a novel idea. Computers and computer programs have been present for more than a decade for the purpose of both mathematics and literacy instruction. Computer games have the potential to motivate children to learn in new and different ways (Yelland, 2002). Computers can introduce or reinforce skills in an existing curriculum. A recent survey of early childhood educators indicated that educators also choose computer software to align specifically to lesson plans and objectives (Yurt & Cevher-Kalburan, 2011).

New technologies, such as touch tablets (e.g., iPad , Android Transformer, Windows Surface) are readily available for use in classrooms. A wide variety of software, often referred to as applications or "apps," is available for touch tablets. The use of handheld technology in learning environments has greatly increased and is expected to grow (Rikala, Vesisenaho, & Jylläri, 2013; Zevenbergen, 2007). Schools increasingly use tablets because of their portability, available software, and lower cost compared with computers.

Prekindergarten children typically manipulate concrete materials, whereas the apps on tablets enable them to manipulate objects digitally. For the purposes of this report, the term *digital manipulatives* refers to the electronic manipulation of objects on touch tablets. In the early learning environment, digital manipulatives can be used for a variety of purposes, including virtual drawing, painting, and storytelling (Couse & Chen, 2010) and have the capacity to address individual learner's needs (Ellis, 2011). Many apps are intended to enhance early math skills. In 2009, almost 50% of the 100 best-selling apps in the iTunes App Store's education section targeted the prekindergarten elementary school learners (Shuler, 2009).

Educators, researchers, and theorists debate the appropriateness of digital technology in teaching mathematics in early childhood classrooms when other, more "concrete" options (that is, traditional manipulatives) are available. However, McNeil & Uttal (2009), for example, caution that the construction of abstract thinking is not guaranteed when young children use concrete materials.

In its position statement on technology, NAEYC asserts that it is vital that digital technology experiences in the early learning environment promote communication, collaboration, creativity, and critical thinking skills (National Association for the Education of Young Children, 2012). Additionally, it is important that educators be proficient in the technology they are using and be intentional and purposeful in how digital technology is used in the early childhood environment (National Association for the Education of Young Children, 2012).

The effective integration of tablets in early childhood environments may also require that educators understand digital technology learning standards (see International Society for Technology in Education, 2008) and develop activities and assessments that incorporate digital technology (Keengwe & Onchwari, 2009).

Purpose of Study

This study was based on the premise that young children in Western cultures have been exposed to digital technology in their everyday lives (Zevenbergen, 2007). The wide variety of technology choices has made the task of selecting digital technology that best fits the needs of children more complex. It is important that educators understand the influence these new digital technologies have on how children learn, how they choose to learn, and how they develop concepts and skills in their experiences with digital technology (National Association for the Education of Young Children, 2012). A clearer understanding of this relationship will assist early childhood educators in determining the types of digital technology best suited for incorporation in their classrooms or whether more traditional approaches to teaching should maintain their dominance in teaching computational skills.

The purpose of this study was to begin to investigate the effectiveness of digital manipulatives as instructional tools for increasing early learner's computational concepts and skills. The research questions which guided this inquiry were: (1) Are digital manipulatives effective tools for increasing prekindergarten children's computational skills? (2) Do traditional or digital manipulatives have a greater impact on improving children's computation skills?

Methods

Quantitative data pertaining to participants' computational mathematical concepts and skills were collected using the third edition of the *Test of Early Mathematics Ability* (TEMA-3) for prekindergarten learners (Ginsburg & Baroody, 2003). A comparison of two groups was made. One group used only digital manipulatives during math instruction, while the other used only traditional manipulatives during math instruction. The teacher took special care to confine computational instruction to the designated small group sessions.

Setting and Participants

The research was conducted with two prekindergarten classes (morning and afternoon) in a university laboratory school in a community of approximately 120,000 in the Midwestern United States. The teacher for both classes, who is one of the researchers/authors, is a Caucasian female with a bachelor's degree in early childhood education and 17 years of teaching experience in prekindergarten, first grade, and third grade. The classroom also has a teacher's assistant who was not involved in the instruction described in this study. Children typically engaged in small group instruction three times a week, with two of these instructional sessions focused on mathematics. That approach was not changed for this study. The sample for this study included 24 prekindergarten children ages 4 and 5 from various socioeconomic and ethnic backgrounds.

The Traditional Manipulatives Group

The traditional group attended in the morning, for three hours a day, five days a week, and consisted of 12 children: 9 boys and 3 girls. The morning class was randomly chosen to be the traditional manipulative group. Participants included one Hispanic child, one Asian child, and 10 Caucasian children. None of the children qualified for free/reduced lunch.

The Digital Manipulative Group

The afternoon class was randomly selected to be the digital manipulative group. This class also met for three hours, five days a week, and consisted of 12 participants (6 boys, 6 girls). The group consisted of one African-American child, one Hispanic child, three Asian children, and seven Caucasian children. One child qualified for free/reduced lunch.

Instrumentation

The dependent variable was improvement in learner computational skills, as measured by the *Test of Early Mathematics Abilities* (Ginsburg & Baroody, 2003).The TEMA-3 is a norm-referenced assessment of informal and formal mathematical concepts and skills in children ages 3, 0 months, to 8 years, 11 months. Educators most commonly employ it to measure learner academic progress, to identify areas that need reinforcement in the curriculum, or for program evaluation. Mathematical tasks addressed by the TEMA-3 include number-comparison facility, numeral literacy, mastery of number facts, calculation skills, and understanding of number concepts. The TEMA-3 reports reliability coefficients of .82 to .97. Two parallel forms of the TEMA-3 are available, each with 72 items. One form was used for the pretest and the other for the posttest given after six weeks of instruction.

Procedures

The study began with the administration of the TEMA-3, which was given individually to children by one of the researchers over a two-week period. Children had not received formal instruction in computational skills before this TEMA-3 pretest. Results were evaluated to identify the area(s) to target during small group instruction. Five test items in the areas of number concepts and calculation were identified as receiving the lowest scores, indicating that all the children might benefit from instruction and practice in computation. Specific computational skills included

- concrete modeling of addition (e.g., using manipulatives to add two sets together).

- solving “missing addend” problems (e.g., I have some pennies in my pocket; my mom gives me three more pennies, now I have five pennies all together. How many pennies were in my pocket?).
- mental addition (e.g., recalling basic facts or solving addition problems without manipulatives).
- equal division (e.g., sharing a group of objects equally among a given number of people).
- counting on strategies (e.g., being able to continue counting on from a number other than one when adding sets together).

Children in each classroom were randomly placed in small groups of four or five, regardless of test scores. Two days each week were scheduled for mathematics instruction. Instruction lasted about 15 minutes. Each week a specific computational skill was addressed until all subcategory areas were covered. For example, during week one, concrete modeling of addition word problems was targeted. During week two, equal partitioning was addressed, and so on.

Children in the traditional group received small group instruction using traditional manipulatives. The digital manipulative class also received instruction in small groups. The teacher made the instruction and activities as similar as possible for both groups so that the main difference was the type of manipulative used. The teacher used the same vocabulary, instructions, and examples for both groups when possible. All groups were given the same range of problems, in regard to level of difficulty.

The teacher began each lesson by explaining and modeling how to perform each task—for example, “Today we are going to learn about adding. We are going to use [type of traditional manipulative or app] to help us learn.” She would then demonstrate how to use the app or the traditional manipulatives to complete the task. Then the teacher and children completed problems together. During the traditional manipulative small groups, the teacher continued to present the problems orally but allowed children time to complete them on their own, providing feedback as needed to the whole group or to individual children. For the digital manipulatives groups, the cycle of problem, solution, and feedback was delivered automatically by the app, which enabled children to move through the problems independently at their own pace. They often had more practice than children in the traditional groups, who were moving through problems together.

A variety of concrete and digital manipulatives were used to teach specific computational skills. Traditional manipulatives included plastic bears, Unifix cubes, candy hearts, and dice. Digital manipulatives included those found in apps listed in the Appendix. The same manipulative or app was used during small group instruction sessions twice each week to teach the targeted skill for a total of about 30 minutes.

After six weeks of instruction, children were reassessed using only the computation-related questions from the TEMA-3 in an attempt to determine growth in computational skills. Responses to these questions determined an overall categorical finding of correct or incorrect for the computational question.

Data Analysis

For the purpose of analysis, an overall computational score was calculated for each child by adding his or her correct responses to the five test items used in the pre- and posttests. Paired samples *t*-tests were used to compare the pre- and posttest computational scores for both the digital and traditional manipulative groups. Independent samples *t*-tests were used to compare the differences in computational scores between the two groups.

Findings

Three dimensional manipulatives are commonly used for teaching and reinforcing math concepts and skills in early childhood programs. This study sought to find out whether use of new technologies in the form of digital manipulatives would produce similar results in children's understanding of mathematical computation as do traditional manipulatives.

Are digital manipulatives effective tools for increasing prekindergarten children's computation skills? A paired-samples t-test was conducted to compare the pre- and posttest computational score for the digital manipulative group. A significant difference in the scores was found between the pretest (M = 1.50, SD = 1.24) and posttest (M = 2.83, SD = 1.19) scores; $t(11) = -3.08$, $p = .010$. These results suggest that the use of digital manipulatives during math instruction assist children in the improvement of computational skills.

A paired samples t-test was also conducted to compare the pre- and posttest computational scores for the traditional manipulative group. A significant difference in the scores was also found between the pretest (M = 1.23, SD = 1.17) and posttest (M = 2.46, SD = 1.20) scores; $t(12) = -4.06$, $p = .002$. These results indicate the positive effect that traditional manipulatives can have on children's computational skills.

Do traditional or digital manipulatives have a greater impact on improving computation skills? To establish that the traditional and digital manipulative groups were similar at the beginning of the study, an independent-samples t-test was conducted to compare the computational scores for the digital and traditional manipulative groups' pretests. There was no significant difference in the computational scores between the digital manipulative (M = 1.50, SD = 1.24) and the traditional manipulative (M = 1.23, SD = 1.17) groups on the pre-test; $t(23) = 0.56$, $p = .58$. This indicates that the two groups were not significantly different in terms of computational skills prior to the computation instruction they received in this study.

To answer the second research question, an independent-samples t-test was conducted, comparing the computational scores for the digital and traditional manipulative groups on the posttest. No significant difference in the computational scores for the digital manipulative (M = 2.83, SD = 1.19) and the traditional manipulative (M = 2.46, SD = 1.20) groups were found; $t(23) = 0.77$, $p = .45$. This suggests that the two groups did not differ in regards to their computational skills after receiving instruction.

Discussion

The findings of this study indicate that both digital and traditional manipulatives are effective tools for improving children's computational skills. At the end of the six weeks, both the traditional manipulatives group and the digital manipulatives group showed significant improvement in ability to solve computational problems, suggesting both were taught with appropriate tools.

The improvement of computational skills in the digital manipulative group supports NAEYC's position that when digital technology is integrated intentionally and purposefully, children benefit and learn in meaningful ways (National Association for the Education of Young Children, 2012). The results indicate digital manipulatives are not merely "edutainment" as some critics claim (Baird & Henninger, 2011, p. 5) but another potential tool for improving computational skills.

Neither group showed significant gains over the other, which suggests that both traditional and digital manipulatives can be effective in a prekindergarten mathematics curriculum. Children were able to manipulate objects in different ways, yet both methods were associated with improved computational skills. Moch (2002) states that manipulating three-dimensional objects makes learning more concrete and provides children with a visual representation of symbolic assumptions. Our study extends these findings to two-dimensional digital manipulatives. We cannot conclude from this study that one type of manipulative had a greater effect on learning; teachers should consider the type of manipulative, digital or concrete, and how it matches the instructional intent.

The primary limitation of this study is its use of a small convenience sample, which restricts the ability to generalize the findings (Fraenkel & Wallen, 2009). The researchers recommend repeating the study in several other prekindergarten settings, across a variety of demographic and socioeconomic settings, so the combined results provide a larger sample size allowing for further generalization of the findings.

Additional limitations include the inability to isolate manipulatives as the main variable affecting children's mathematical knowledge. Children in both classes were exposed to mathematical concepts and skills informally throughout the day, during other lessons, and in play-based activities in other learning centers. In addition, parents/guardians may be working with their children on mathematical skills at home. Such exposures may also have an impact on children's mathematics learning. Therefore, neither the digital nor traditional manipulatives should be cited as the only reason for improved performance on the TEMA-3.

Preliminary Recommendations and Conclusion

These findings suggest that both digital manipulatives and traditional manipulatives can be used to teach computational skills and can assist early childhood educators in providing children with a variety of experiences. Educators need not be reluctant to integrate digital manipulatives into prekindergarten mathematics curricula. Digital technologies are cultural tools used by young children in their everyday lives. If children's experiences prior to school are changing to include digital technology so they are naturally seeking it out for learning or entertainment purposes, then early childhood educators can consider examining their curriculum and personal pedagogies in regard to the potential of the technology. Digital technology can be developmentally appropriate not only for older children but also for prekindergarten children when used during planned instruction (Zevenbergen, 2007).

Research should continue into prekindergarten children's use of digital manipulatives as a means for instruction. This type of research should be repeated and other mathematics concepts and skills should be targeted.

As technology constantly evolves and changes, educators should constantly reevaluate its use in their classrooms. Early childhood educators should be encouraged to explore the use of new technologies and participate in professional development opportunities in this area. Learning how to use the digital tools themselves and then purposefully integrating them into their existing mathematics curriculum can only benefit the children in their classrooms.

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Appendix

DinoKids – Math Lite (Version 1.0.2) [Computer software]. Ho Chi Minh City, Vietnam: divmob.

Hungry Fish (Version 2.2) [Computer software]. Motion Math.

Math Express (Version 1.0.1) [Computer software]. Kidapps.com.

Maths, age 3–5 (Version 1.2.1) [Computer software]. London, England: EuroTalk.

Park Math (Version 1.0.5) [Computer software]. Duck Duck Moose.